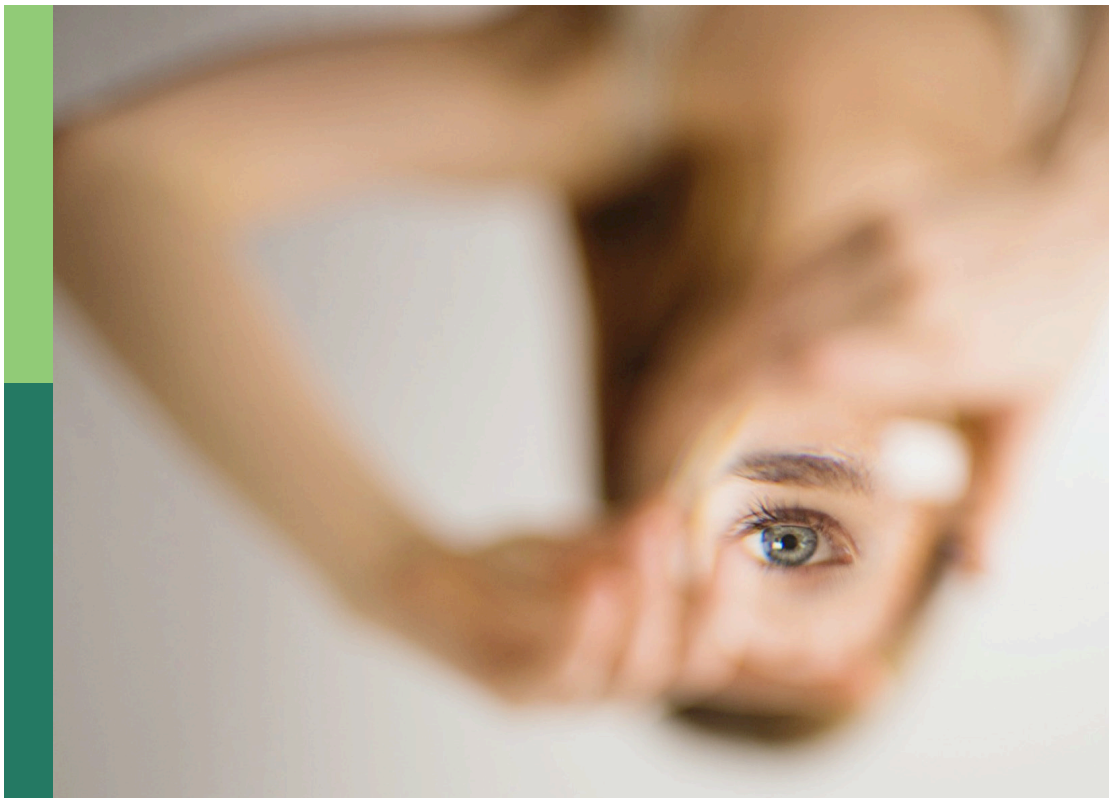
frontiers | Research Topics

International symposium on performance science 2021

Edited by
Aaron Williamon, Isabelle Cossette, Krzysztof Paweł Dąbrowski, Solange Glasser, Isabelle Héroux, Fabrice Marandola and Laura A. Stambaugh

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International symposium on performance science 2021

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Hard Work and Hopefulness: A Mixed Methods Study of Music Students' Status and Beliefs in Relation to Health, Wellbeing, and Success as They Enter Specialized Higher Education

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Using mixed methods, we explored new music students' concepts of wellbeing and success and their current state of wellbeing at a university music department in Switzerland. Music performance is a competitive and achievement-oriented career. Research suggests musicians face vocation-specific challenges to physical health and mental wellbeing but has yet to investigate music students' beliefs about wellbeing and success. With a self-report questionnaire ($n = 99$, Bachelor/Master students) we investigated new music students' quality of life (WHO-5; WHOQoL-BREF) and self-efficacy (ASKU). Through qualitative workshops (17 groups, $n = 5$–8) we explored students' understanding of the term "wellbeing," and how this relates to "success." Over half new music students (55%) believed the institution has 40–60% responsibility for their wellbeing. A simple linear regression showed that self-efficacy could predict better wellbeing, explaining 12% of the variance. Self-efficacy predicts wellbeing for new music students ($\beta 1 = 8.81$, $p = 0.001$). The 17 flipcharts generated 121 inputs clustered into themes. Four themes solely described "wellbeing" (Health, Safety, Vitality, and Attitude) and four separately depict "success" (Achieving Objectives, Recognition, Career, and Financial Goods). Some themes intersected as elements of both constructs (Intersection: Relationships & Environment, Development, Happiness, Meaningfulness, Balance and Authenticity). Four further themes illustrated the relationship between the two (Reciprocity, Conditionality, Stability and Perspectivity). Music students believe responsibility for wellbeing is shared between themselves and their institution. As they scored low on both self-efficacy and wellbeing, these findings are an urgent call for action for school management and stakeholders of the music student population.

Keywords: music, students, higher education, wellbeing, self-efficacy, self-determination, health, success

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INTRODUCTION

For musicians, there appears to be a paradox in the music and health narrative; on the one hand the mental and physiological challenges involved in trying to become or sustain a career as a musician can be detrimental to one's physical health and psychological wellbeing (i.e., musculoskeletal problems, hearing damage, stress, and performance anxiety, see e.g.,

Vaag et al., 2014; Kenny and Ackermann, 2015). On the other hand, from a eudaimonic perspective (i.e., enjoying a meaningful vocation in life), musicians seem to enjoy a better sense of wellbeing in comparison to non-musicians (Ascenso et al., 2017, 2018). In order to know how best to promote and tailor wellbeing programs for musicians, it is important to understand the development over time of trigger issues for different aspects of musicianship, i.e., which psychological and physiological issues are "in play" for whom and at what stage. As shown in a longitudinal study, providing modules that offer psychoeducation tailored to music students' issues does not necessarily improve health and wellbeing behaviors (Spahn et al., 2017).

As studies suggest it is the transition between student and professional life that is critical, personal and professional skills need to be adapted to self-support health and wellbeing, and notions of "success" may need to be re-framed as part of the reality of developing a portfolio career (Ascenso et al., 2016; López-Íñiguez and Bennett, 2020). The role of music institutions is not only to assess and guide playing abilities, but also to provide appropriate skills for the vocation (Wijsman and Ackermann, 2018). In terms of the development of the role of higher education (HE) music institutions, it is important to plan for and provide a framework of specialized support, especially considering the potential impact of the Covid-19 pandemic on musicians' livelihoods (Elmer et al., 2020; Stanhope and Weinstein, 2020).

Few investigations however have documented the status of music students' wellbeing at the start of their tertiary programs. In our previous study (Alessandri et al., 2020), we compared students enrolled on high performance study programs (sports and music) to students undertaking more typical university courses (e.g., sciences and humanities). Whilst wellbeing was compromised for all students compared to normative data, the personality trait of Emotional Stability and having an optimistic outlook contributed to predicting wellbeing in general for all students, with the personality trait Conscientiousness additionally contributing for sport and music students, and for music students only, perceived competence in their chosen vocation directly impacted their wellbeing. As the next step in understanding the state of play for our newly enrolled music students (what issues are already hiding in their music cases?), we present a cross-sectional mixed methods observational study of new music students at our institution. Specifically, this study focuses on new students during their first week in a Swiss HE music institution.

Our first aim was to document new music student wellbeing and perceived quality of life. Based on our previous study (Alessandri et al., 2020), we also included a measure of self-efficacy. Self-efficacy is a central tenet of self-determination theory and especially important in the study of music students as it directly relates to beliefs in one's own capabilities to effect change (Bandura, 1977; De Castella and Byrne, 2015; Rose, 2016; Alessandri et al., 2020; Cohen and Panebianco, 2020). As noted by Morton et al. (2014), the ability to manage stressors is underpinned by self-efficacy as difficulties encountered are seen as challenges to be overcome, rather than obstacles that undermine progress. We therefore surmised that higher levels of self-efficacy would predict higher levels of physical and psychological health (i.e., wellbeing) in music students.

As a further exploratory avenue of qualitative investigation, we asked our music students what they understood "wellbeing" to be in their context (i.e., training to be professional musicians), and expanded upon the notion of self-efficacy by asking students about "success" and how this might be linked to wellbeing for them. Our aim was to establish baseline information to understand the wellbeing status of our students, and how they are thinking about success and wellbeing as part of their vocational choice as they enter the first stages of their final training at our institution. With this information, our institution can then plan how best to support them through their transition into professional musicians, providing the adaptive skills necessary for life satisfaction and career longevity (López-Íñiguez and Bennett, 2020).

To summarize, our aims with this study were: (a) to document new music student wellbeing as the first stage of research in a longitudinal study using standardized measures that can be compared to other samples and populations, (b) to explore the role of self-efficacy in relation to the wellbeing of music students within the framework of self-determination theory, and (c) to consult our students about their beliefs with regard to wellbeing and success within the HE framework.

MATERIALS AND METHODS

This was a pilot study nested within a longitudinal research strategy to investigate music student wellbeing in specialist HE music institutions. Here we used a mixed method design with new students (i.e., in the first week of their first semester at our school). To provide further context, given the tremendous negative impact Covid-19 has had on HE students and the cultural sector in general (see e.g., Elmer et al., 2020; Cohen and Ginsborg, 2021): this study was conducted in Switzerland from 8th to 10th of September 2020. Social distancing and hygiene measures had been in place since March 2020 and during spring semester 2020 most of the university courses had to be held in a complete distance-learning-format. Our music school moved to new premises during summer 2020 and in combination with the covid-related restrictions, access to practice and rehearsal resources was limited. However, over summer and at the beginning of 2020's autumn semester, some measures were loosened by the government providing a sense of hope (e.g., mixed format teaching was allowed, together with some smaller concerts, then larger events). Although the focus of the study was not related to the effects of Covid-19 on music students, we asked participants, "Are you currently concerned that the Covid-19 pandemic could have a negative impact on your musical activity?." Just over half ($n = 54$, 55%) affirmed they were concerned about this matter. At the time of data gathering for this study, the gradual loosening of the restrictions may have instilled a sense of hopefulness in terms of professional and personal prospects for the students. Nevertheless, general travel restrictions were in place with conditions which may have negatively impacted concert-related travel and the large international student contingent.

Procedure

Quantitative and qualitative data were collected from 8th to 10th September 2020 exclusively during a new 90-min introductory course on "Health and Wellbeing" offered to all new music major Bachelor and Master students during the university opening week. The course was mandatory for Bachelor students and non-mandatory for Master students. First, questionnaires (please see **Supplementary Material 1** for the questionnaire text) were presented as hard copy forms in German language. Participants were then assured that the study had been granted ethical approval by the appropriate authorities and were provided with the Participant Information Sheet. The music students were then asked to provide demographic information, and then to answer the selected self-report measures. Participation was voluntary and options were offered, within that timeframe, for students to fill-out the questionnaire in privacy. After a short break, students were then invited to participate in a brainstorming session in groups of 5–8 students. Each group received flipcharts and colored markers to visualize their ideas. There was a brief presentation by each group at the end and participants were debriefed about the nature of the research. All Covid-19 related requirements such as mask-wearing and physical distancing as well as proper sanitization and hygiene were met during the sessions.

Participants and Recruitment

All newly enrolled Bachelor students, for whom the Health and Wellbeing course is mandatory, chose to participate in the study ($n = 89$). However, six questionnaires were not completed sufficiently (< 60% completion) to warrant inclusion. For Master students, for whom the course is non-mandatory, half the class attendees chose to participate ($n = 17$). Of these questionnaires, only one was not included due to non-completion. This led to a final sample of $N = 99$ for the survey data; 83 Bachelor and 16 Master music students.

Qualitative Methods

Brainstorming techniques (Osborn, 1963) have been shown to be useful for idea generation within the higher education context (see review, Al-Samarraie and Hurmuzan, 2018). Seventeen groups of 5–8 students were asked, in a face-to-face setting, to brainstorm (i.e., discuss and illustrate) their definitions of (1) "wellbeing," (2) "success," and (3) to describe the relationship between the two constructs. The groups (which due to Covid-19 safety regulations were formed in advance by school management) were separated from each other, but not inaudibly. During sessions lasting 15–20-min, the groups produced handwritten flipcharts (see **Supplementary Material 2** for a selection of these data). The sessions were facilitated by the final author who clarified the questions or tasks but did not moderate the sessions to minimize interference with process and group dynamics. The flipcharts were then independently and inductively coded by the second and the final authors in close alignment with guidelines for *Structured Content Analysis* (Kuckartz, 2019). Codes were compared and categorizations derived with main themes summarized in an iterative process, performed using MAXQDA 2020 (VERBI Software, 2019).

Quantitative Measures

The survey included demographic variables to characterize the sample as well as the following self-report measures:

The WHO-5 is a brief (five item) generic rating scale of subjective wellbeing (Bech et al., 2003; Topp et al., 2015). The five statements are positively worded and scored using a 6-point Likert scale over the past two weeks. The Cronbach's alpha coefficient reported for the WHO-5 is >0.80 (e.g., Garland et al., 2018).

The WHOQoL-BREF (WQB; Whoqol Group, 1998) is an abbreviated (26 item) version of the WHOQoL-100 which provides a Quality of Life (QoL) profile based on data from 18 countries. The manual defines QoL as *"an individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns"* (p. 3). Two separate items concern the individuals' perception of a) their overall QoL and b) their general health. The remaining items produce scores for four domains (please see **Supplementary Material 3** for details on domain concepts) described as Physical Health (7 items), Psychological Health (6 items), Social Relationships (3 items) and Environment (8 items). All items are rated using appropriate 5-point scales (i.e., *intensity*, *evaluation*, *satisfaction*, *capacity*, and *frequency*). The reliability of the domains is acceptable according to Cronbach alpha values (0.68, 0.75, 0.64, and 0.74 respectively, DeVellis, 2003).

The Self-Efficacy Scale – Short form (Allgemeine Selbstwirksamkeit Kurzskala (ASKU) in German, Beierlein et al., 2012) contains three items (related to self-reliance for situation-, problem-, and task-solving) scored using a 6-point Likert scale. The ASKU is a shortened and validated version of the 10-item General Self-Efficacy Scale by Schwarzer and Jerusalem (1995). Beierlein et al. (2013) provide reliability estimates using McDonald's Omega values between 0.81 and 0.86, which they interpreted as sufficient.

The following section characterizes the students in terms of general demographics and information specific to music students.

RESULTS

Data Preparation and Analyses

When assumptions for parametric analyses were met, Student *t* tests were used where appropriate (i.e., one sample *t*-test against normative/other published values). Non-parametric analyses were conducted where appropriate, for example due to the unequal sample (i.e., Welch's t tests were used to compare between Bachelor and Master student groups, Delacre et al., 2017).

The choice to compare the data from this sample with three published data samples for the standardized tests (WHO-5 and WHOQol-BREF) was to provide contextual comparisons from the various perspectives. Students in higher education (HE) have been shown to have lower wellbeing than normative data in general, and some differences have been shown between students in HE whose focus is performance based in comparison to "other" types of study (Alessandri et al., 2020).

The provision of contextual perspectives is especially important during extraordinary times such as those we are experiencing during the Covid-19 pandemic, where the burden educational institutions and the arts sector face (Marinoni et al., 2020; Spiro et al., 2021) reduces recruitment capacity for gathering directly comparative data.

Equal variances can be assumed unless otherwise reported. Alpha p value was adjusted for multiple comparisons using the Bonferroni method; alpha $p = p < 0.005$. Multiple regression analyses were conducted to ascertain the predictive value of variables of interest on wellbeing within this sample. Pearson's bivariate correlational analyses (two-tailed) were conducted between measures. Where n and % are reported, the percentage data refers to the valid percent (i.e., the percentage is weighted according to missing values). Data was analyzed using the Statistical Package for Social Sciences (SPSS; v27, IBM).

Quantitative Results

As this study focused on new intake students only, we compared the large intake of Bachelor and the small number of Master students using Welch's t-test (which is robust against difference in group sizes). We expected significant differences in Age (and the related variables; "Years of Study" and "Average numbers of concerts performed per year (pre-Covid-19)." As expected, Master students were older, had spent more time studying their main instrument (14 rather than 11 years), and performed more concerts per year (prior to Covid-19) on average (between 11 and 40 concerts per year compared to between seven and ten) than Bachelor students (see **Table 1**). With regard to wellbeing measures, although a significant difference was found between student groups for the single item WQB-QoL with Master students experiencing worse QoL than Bachelor students (see **Table 1**), this result was not a robust finding once adjusted to the alpha p value for multiple comparisons. No other between-group differences were found in this sample. The general lack of difference between groups justified collapsing the data sets to combine Bachelor and Master students in their first semester at our institution.

The final sample ($N = 99$; 83 Bachelor, 16 Master students) had a mean age of 22.39 ($SD = 4.84$, range 17–52). The sample was split evenly between males ($n = 47$, 48%) and females ($n = 49$, 50%) with three participants choosing not to describe their gender. Almost half ($n = 46$, 47%) had a side job for which they spent, on average, seven hours per week working (ranging from 1 to 20 hours per week). Instruments included Voice ($n = 22$, 22%), Guitar and Piano ($n = 11$, 11% each), Violin ($n = 9$, 9%), Drums ($n = 5$, 5%), Clarinet, Viola, Flute and Cello ($n = 4$, 4% each), Saxophone, Trumpet, French Horn, and Conducting ($n = 3$, 3% each), Double Bass, Electric Bass, Organ, Trombone and Oboe ($n = 2$, 2% each), and Choir Leading, Schwyzerörgeli, and Harp ($n = 1$, 1% each).

Descriptive Statistics

Student Self-Report of Instrument-Related Issues and Discomfort While Playing

We asked students whether they are currently and/or have in the past suffered from complaints that could be related to their musical activity physically and psychologically (forced choice;

TABLE 1 | Demographic and descriptive information about the sample and between group statistics.

	Bachelor ($n = 83$)			Master ($n = 16$)			Welch's t-test statistics
	Mean	SD	Range	Mean	SD	Range	Between groups
Age (years)	21.78	4.92	17–52	25.56	2.76	22–31	$t(97) = -2.97$, $p = 0.004$
Time per week doing side job (hours)	6.86	4.74	1–20	9.4	3.45	6–15	ns, $p > 0.2$
Total time studying main instrument (years)	11.16	4.17	2–23	14.06	4.51	3–23	$t(97) = -2.52$, $p = 0.013$
Amount of daily musical practice(hours per day)	2.77	1.37	1–7	3	1.24	1–6	ns, $p > 0.5$
Amount of daily other study (hours per day)	1.44	1.17	0–6	1.12	0.67	0–2	ns, $p > 0.3$
Number of concerts played per year (pre Covid-19)[a]	2.98	1.36	0–6	4.38	1.26	2–6	$t(96) = -3.81$, $p < 0.001$
Psychological issues in relation to musical activities[b]	2.61	0.61	1–4	2.54	0.66	1–3	ns, $p > 0.6$
Physical issues in relation to musical activities[b]	2.23	0.83	1–3	2	0.82	1–3	ns, $p > 0.3$
Continued practice despite physical discomfort[c]	3.52	1.54	1–5	3.5	1.41	1–5	ns, $p > 0.9$
Covid related anxiety aboutmusical activity[d]	1.46	0.5	1–2	1.44	0.51	1–2	ns, $p > 0.8$
WQB QoL (Raw)	4.31	0.74	2–5	3.86	0.66	3–5	$t(92) = 2.17$, $p = 0.034$
WQB General Health (Raw)	3.69	0.78	2–5	3.87	0.74	2–5	ns, $p > 0.4$
WQB Physical Health (%)	74.45	15.38	21–100	72.14	16.98	36–100	ns, $p > 0.6$
WQB Psychological Health (%)	69.62	14.96	4–96	74.17	14.10	54–96	ns, $p > 0.2$
WQB Social Relationships (%)	75.22	17.57	33–100	76.92	17.73	42–100	ns, $p > 0.7$
WQB Environment (%)	78.29	14.56	39–100	75.0	12.99	47–94	ns, $p > 0.4$
WHO-5 (%)	61.82	15.56	12–84	60.57	21.56	24–96	ns, $p > 0.7$
ASKU (Raw)	3.75	0.68	1–5	3.73	0.57	1–5	ns, $p > 0.9$

[a] *Coded scale per year: 1 = one to three, 2 = four to six, 3 = seven to 10, 4 = 11 to 20, 5 = 21 to 39, 6 = 40+ concerts.*
[b] *Coded scale: 1 = currently, 2 = in the past, 3 = never.*
[c] *Code scale: 1 = Never, 2 ≤ once per month, 3 = 1–3 times per month, 4 = 1–3 times per week, 5 = almost daily.*
[d] *Covid Anxiety 1 = Yes, 2 = no.*

TABLE 2 | Comparison of WHO-5 and WHOQoL-BREF (WQB) wellbeing scores against study sample and comparative data (i.e., published normative, music and other student data).

	Study Sample	Topp et al. (2015) (Normative Data; German sample)		Baumann et al. (2014) (General HE Students)		Antonini Philippe et al. (2019) (Music HE Students)	
Variable	**Mean (SD)**	**Mean (SD)**	**Statistic**	**Mean (SD)**	**Statistic**	**Mean (SD)**	**Statistic**
WHO-5 (%)	61.63 (16.46)	66.3	$t(92) = -4.66, p = 0.008$				
WQB – Physical Health (Raw)	5.86 (2.49)	16.8 (2.6)	$t(96) = -3.74, p < 0.001$				
WQB - Physical Health (%)	74.09 (15.57)			72.90 (14.90)	ns, $p > 0.4$	69.46 (12.79)	$t(96) = 2.93$, $p = 0.004$.
WQB - Psychological Health (Raw)	15.25 (2.38)	15.7 (2.4)	ns, $p = 0.07$				
WQB - Psychological Health (%)	70.34 (14.85)			73.60 (14.40)	$t(94) = -2.14$, $p = 0.35$	69.09 (12.54)	ns, $p > 0.4$
WQB - Social Relationships (Raw)	16.07 (2.80)	14.4 (2.9)	$t(89) = 1.67, p < 0.001$				
WQB - Social Relationships (%)	75.46 (17.51)			74.00 (18.30)	ns, $p > 0.4$	77.02 (17.19)	ns, $p > 0.4$
WQB - Environment (Raw)	16.45 (2.28)	13.0 (2.3)	$t(94) = 14.76, p < 0.001$				
WQB - Environment (%)	77.77 (14.31)			74.00 (13.80)	$t(93) = 2.55$, $p = 0.012$	72.83 (15.64)	$t(93) = 3.34$, $p = 0.001$

currently, in the past, never). Just under two thirds ($n = 56$, 61%) of the students reported currently and/or having suffered with playing related physical issues, and one third ($n = 29$, 33%) of students reported currently and/or having suffered with playing related psychological issues. Overall, $n = 64$ (68%) of student reported they had at some stage suffered with playing-related issues (either physical or psychological), $n = 20$ (21%) of these students reported having suffered with both types of issues, and $n = 30$ (32%) of students surveyed reported they had never suffered with playing-related physical or psychological issues.

Students were not asked to provide details on the nature of the experienced issues.

In this sample, $n = 82$, 85%) of music students reported that over the last six months they practiced on their main instrument, despite experiencing physical discomfort. Specifically, $n = 39$ (40%) reported this was something they did almost daily, $n = 16$ (17%) reported 1 to 3 times per week, $n = 13$ (13%) reported 1 to 3 times per month, $n = 14$ (14%) reported less than once per month. In the last six months, $n = 15$ (16%) reported that they never practiced on their main instrument while experiencing physical discomfort.

Student Beliefs About Ratio of Responsibility: Student and Music School

We asked students to rate the proportion (percentage) to which the music school carries responsibility for their own wellbeing using two slider scales (one for the individual, the other for the institution, indicating the total amount should be 100%, see **Supplementary Material 1**). Almost all of the music students surveyed ($n = 82$, 98%) believed that the music school was at least 20% responsible for their wellbeing.

Specifically, $n = 27$ (32%) of music students surveyed believed they themselves were 80% responsible for their own wellbeing, $n = 26$ (31%) believed they were 60% responsible, and $n = 22$ (26%) believed the responsibility was split equally between themselves and their institution (i.e., 50%/50%). No students believed their institution was more than 80% responsible for their wellbeing, but $n = 5$ (6%) of students believed the institution was 60% responsible for their wellbeing, and $n = 2$ (2%) believed their institution was 80% responsible for their wellbeing. Students were not asked to specify the areas of responsibility.

Components of Success Ranking

Students were asked to rank the relative importance of *practice*, *luck*, and *talent* for their success as a musician (forced choice between the three factors). Two thirds of students surveyed $n = 53$ (65%) ranked *practice* as the most important factor, almost a half ($n = 35$, 44%) ranked *talent* as the second most important factor, and almost a half ($n = 56$, 46%) ranked *luck* as the least important factor. The most popular ranked order was Practice, Talent, Luck ($n = 32$, 39%).

Inferential Statistics

WHO-5

Table 2 presents the results of the inferential analyses. Normative data for the WHO-5 should be based on the country of the participants [see Supplementary Table 2 in Topp et al. (2015) for country specific normative data]. In this study, Germany was the closest cultural match to German speaking area of Switzerland with a Mean percentile score of 66.3%. Therefore, this percentile score was used in statistical analysis to compare this sample with the normative data (one-sample Student *t* tests). Students in this study reported WHO-5% Mean score that was significantly lower than the Topp et al. (2015) normative data from Germany (*Mean difference* $= -4.67$, *CI* $= -1.28$ to -8.06).

WHOQoL-BREF

For the nearest geographical/cultural norms, the raw data[1] from the German field trials were used ($n = 2408$, Skevington et al., 2004). Music students at our institution scored significantly lower than German norms for Physical Health (*Mean difference* $= -0.95$, *CI* $= -0.44$ to -1.45), but significantly

[1]Percentile data are not available for Swiss norms.

higher than German norms for Social Relationships (*Mean difference* = 1.67, *CI* = 1.09–2.26) and Environment (*Mean difference* = 3.45, *CI* = 2.98–3.91). The sample from our institution did not significantly differ from German norms for Psychological Health.

To compare our data to general students[2] in Western Europe, we used data from Baumann et al. (2014) who investigated first year students at the University of Luxembourg ($N = 973$), *Mean age* = 20.6 ($SD = 3.2$), range 18-44, 46% female. Our sample differed from Baumann et al. on two factors: percentile scores for Psychological Health were significantly lower for the students at our institution compared to general HE students (*Mean difference* = −3.26, *CI* = −0.24 to −6.29). However, the significance level of this statistic does not withstand adjustment for multiple comparisons. Our sample scored significantly higher for Environment (*Mean difference* = 3.77, *CI* = 0.83–6.7). Our sample did not significantly differ from general HE student scores for Physical Health and Social Relationships.

To compare our data to music students in Switzerland we used data published in Antonini Philippe et al. (2019). Their sample ($N = 126$) comprised music students (amateur and in higher education for music) in a French speaking area of Switzerland. Where possible, statistics were compared to the Higher Education subset of music students ($n = 46$). Music students at our institution scored higher than in Antonini Philippe et al. (2019) study on Physical Health (*Mean difference* = 4.63, *CI* = 1.49–7.77), and Environment (*Mean difference* = 4.94, *CI* = 2–7.87). Our sample did not significantly differ from scores at this comparable music school for Psychological Health and Social Relationships.

To summarize the significant results of the WQB measures, our sample scored lower than German norms and general HE students on Physical Health though higher than a comparable music school, higher than German norms for Social Relationships, and higher than German norms, general and music specific HE students for Environment.

Allgemeine Selbstwirksamkeit Kurzskala Measure of Generalized Self-Efficacy

Students at our institution scored a mean value of 3.77 ($SD = 0.68$) for the ASKU. This was significantly lower than the appropriate stratification of normative data for German residents, aged 18-35, who have completed 11 or more years of schooling ("*High*" *Norm mean* = 4.28, $t(92) = -7.73$, $p < 0.001$. Mean difference = −0.53, CI = −0.40 to 0.67).

Correlations

The WQB-Psychological Health and Physical Health factors were correlated with the WHO-5% ($r = 0.75$, $p < 0.001$, and $r = 0.59$, $p < 0.001$ respectively). In line with our previous study (Alessandri et al., 2020), the WHO-5% was considered the most parsimonious measure of wellbeing that accords with the WHO conceptual and holistic approach to wellbeing as a subjective life experience and not merely the absence of disease or infirmity (World Health Organisation [WHO], 1948).

[2]Fields of study described as Science & Technology, Law & Finance, and Social Sciences.

Simple Linear Regression

A simple linear regression was carried out to test if self-efficacy significantly predicted wellbeing as conceptualized with the WHO-5%. The results of the regression indicated that the model explained 12.1% of the variance and that the model was significant, $F(1, 89) = 12.31$, $p < 0.001$. Self-efficacy significantly predicted wellbeing for new music students ($\beta 1 = 9.60$, $p = 0.004$). The same analysis was used to explore whether self-efficacy significantly predicted physical health indicated that the model explained 18.4% of the variance. The model was significant, $F(1, 91) = 20.58$, $p < 0.001$. Self-efficacy significantly predicted physical health for new music students ($\beta 1 = 8.53$, $p < 0.001$).

Qualitative Findings

Over the 17 flipcharts (see **Supplementary Material 2** for examples of raw data), students used a total of 121 inputs (i.e., keywords or short statements) to describe "wellbeing" and a total of 73 inputs to describe "success." Students' descriptions of "wellbeing" and "success" could be clustered in 15 themes. Four further themes emerged, that illustrate how students see the *relationship* between the two constructs. **Figure 1** shows a summary visualization of the themes. "Wellbeing" and "success" emerged from students' descriptions as being intimately interconnected: over one third of the descriptors used to describe "wellbeing" and "success" (*Relationships & Environment*, *Development*, *Happiness*, *Meaningfulness*, *Balance* and *Authenticity*) were identified as being elements of both constructs (*Intersection*). Four elements were described as belonging to "wellbeing" alone (*Health*, *Safety*, *Vitality*, and *Attitude*) and four to "success" alone (*Achieving Objectives*, *Recognition*, *Career*, and *Financial Goods*). "Wellbeing" and "success" as well as components thereof were described in general as influencing each other (*Reciprocity*). Students also tried to capture the *Conditional* relationships between the two constructs: they emphasized that while "wellbeing" and "success" are strongly connected, and yet neither of them is sufficient to achieve the other – although "wellbeing" is necessary precondition for "success" (S – > W). In two flipcharts, "wellbeing" and "success" were described as balancing each other out (*Stability*). Finally, students described "wellbeing" and "success," with all their components, as being dependent on individual values, as well as cultural and societal norms and expectations (*Perspectivity*). **Table 3** reports the full list of themes.

DISCUSSION

This cross-sectional study allows only a snap-shot view of the status and beliefs of new music students in relation to wellbeing and success as they enter the final stages of their music education. As surmised, self-efficacy predicted physical and psychological health/wellbeing. However, levels of self-efficacy were low, and we cannot be sure to what extent the Covid-19 situation impacted self-efficacy scores. In this respect it will be interesting to collect longitudinal data to see how those scores develop. Nevertheless, as students perceived a "shared responsibility"

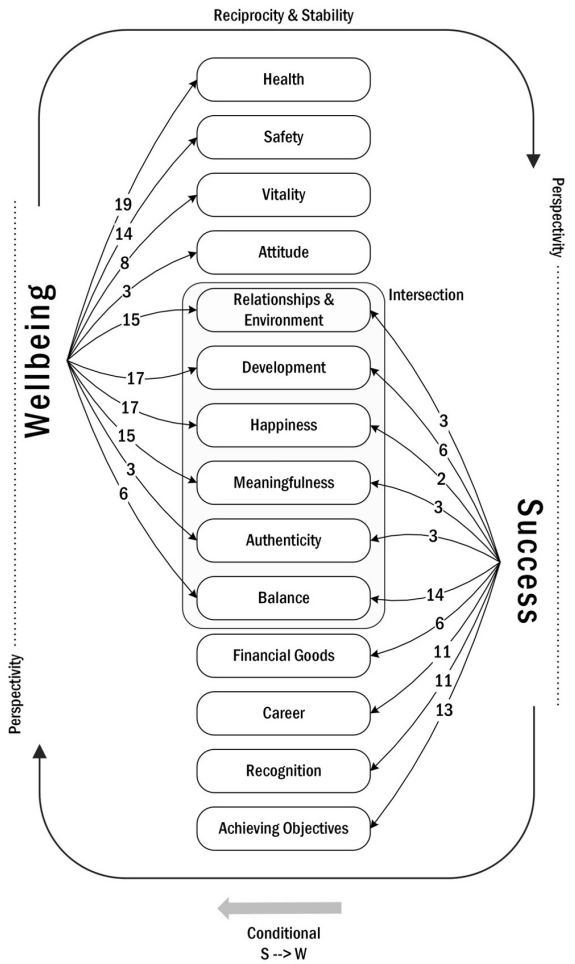


FIGURE 1 | Visualization of themes emerged from the qualitative analysis of students' flipcharts.

between themselves and the institution in terms of wellbeing, believed that practice is what matters the most in terms of their success, and yet weren't confident they could shape their own future, these findings support calls for concrete action within higher education music schools.

Researchers have suggested a cultural shift is necessary to truly support students through this critical transition stage, and that a holistic approach is required, yet these aims may be at odds with the priorities of many institutions (Ascenso et al., 2016; Wijsman and Ackermann, 2018; Burland, 2020; López-Íñiguez and Bennett, 2020). Here we discuss how findings from this study can contribute to understanding the needs of our students in relation to the role of self-efficacy in transformative professionalism, the importance of environmental and social aspects of higher music education institutions, and the necessity to re-frame what constitutes "success," and notions about playing through pain.

Self-efficacy has been linked to success in study and work, as well as good health and wellbeing in terms of motivating and maintaining behaviors, and appraising one's own competencies to plan, act and achieve one's desired goals (Bandura and Schunk, 1981; Dweck and Master, 2012). Recommendation to learn more about health-promoting behaviors has resulted in optional modules being offered in higher music education curricula due to the high prevalence of physical and psychological difficulties, though this approach only improves health-promoting behaviors in a minority of students (Spahn et al., 2017). However, the way a person regulates their behaviors may be an interaction between their own beliefs and actions, and their contextual environment. In this study for example, Bachelor and Master students appeared similar as they entered their new school of music, but future studies should also take care not to assume that Bachelor and Master students develop at the same rate depend on which variables are of interest. A recent study of musicians and self-efficacy in relation to the uptake of health-promoting behaviors (Cohen and Panebianco, 2020) showed that not only did self-efficacy mediate the influence of the personality traits of conscientiousness and extraversion in musicians, but also that students enrolled at a coastal university campus engaged in more physical activity than those whose campuses were further inland. This finding is in accordance with Bandura's Social Cognitive Theory (Bandura, 1989) which posits that environment can either facilitate, or be perceived as barriers, be perceived as a barrier to motivations and behaviors that support wellbeing.

In our study, students scored higher than average on the Environment and the Social Relations domains of the WQB. Our sample specifically focused on new students, and furthermore, these students were the first intake of a new school of music building, specifically designed for musicians, including various spaces for music students to study, socialize and relax. The school is well positioned with a large lake and mountains nearby, and good public transport links. However, being accepted to a higher education music program usually requires years of cost-intense musical education and practice, which might imply a positive association between socioeconomic background and access to music education (Associated Board of the Royal Schools of Music [ABRSM], 2014; Burland, 2020). It will be important for future studies to further investigate the individual impact of contextual matters such as family, school, and local environment on students' wellbeing.

A general study of Swiss student experiences during lock-down emphasized the importance of social relations in terms of wellbeing (Elmer et al., 2020). We see here some evidence that music students' social networks were strengthened despite reduced physical and psychological wellbeing. We speculate that these new students either relied upon previously established support networks, or (less likely) identified and bonded with each other over their experience in a new environment. Considered in light of the three pillars of self-determination theory (i.e., relatedness, autonomy, and competence) the impact of social relations in music schools should not be underestimated, alongside the impact of contextual factors such as environment. We therefore suggest a holistic model of wellbeing should make use of local resources within and beyond the school and emphasize the design of social spaces to facilitate sustainable social interactions between students. As WQB does not deliver a descriptive answer to regular health and risk behaviors of music students, further research will be needed to better

TABLE 3 | Qualitative coding for elements of, and relationship between, wellbeing and success according to music students.

Theme	Frequency		Definition of theme
	Wellbeing	Success	
Elements			
Health	19	0	Physical and psychological health. Students often used the term "health" directly or variations of "being fit." Physical pain and discomfort are also included here, along with conditions of sleep (or lack thereof) as a symptom associated with health.
Safety	14	0	Safety is either directly mentioned or aspects of it are thematized such as financial security, protection, being worry-free, and the fulfillment of basic needs.
Vitality	8	0	Inputs describe having energy and being active (i.e., doing something, or going for a walk), or lack thereof, such as being "exhausted."
Attitude	3	0	Here instances of "acceptance" and "attitude" are clustered. Attitude is conceptualized as readiness to accept a situation, person, or reality.
Relationships & Environment	19	4	Terms that either describe social bonds (family, friends, social contacts) or assume functioning relationships (e.g., "constructive feedback," "love"). This theme also includes terms that describe the social or daily environment ("life situations," "relationship with the world," "good food/drink"). One instance mentioned having a "good relationship with yourself."
Development	17	6	Personal development including aspects of learning and discovery ("experience new things," "learn something new," and "develop yourself").
Happiness	17	2	Short or long-lasting positive feelings, positive awareness of own emotional state, e.g., "to feel good," "to be happy." This theme also includes direct or indirect mentions of "peace" and "relaxation" ("calm," "breathe," "serenity").
Meaningfulness	15	3	Having purpose and making meaning of one's actions and activities including "motivation" and "feeling involved." Also perceiving one's work as a "vocation," having objectives, and making an impact on other people ("to have an effect," "to reach people").
Authenticity	3	3	Feeling of identity and inner coherence ("authenticity," "find your true self," "resonate with your core self and with the world (body, spirit, soul)"). Constructs of "self-worth," "self-realization," and "freedom" are also included here.
Balance	6	14	Inner psychological balance (e.g., between Eu- and Distress) or balance between life areas ("work-life balance"). Instances of "free time," "having time for yourself" as well as "being satisfied" are also encompassed, alongside "satisfaction" which is understood by the students as equation between expectations and reality.
Financial Goods	0	6	Relevant economic goods, like money, good payment, or material possessions.
Career	0	11	Work and career, including "performance," "job" and in general having a chance to play in public and enjoying a "large audience." This theme also includes inputs that focus on career status and quality of the work done, e.g., "career at professional level" or "a place in an orchestra."
Recognition	0	11	Recognition, respect, appreciation, and esteem, e.g., perceived "status," and peer acknowledgment "confirmation through colleagues."
Achieving Objectives	0	13	Students often mention achieving personal or self-given objectives, i.e., "reaching goals."
Perspectivity	2	9	Success and in two instances also wellbeing are viewed here as being subjective, "individual," and dependent on situations, personal values, and expectations, including cultural and societal norms.
Relationship			
Reciprocity	10		Mutual influence between Wellbeing and Success (or components thereof), either generally expressed "success and wellbeing are strongly connected" or implying causality through arrows and words (e.g., "wellbeing leads to success" or "can influence each other." In one instance this relationship between Wellbeing and Success was described as "symbiosis."
Conditional	6		Necessity and sufficiency. Students affirm that despite the strong interconnection between Wellbeing and Success, alone neither would be sufficient to achieve the other. However, Wellbeing was described as necessary for Success.
Intersection	5		Wellbeing and Success are seen as overlapping (intersecting) sets. Success (and its components) was described as part of Wellbeing and reverse.
Stability	2		Wellbeing and Success balance each other out.

understand the nature and quality of students' regular health and risk behaviors (e.g., habits in regards to exercise, diet, sleep, drug use and/or misuse of medication and other behaviors to cope with stressful situations) and their effect on musicians' health and wellbeing as well as performance, as previous studies provide somewhat ambiguous results (Kreutz et al., 2008; Ginsborg et al., 2009; Perkins et al., 2017; Cruder et al., 2020).

Recent studies have suggested that musicians should now be considered as multi-professionals, but that the challenges associated with such a myriad skillset (i.e., struggling with enforced entrepreneurship, building, and running a small business, and having to take on other work to support themselves) is a problem much exacerbated in recent times (López-Íñiguez and Bennett, 2020; Spiro et al., 2021). To prepare music students for the realities of professional life, institutions

need to move beyond prescriptive teaching and learning of repertoire, technique, and skills. In their investigation of a fellowship program with the Civic Orchestra of Chicago, Ascenso et al. (2016) found that when music students were immersed in a professional context, they extended their beliefs and behaviors beyond the comfort zone of conservatoire life. Students reported gaining perspective and improving their wellbeing by considering their roles as musicians and citizens. In addition to developing professional and social skills (i.e., time-management and networking), the students acquired confidence in their abilities to sustain a multi-faceted career in music. They felt like they had "something to say" (p. 161) and realized "there is so much more to music than just perfect performance" (p. 162). Rather than being directed to one goal, they could see there were multiple avenues available and felt more connected rather than disillusioned. Similarly, in their study reviewing the career profiles and opinions of successful cellists, López-Íñiguez and Bennett (2020) found that reframing of the concept of success was seen as an essential way to overcome hierarchical and narrow perceptions of achievement in the classical music world and avoid a crisis of identity later in their careers. Moreover, developing ways to uphold ethical behaviors (e.g., being able to challenge bullying, sexism and racism) was seen as a way to avoid the repetition of default teaching modes (i.e., the master-apprentice model of instrumental learning, Burwell, 2016) and instead foster artistic as well as social and professional diversity.

The insights gained from the qualitative part of our study suggest the students may be ahead of the institutions in these matters. Students saw a clear connection between wellbeing and success and described success not just in terms of tangible or external outputs like concerts, earning or recognition, but also in terms of psychological and life balance, social relationships, and finding meaning in their own doing. They spoke of authenticity and integration in their communities that reflect the studies described above and demonstrate how musicians now embrace being agents of social change, rather than accepting the *status quo*. The interconnection between success and wellbeing—as described by our students—suggests an implicit understanding of wellbeing in line with current models of eudemonic wellbeing (Ryff and Singer, 2008; Huta, 2013). In our students' views, feelings of happiness, safety and inner balance are enmeshed with achievement and excellence: they not only influence each other but perhaps even define what "success" ought to be, including concepts such as personal development, meaningfulness and authenticity. In addition to the wellbeing elements to be found in eudemonic models of wellbeing like PERMA (Seligman, 2011), in a few instances our students described a readiness to accept circumstances as they are (i.e., acceptance) as a component of wellbeing. Contentment and acceptance have been recently embedded in wellbeing models rooted in existential positive psychology, like the mature happiness model (Wong and Bowers, 2018). During the time of the Covid-19 pandemic, the mature happiness model was shown to be a better predictor of general psychological distress than the PERMA model (Carreno et al., 2021). This construct of attitude as an ability to accept and find personal growth in negative or non-optimal aspects of living emphasizes once more the importance of a holistic approach to wellbeing and a redefinition of the notions of success that HE music institutions nurture among students.

Nevertheless, the issue of playing-related pain remains in our sample. The high proportion of students reporting instrument-related physical issues and the low level of physical health resonate as a call for help in students' flipcharts, in which physical health, including freedom from pain, are identified as a main component of their wellbeing. This is in line with the findings of Wijsman and Ackermann (2018) who suggest that whilst the development of performance-based medical disorders began in childhood (for many musicians), practice habits exacerbate this, contributing to chronic conditions in later life. At the point of entry into tertiary music education, most music students face an increased risk of injury due to increased practice and performance demands. They suggest a cultural shift is required, including a settings-based approach to health literacy as low levels of health literacy among teachers can perpetuate the cycle. The authors further propose that the success of such a program will depend on contextual factors such as *relevance*, *accessibility*, *legitimacy of knowledge*, and the *practical implementation of injury prevention strategies*. This translational approach to developing learning cultures is recognized in the WHO Shanghai Declaration (World Health Organisation [WHO], 2017) which states that health literacy must be an integral part of the skills and competencies developed over a lifetime and incorporated into the educational curriculum. As pointed out by Stanhope and Weinstein (2020), musculoskeletal disorders are the most common and costly compensation claims made by musicians. They suggest that although medical advice is typically to cease doing whatever is causing the pain, musicians may require a more nuanced approach to treatment. This is because: (a) they are more likely to experience pain of greater intensity than any tissue damage indicates (compared to population norms) owing to both neurological differences and higher prevalence of sleep problems and psychological distress, and (b) taking time off has serious consequences for musicians such as financial jeopardy, stigma, and loss of reputation (letting colleagues down), as well as a potential loss of identity, and supportive social connections. The multi-center study being carried out by Cruder et al. (2020) will undoubtedly provide valuable insights for institutions considering how best to implement prevention and treatment programs.

In terms of our study, to protect the anonymity of the participants, we did not ask for specific details about the nature of the playing related pains, and/or other physical and psychological conditions our students reported. Nevertheless, that they reported such high incidences suggests that the sacrifice involved in "playing through the pain" (a concept also prevalent in elite sports) may be related to the conflict between talent myths and self-determination theory; how can one overcome the lack of magic dust? Only by practicing more. These conflicts and paradoxes are inherent within the system of musical learning; from motivating beginners (practice makes perfect narratives) to honing the skills of the advanced students (how can you be better than everyone else). As we move forward with considering how best to support our students, the potential of a "living curriculum" approach (Johnsson and Hager, 2008) that emphasizes curiosity and creative autonomy would seem

to capitalize in the intrinsic motivation for lifelong learning apparent in musicians (Rose, 2016; Burland and Davidson, 2017). Moreover, empowering not just the students as stakeholders, but also the whole staff in terms of a culture of learning that underpins good practice to embed health and wellbeing in music education is necessary from an institutional perspective (Riva et al., 2020). The "process of discovering" forms part of a growth mindset (in contrast to a fixed mindset focused on the achievement of externally devised goals thereby undermining self-efficacy, Dweck and Master, 2012; De Castella and Byrne, 2015), that can be applied in both directions (i.e., staff and students). López-Íñiguez and Bennett (2020) suggest four key areas for change: 1. enabling musicians to become *agents of learning*, 2. reducing reliance on the master-apprentice model of instrumental learning, 3. fostering ideas around multi-professional nature of life as a musician, and 4. promoting the social consciousness of students (musicians as citizens) to encourage perspective related wellbeing. Future directions include an ongoing international study comparing music schools and music students across stages and types of study to understand the changes throughout the undergraduate process and into the post graduate stages.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study, involving human participants, was reviewed and approved by the Ethics Committee of Lucerne University of Applied Sciences and Arts, Lucerne, Switzerland. The participants provided written informed consent prior to taking part in the study.

AUTHOR CONTRIBUTIONS

DR and EA designed the study. DR analysed the quantitative data. EA conducted the qualitative workshops; EA and CS analysed the qualitative data. All authors contributed to the manuscript and approved the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.740775/full#supplementary-material

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Playing-Related Musculoskeletal Disorders, Risk Factors, and Treatment Efficacy in a Large Sample of Oboists

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Objectives: During their lifetimes, a majority of musicians experience playing-related musculoskeletal disorders (PRMD). PRMD prevalence is tied to instrument choice, yet most studies examine heterogeneous groups of musicians, leaving some high-risk groups such as oboists understudied. This paper aims to (1) ascertain the prevalence and nature of PRMDs in oboists, (2) determine relevant risk factors, and (3) evaluate the efficacy of treatment methods in preventing and remedying injuries in oboe players.

Methods: A 10-question online questionnaire on PRMDs and their treatments was completed by 223 oboists. PRMDs were compared across gender, weekly playing hours, career level, age, and years of playing experience.

Results: Of all respondents, 74.9% (167/223) reported having had at least one PRMD in their lifetime. A majority of these injuries (61.9% of all respondents) were of moderate to extreme severity (5 or higher on a scale of 1 to 10). Females (mean = 5.88) reported significantly more severe injuries than males. No significant effects of career level (i.e., professional vs. student vs. amateur), age, or years of playing experience were observed. We found significant non-linear relationships between weekly playing hours and PRMD prevalence and severity. Injuries were most commonly on the right side of the body, with the right thumb, wrist, hand, and forearm being most affected in frequency and severity. Of those injuries for which recovery information was provided, only 26.1% of injuries were "completely recovered." The perceived effectiveness of a few treatments (physical therapy, rest, stretching, occupational therapy, massage) tended to be ranked more highly than others.

Conclusion: The oboists in this study experienced high rates of PRMD, particularly in the right upper extremities. Females and those playing 7-9 and 16-18 h per week reported a significantly higher severity of injuries than other groups.

Keywords: oboe, musculoskeletal disorders, woodwind, occupational health, prevalence, risk factors, musician, playing-related injuries

INTRODUCTION

At some point in their careers, most musicians experience the painful and disabling effects of playing-related musculoskeletal disorders (PRMD). For professional musicians, these injuries can mean lost income and increased financial precarity, social stigma and strain on relationships, and the psychological and emotional hardships of not being able to make music (Guptill, 2011).

Research has provided insight into the nature and prevalence of PRMD in musicians in general; however, the majority of these studies deal with large, heterogeneous groups of musicians, leaving some specific groups of musicians understudied. Preliminary findings suggest that one of these understudied groups, oboists, are among the most at risk (Thrasher and Chesky, 2001; Nemoto and Arino, 2007; Stanek et al., 2017). This elevated risk is most often attributed to the oboe's asymmetrical playing position (Thrasher and Chesky, 2001; Nemoto and Arino, 2007). Professional-level oboes weigh between 590 and 735 grams (J. Mason, personal communication, November 13, 2020), and this entire weight is supported by the right thumb, leading to possible strain and injury in the right upper extremities. Despite their elevated risk, oboists are typically underrepresented in studies (three largest sample sizes: n = 60, 28, and 12) (Thrasher and Chesky, 2001; Nemoto and Arino, 2007; Stanek et al., 2017), and there is little consensus on the precise nature and prevalence of PRMD in this population. To gain a fuller and more nuanced understanding of oboists' PRMD, researchers must target a larger sample size of oboe players. In this paper, we present the results of the first large-scale survey of oboists designed to capture variation across the spectrum of career level, experience, age, and gender.

Although much work has been done to identify PRMD risk factors in musicians in general, little is known about the extent to which these risk factors hold true for oboists. Risk factors identified in musicians at large include time spent playing the instrument (Fry, 1987; Manchester and Park, 1996; Ranelli et al., 2011; Fotiadis et al., 2013; Lopez and Martinez, 2013; Robitaille et al., 2018), and younger age (Yeung et al., 1999; Davies and Mangion, 2002; Ranelli et al., 2011; Nawrocka et al., 2014; Kok et al., 2018; Selms et al., 2020). Due to small sample sizes of oboists in existing studies, it has not yet been established to what extent these factors influence PRMD prevalence in oboe players. Only one study to date has had a large enough sample size to infer anything about demographic predictors of PRMD in oboists, yet this study only examined the effects of gender (females were more likely to be injured than males), and did not collect data on the many other possible demographic risk factors (Thrasher and Chesky, 2001).

Similarly, studies on treatment methods have typically tested interventional exercise or postural methods on heterogeneous groups of musicians in which the oboe is underrepresented (Brandfonbrener, 1997; de Greef et al., 2003; Lopez and Martinez, 2013; Chan et al., 2014; Arnason et al., 2018). While some of these methods showed promise, others were inconclusive, often due to a low participation or high dropout rate. This search for a "one size fits all" cure for PRMD ignores the diversity of physical challenges presented by various instruments. Since injury rates and types are tied to instrument choice, it follows that treatment methods will have more consistent results when evaluated in a group of instruments with the same or similar issues.

To simultaneously address all the issues pointed out above, this survey has three main aims. (1) We aimed to ascertain the prevalence and nature of PRMDs in oboists. We anticipated that rates would fall within or near the 72-85.7% range established by previous studies with smaller sample sizes of oboists, and that injuries would be primarily on the right side of the body. (2) We also aimed to determine any predicting demographic or other risk factors. Based on existing literature, we hypothesized that female gender, a greater number of playing hours, and younger age or fewer years of experience would all be associated with higher rates of injury. Few existing studies evaluated career level (e.g., student vs. professional vs. amateur) as a risk factor, but based on our understanding of the demands of these various career levels, we anticipated that professionals and students would experience a higher rate of injury than amateurs, who are more likely to be playing for fewer hours per week. (3) Lastly, we aimed to evaluate the efficacy of various treatment methods in preventing and remedying these injuries in oboe players. We anticipated perceived effectiveness of the methods listed would have high variability.

MATERIALS AND METHODS

This project obtained approval from the University of Toronto Research Ethics Boards (protocol #39562). Participants were recruited via email and oboe-specific Facebook groups between September 3rd and September 21st, 2020 to complete a voluntary 10-question survey on their history with playing-related musculoskeletal disorders and treatments.

Participants

Participants were 223 self-identified oboists recruited from oboe and double-reed Facebook groups (primarily English-speaking) and from emails to oboe professors at North American universities. The average age of the sample was 41.1 (Range = 18 - 81; SD = 16.50) (see **Figure 1**). Three respondents did not specify age. A large majority of respondents identified their gender as female (70.0%, n = 156). Other responses for gender were male (28.1%, n = 65), non-binary (0.4%, n = 1), and other (0.4%, n = 1, who specified in the comments being a trans man). Participants were diverse in professional status: 39 students (17.5%), 61 amateurs (27.4%), and 123 professional (55.2%). Participants had an average of 27.69 years of experience on oboe (Range = 0 - 69; SD = 16.96). The average age at which they started oboe was 13.37 (range = 3 - 62; SD = 7.04). The weekly time spent playing the oboe (see **Figure 2**) was reported as 1-3 h (13.6%, n = 30), 4-6 h (13.1%, n = 29), 7-9 h (16.7%, n = 37), 10-12 h (15.8%, n = 35), 13-15 h (10.9%, n = 24), 16-18 h (7.2%, n = 16), and 19+ h (22.6%, n = 50). 2 respondents did not specify weekly playing time.

Survey Materials and Procedure

The 10-question survey was conducted online using the SurveyMonkey platform. The survey took an estimated 5-7 min to complete. Three existing questionnaires were

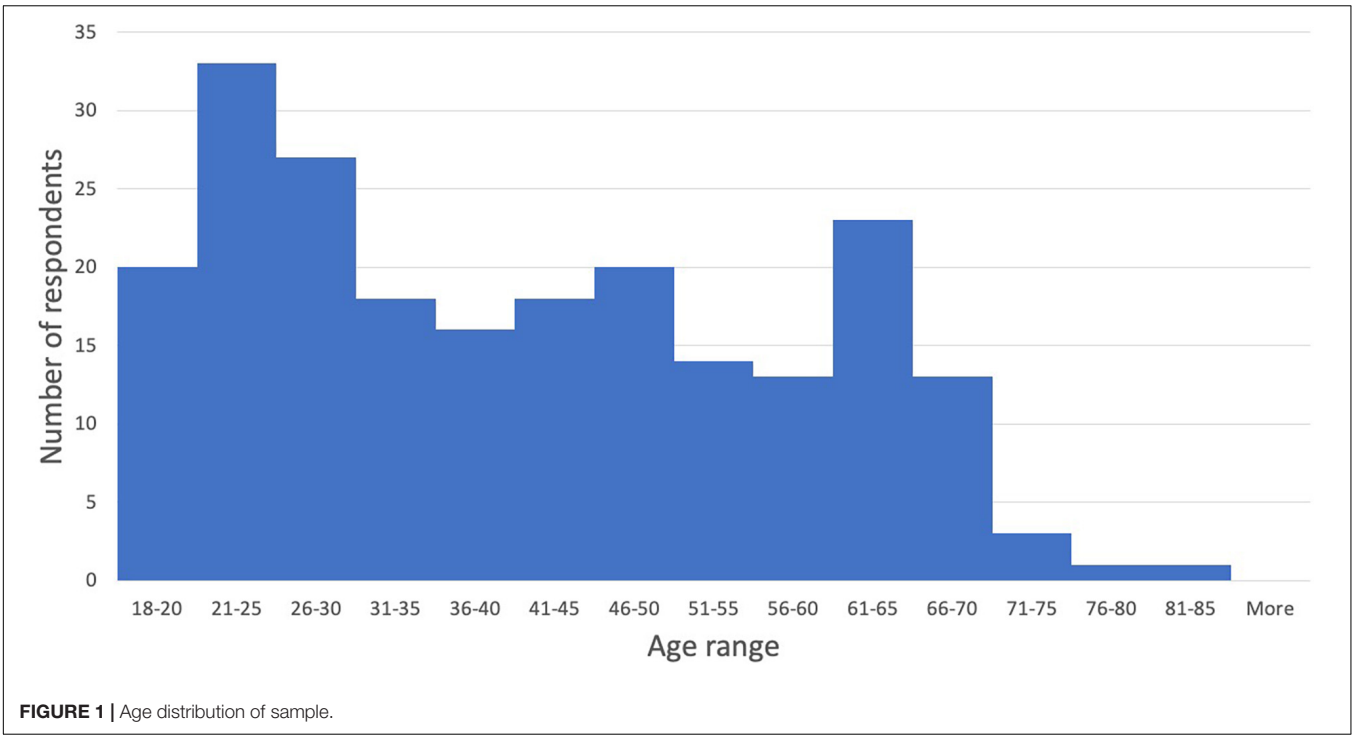


FIGURE 1 | Age distribution of sample.

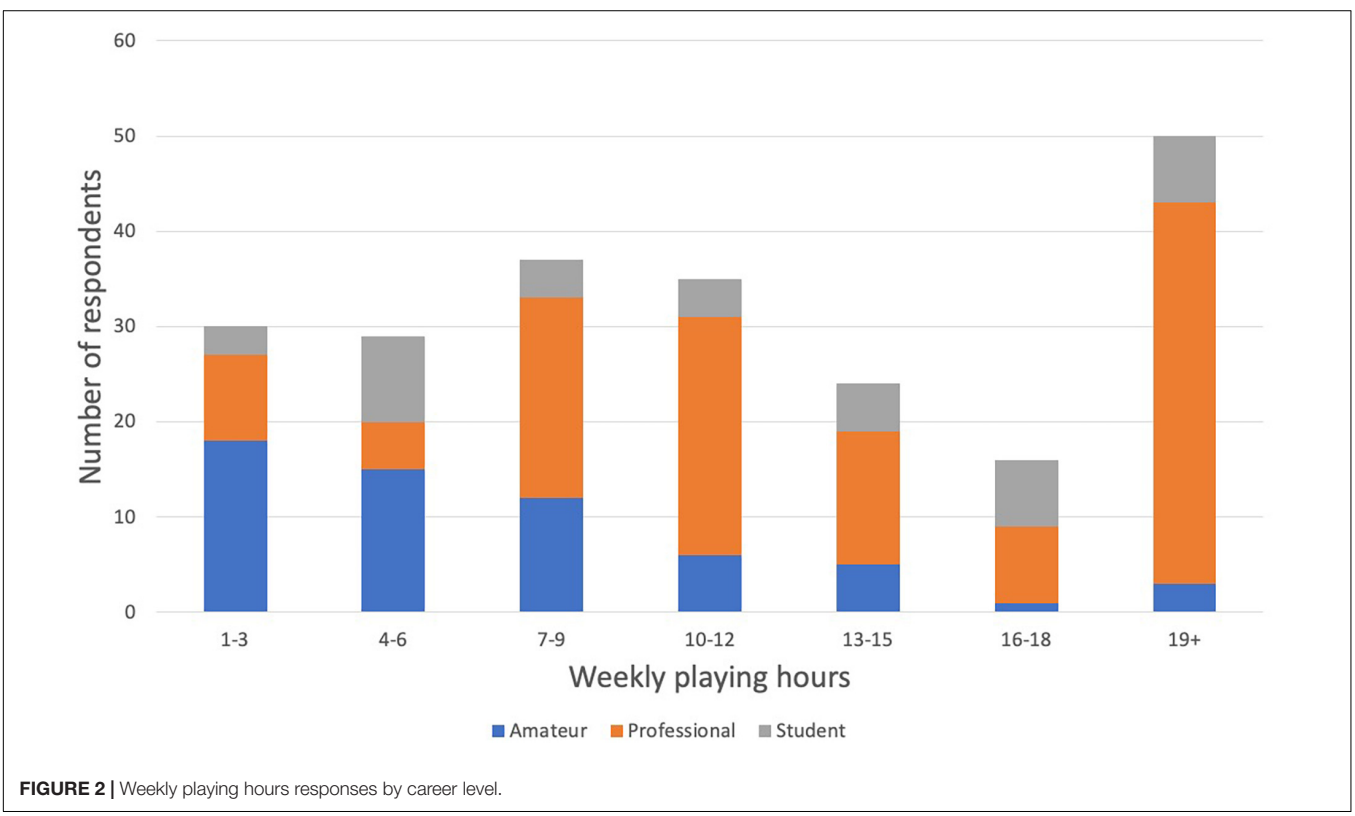


FIGURE 2 | Weekly playing hours responses by career level.

consulted in the making of this survey (Kuorinka et al., 1987; Ackermann and Driscoll, 2010; Lamontagne and Belanger, 2012). Ultimately, most questions were adapted from Ackermann and Driscoll (2010) because of its specific tailoring to musicians and the applicability of its questions to our research questions. The first 5 questions collected demographic data (age, gender, oboe start age, career level, weekly playing time), and the latter 5 questions asked about respondents' experiences with

injury and preventive methods. As in Ackermann & Driscoll's questionnaire, a playing-related musculoskeletal disorder (PRMD) was defined as "any pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level to which you are accustomed," which itself was based on the definition used by Zaza and Farewell (1997). Respondents were asked to identify any PRMDs they had experienced, from a list of 22 specified body parts plus "other (please specify)," and to rate the severity of the injury on a scale of 1 (mild) to 10 (extremely severe). The list of injury locations was adapted from two surveys (Kuorinka et al., 1987; Ackermann and Driscoll, 2010). Two main changes were made to the lists: since the majority of PRMDs reported to date among woodwind players occur in the upper extremities (Nemoto and Arino, 2007), the list of upper extremity injury locations would ideally be more nuanced than that in the general purpose Nordic Musculoskeletal Questionnaire (NMQ; Kuorinka et al., 1987). Therefore, instead of broader categories such as "wrist/hand," the upper extremities were subdivided into fingers, thumb, hand, wrist, forearm, elbow, upper arm, and shoulder as in Ackermann and Driscoll (2010). Furthermore, since injuries in the lower body (feet/ankles, legs, knees) are unlikely to be caused by or to have a strong effect on playing a wind instrument, these injury locations were omitted and replaced with "other (please specify)." The 1 to 10 or 0 to 10 scale for rating pain and effectiveness has been used previously in validated questionnaires (Ackermann and Driscoll, 2010; Lamontagne and Belanger, 2012). This scale was adopted based on its ability to gather nuanced data on the severity of pain and perceived effectiveness of treatments. The 0 to 10 scale has the added benefit of a definitive 0 point (relevant only for questions that have a definitive 0 answer) and is simple for most people to conceptualize, as similar scales are used in everyday life (e.g., percentage points). For each injury, they were asked to describe the pain using checkboxes (multiple selections allowed) for descriptors "tingling," "numbness," "pain," "weakness," "cramps," "involuntary movement," and "other." Respondents were asked whether their PRMD had been diagnosed by a healthcare professional, and if so, to specify what the diagnosis was. They were also asked to what extent they had recovered from their PRMD(s) between a choice of "No, not recovered at all," "Somewhat recovered," "Mostly recovered," and "Yes, completely recovered." A final question asked respondents to rate the effectiveness of various remedial and preventive solutions that they had experience with (multiple selections allowed), on a scale of 0 (no effect) to 10 (greatest effect of all). The list of treatments was adapted from Ackermann and Driscoll (2010). Additional candidate treatments were added to the list based on consultation with numerous oboists and musicians' health researchers. In these final five questions, respondents were instructed to skip any rows that discussed a PRMD or preventive measure they did not have experience with.

For quality control, the survey was informally pilot tested by performing arts medicine researchers at the University of Toronto and several professional and student oboists in Canada. Reviewers were asked whether the survey's questions were clear, whether any information should be added or omitted, and whether, in their opinion, the survey would serve to answer the stated research questions. Changes to the survey prompted by these reviewers included changes to wording to increase accessibility of the survey, and the addition of treatments to the final question.

A copy of the questionnaire can be found in the **Supplementary Materials**.

Statistical Analysis

Descriptive statistics and associated plots were created in Python using the *pandas* package (Mckinney, 2010) and in Microsoft Excel, respectively. Statistical analyses (e.g., logistic regression analysis) were conducted in R and in Python using the *pandas* and *statsmodels* packages (Seabold and Perktold, 2010). Statistical analyses were performed in regression contexts to assess risk factors associated with PRMDs both categorically (0 = no history of PRMD, 1 = history of PRMD, with models run in the logistic regression framework) and dimensionally (severity of worst PRMD on scale of 1 – 10 analyzed as a continuous outcome utilizing only individuals reporting at least one PRMD, with models run in an ordinary least squares framework). We were interested in five risk factors motivated by literature review (gender, hours of playing, career level, age, years of playing experience). No correction for multiple tests across these five factors was performed. A significance level of p(alpha) < 0.05 was selected for reporting. Additionally, results that survive Bonferroni correction for conducting two analyses within each risk factor (the categorical prevalence model and the two dimensional severity model) are marked in-text with an asterisk (*: $p < 0.025$). Subjects with missing age data were excluded from models that included the age variable. For models that included the gender variable, two gender groups that contained only a single observation were excluded ("non-binary" and "Other").

RESULTS

Prevalence and Severity

Of all respondents, 74.9% (167/223) reported having at least one PRMD in their lifetime. Seventy-nine (47.3%) of these 167 reported having had a diagnosis from a medical professional, while 84 (50.3%) had not received a diagnosis. The remaining 4 (2.4%) individuals were either among the 8 who selected "not applicable," or they did not respond to this question.

A majority of respondents reported having had severe injuries, with 52.0% (n = 116) of all respondents reporting at least one injury rated between 7 and 10, and 61.9% (n = 138) reporting at least one injury rated 5 or higher (see **Figure 3**).

Location and Symptoms of Injuries

A majority of injuries were on the right side of the body. The most common PRMD location was the right thumb (61.9%), followed by the right wrist (48.4%), right hand (47.8%), and right forearm (47.5%). The most common injuries also tended, on average, to be the most severe: the average severity rating was highest in the right thumb (5.77), right wrist (5.59), right hand (5.23), and right forearm (4.96). See **Figures 4**, **5** for a complete list of prevalence and average severity by location.

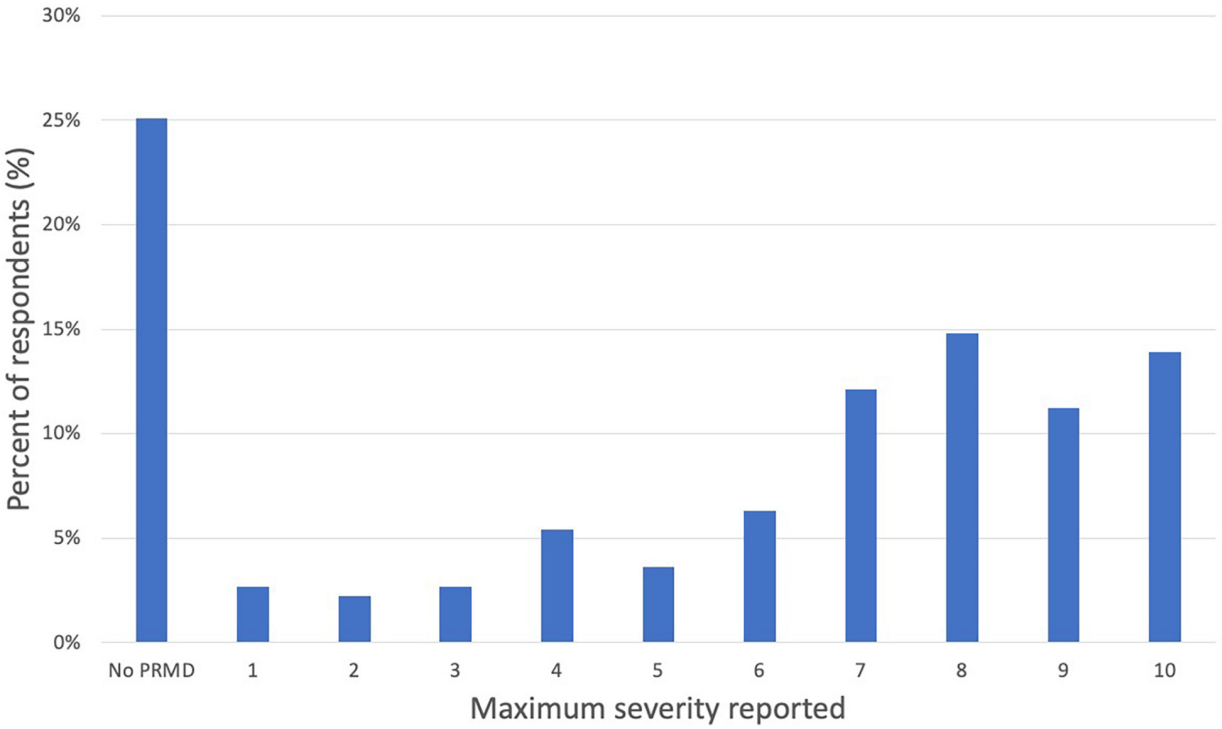


FIGURE 3 | Distribution of maximum severity reported (scale of 1 to 10).

Pain was the most common descriptor for all injury locations except for respiratory system (weakness) and right and left fingers (tingling). See **Figure 6** for complete sensation profiles for all injury locations.

Recovery Rates

Not all respondents reporting an injury answered the question on recovery. For unknown reasons, a surprising number of participants chose not to disclose recovery status. For example, of 138 people reporting a right thumb injury, only 121 disclosed recovery status. Out of a total of 1,545 injuries reported, recovery data for 1,072 of these injuries was provided (for a response rate on the recovery question of 69.4%). This caveat being said, of those who did respond to this question only 280 of these 1,072 injuries (26.1%) were reported as being fully recovered (see **Table 1**).

Risk Factors

We were interested in a number of variables previously linked to PRMD prevalence and severity (see Introduction). In the following sections, we describe the results of regression analyses quantifying the effects of gender, playing hours, career level, age, and years of playing experience on PRMD prevalence and severity.

Gender

See **Table 2A** for descriptive statistics of PRMD prevalence and maximum severity of PRMD for male and female oboists. *Prevalence model*. Although females were more likely to report a PRMD than males, the difference was not statistically significant. *Severity model*. Females reported a significantly higher severity rating of their worst PRMD (Contrast: 0 = F vs. 1 = M, $\beta = -1.87$, $t = -3.39$, $p < 0.001^*$).

Playing Hours

See **Table 2B** for descriptive statistics of PRMD prevalence and maximum severity of PRMD for each of the seven "hours played per week" categories. There were several significant differences in PRMD prevalence and severity based on number of hours played per week. *Prevalence models*. **Figure 7** shows that there is potentially a complex relationship between prevalence of PRMD and hours of playing per week. To test this, we conducted a regression analysis, with the seven evenly spaced categories of "hours of playing per week" coded in orthogonal polynomial form to capture possible complex-shaped relationships with prevalence of PRMD. Coding of the seven categories resulted in six regressors coding for shapes ranging from a simple linear relationship between the two variables through a sixth order polynomial relationship. For regression statistics, see **Table 3A**. We found (1) a negative quadratic relationship, suggesting an inverted "U" shape relationship*, and (2) a negative fifth degree polynomial relationship*, confirming that the visual observation of multiple peaks in **Figure 7** is a statistically significant complex pattern. This regression analysis could alternatively be conceptualized with treatment coding rather than polynomial coding to contrast prevalence of PRMD in the 1 to 3 h of practice per week group to all of the other groups. For regression statistics, see **Table 3B**. We found PRMD was more prevalent for

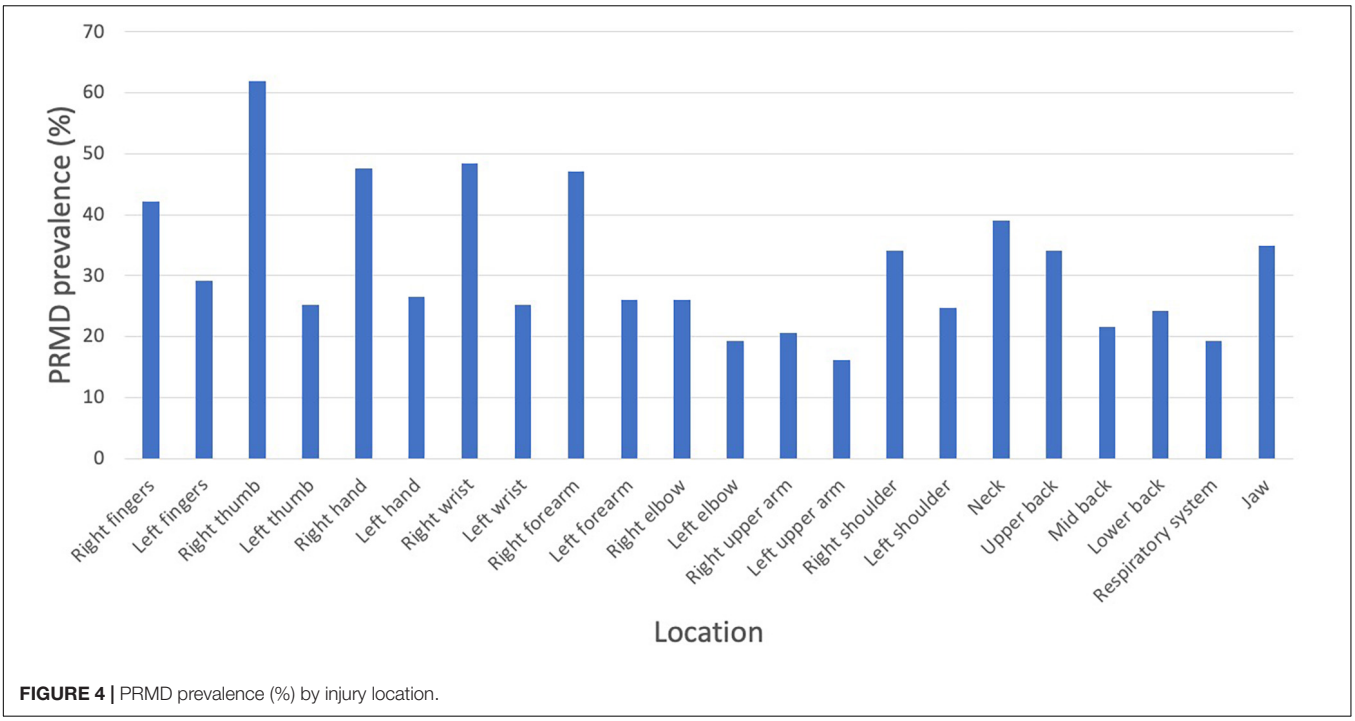


FIGURE 4 | PRMD prevalence (%) by injury location.

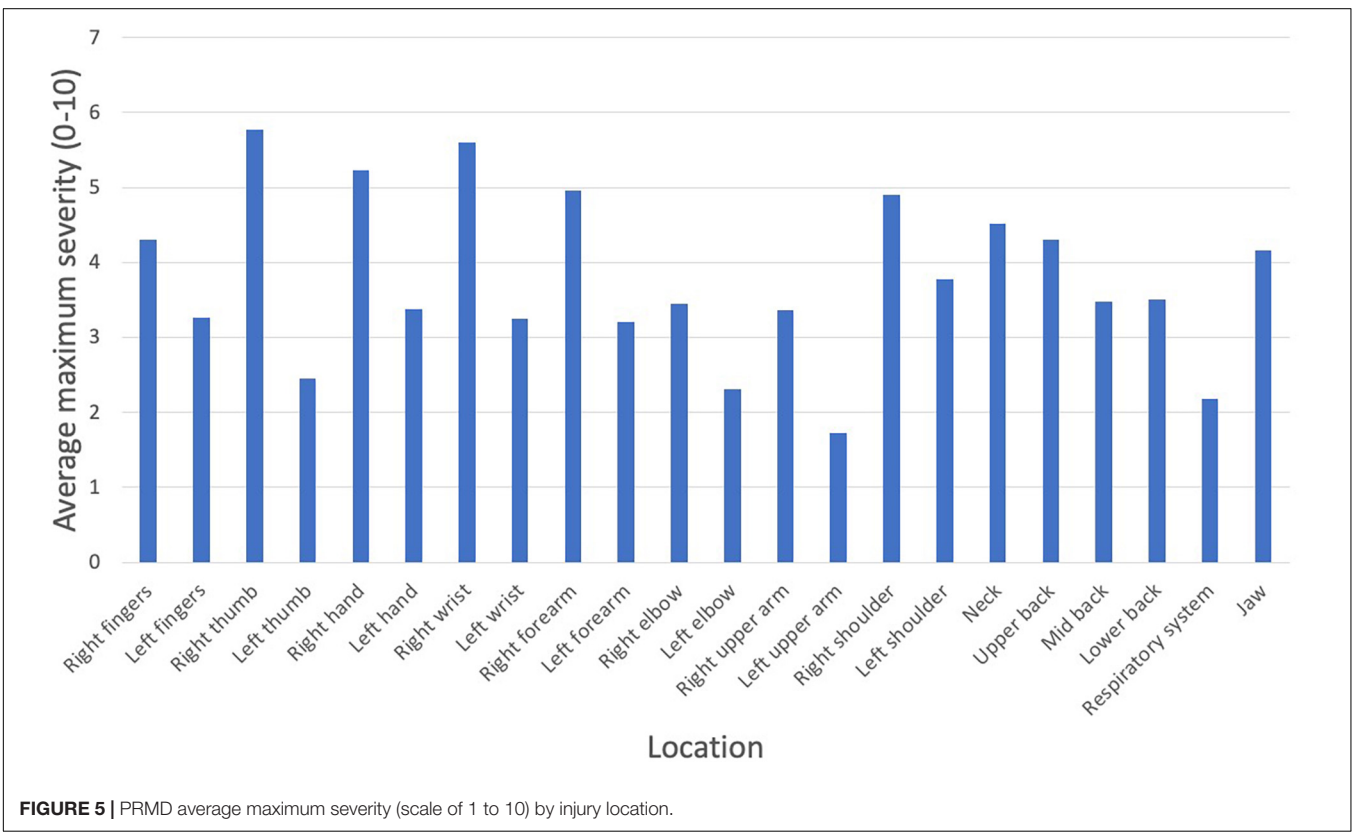


FIGURE 5 | PRMD average maximum severity (scale of 1 to 10) by injury location.

individuals who played 7-9*, 10-12, 13-15, and 16-18* h per week than for individuals who played only 1 to 3 h per week.

Severity models. **Figure 8** shows the complex shape of the relationship between maximum PRMD severity and hours of playing per week; thus we used the same polynomial coding described in the previous section. For regression statistics, see **Table 3C**. We found (1) a positive linear relationship between the maximum severity of injuries and hours of playing per week*,

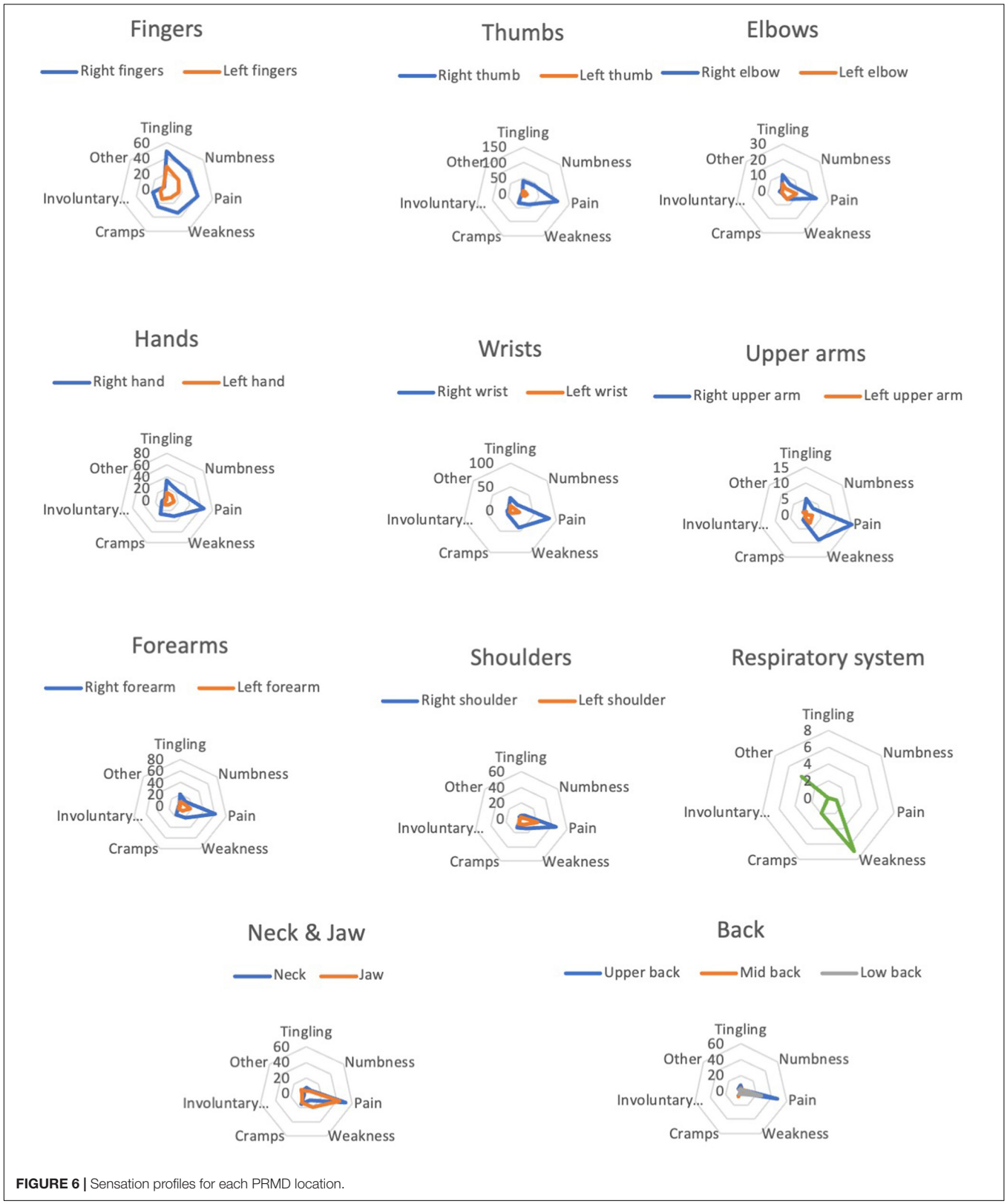


FIGURE 6 | Sensation profiles for each PRMD location.

TABLE 1 | Number of respondents reporting recovery.

Body part	Percent of respondents reporting a lifetime injury	Number of injured respondents who reported on recovery status	Completely recovered (*n*)	Mostly recovered (*n*)	Somewhat recovered (*n*)	Not recovered at all (*n*)
Fingers (right)	42.2% (*n* = 94)	88	28	26	21	13
Fingers (left)	29.1% (*n* = 65)	51	16	15	14	6
Thumb (right)	61.9% (*n* = 138)	121	29	38	35	19
Thumb (left)	25.1% (*n* = 56)	32	12	6	10	4
Hand (right)	47.5% (*n* = 106)	95	26	28	31	10
Hand (left)	26.5% (*n* = 59)	36	13	9	11	3
Wrist (right)	48.4% (*n* = 108)	102	24	35	33	10
Wrist (left)	25.1% (*n* = 56)	36	12	6	15	3
Forearm (right)	47.1% (*n* = 105)	74	19	25	21	9
Forearm (left)	26.0% (*n* = 58)	24	10	3	8	3
Elbow (right)	26.0% (*n* = 58)	29	8	10	8	3
Elbow (left)	19.3% (*n* = 43)	14	4	2	6	2
Upper arm (right)	20.6% (*n* = 46)	26	7	8	8	3
Upper arm (left)	16.1% (*n* = 36)	10	1	2	5	2
Shoulder (right)	34.1% (*n* = 76)	56	13	17	16	10
Shoulder (left)	24.7% (*n* = 55)	31	6	8	9	8
Neck	39.0% (*n* = 87)	62	9	18	24	11
Upper back	34.1% (*n* = 76)	55	7	18	18	12
Mid back	21.5% (*n* = 48)	26	5	7	9	5
Lower back	24.2% (*n* = 54)	34	6	9	12	7
Respiratory system	19.3% (*n* = 43)	12	6	2	1	3
Jaw	35.0% (*n* = 78)	58	19	18	15	6

suggesting that overall longer playing hours was associated with more severe injuries, (2) a negative quadratic relationship*, suggesting an inverted "U" shape relationship, and (3) a negative fifth degree polynomial relationship*, confirming that the visual observation of multiple peaks in **Figure 8** is a statistically significant complex pattern. As in the previous section, we reran the regression analysis with treatment coding to contrast severity of PRMD in the 1 to 3 h per week group to all of the other groups. For regression statistics, see **Table 3D**. We found maximum PRMD severity was significantly higher for individuals who played 7-9*, 13-15*, 16-18*, and 19+ h per week than for individuals who played only 1 to 3 hours per week. The contrast of the 10-12 h per week group and the 1-3 h per week group was trending but not statistically significant.

TABLE 2 | Descriptive statistics (Gender, Playing hours, and Career level).

	N_{noPRMD}	N_{PRMD}	$\%_{PRMD}$	$M_{severity}$	$SD_{severity}$
A. Gender					
Male	19	46	70.8%	4.05	3.44
Female	37	119	76.3%	5.88	3.79
B. Weekly playing hours					
1 - 3 h	15	15	50.0%	3.47	4.00
4 - 6 h	9	19	67.9%	4.10	3.84
7 - 9 h	1	36	97.3%	6.86	2.52
10 - 12	8	27	77.1%	5.20	3.59
13 -15 h	5	19	79.2%	5.75	3.59
16 - 18 h	1	14	93.3%	7.19	7.19
19+ h	17	33	66.0%	5.24	5.24
C. Career Level					
Student	8	29	78.4%	5.21	3.32
Amateur	16	45	73.8%	4.69	3.61
Professional	32	91	74.0%	5.73	3.94

Career Level

See **Table 2C** for descriptive statistics of PRMD prevalence and maximum severity of PRMD for students, amateurs, and professional oboists. *Prevalence model.* Although student and professional musicians reported higher rates of PRMD than amateurs, no statistically significant group differences in PRMD prevalence were found based on career level. *Severity model.* Although professionals reported the most severe PRMDs, followed by students, then amateurs, there were no significant differences in maximum PRMD severity based on career level.

Age

Prevalence model. No significant relationship was found between age and prevalence of PRMD. *Severity model.* No significant relationship was found between age and maximum PRMD severity.

Years of Playing Experience

Prevalence model. No significant relationship was found between years of playing experience (calculated as the difference between current age and the age at which participants began playing the oboe) and prevalence of PRMD. *Severity model.* No significant relationship was found between years of playing experience and maximum PRMD severity.

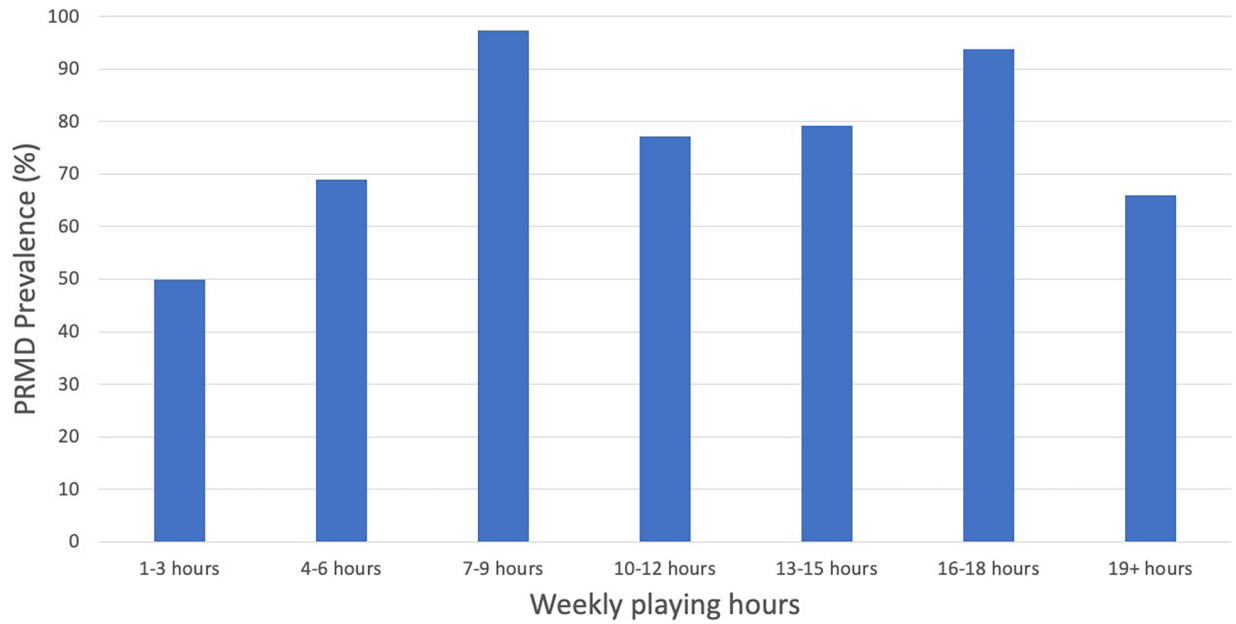


FIGURE 7 | PRMD prevalence (%) by weekly playing hours.

Treatment Methods

The treatment methods rated as most effective varied from individual to individual. As not all respondents had tried every method presented in question #10, there was a great deal of variability in the response rates for each method (e.g., 156 respondents evaluated "rest," while only 13 evaluated "Feldenkrais"). Rest, stretching, exercise, massage, ice, and pain killers had the highest response rates, while Feldenkrais, occupational therapy, acupuncture, chiropractic, medical, and Alexander Technique had the lowest response rates. Despite this variability in response rates, some trends can be discerned. The mean rankings, on a scale of 0 to 10, of physical therapy (6.69), rest (6.37), stretching (6.22), occupational therapy (6.05), and massage (5.94), were higher than most. It is worth noting, however, that for every method there was a very wide variability in perceived effectiveness, and it is clear that there is no single universally effective method (see **Figure 9**).

Several respondents suggested treatment methods that were not listed in the survey (**Table 4**). The most common of these was instrument modifications, such as pegs and neck straps that help take weight of the oboe off of the thumb. Body mapping (an awareness technique related to Alexander Technique) and technique or hand position corrections were also mentioned multiple times. Most of these alternative methods were rated very highly, but a few (such as change of activity and marijuana) rated below 5.

DISCUSSION

This study sought to (1) ascertain the prevalence of PRMDs in oboists, (2) determine any predicting demographic factors, and (3) evaluate the self-reported efficacy of various treatment methods in preventing and remedying these injuries in oboe players. The study has the advantage of being the largest sample size of oboists in any known comparable study.

Prevalence, Severity, and Location of Injuries

Of the 223 survey respondents, 167 (74.9%) reported having had a PRMD in their lifetime. Though there is a wide range of prevalence rates in the literature, this is often attributed to the wide variety of definitions used for PRMD (e.g., Berque et al., 2016). Our result falls in line with results of comparable studies that also used Zaza and Farewell's definition of PRMD (1997). These studies similarly reported a lifetime PRMD frequency among musicians of between 63 and 78% (Baadjou et al., 2015; Berque et al., 2016; Ballenberger et al., 2018; Kok et al., 2018; Shanoff et al., 2019). Our result is also in the range of oboe-specific PRMD rates previously determined by smaller studies: 75% (with a sample size of 12 oboists), 72% (with a sample size of 60), and 85.7% (with a sample size of 28) (Thrasher and Chesky, 2001; Nemoto and Arino, 2007; Stanek et al., 2017).

By gathering data on injury severity, we were also able to achieve a more nuanced understanding of the degree to which oboists are incapacitated by their injuries. A majority of respondents had experienced severe injuries: 52.0% of all respondents reported at least one injury rated between 7 and 10 out of 10, and 61.9% reported at least one injury rated 5 or higher.

The most common injuries were found to be on the right side of the body, which confirms the findings of previous studies on oboe players (Thrasher and Chesky, 2001; Nemoto and Arino, 2007). The injuries that were the most common (right thumb, right wrist, right hand, and right forearm) also tended to be the

TABLE 3 | Regression analysis (Playing hours).

	A. Prevalence - Polynomial Coding			
Contrast	**Beta**	**Std. Error**	**z**	**p**
Linear	0.67	0.54	1.24	0.21
Quadratic	−1.78	0.48	−3.68	**0.00***
Cubic	0.41	0.68	0.61	0.54
4th degree	−0.83	0.67	−1.24	0.21
5th degree	−1.99	0.79	−2.53	**0.01***
6th degree	0.96	0.66	1.46	0.15
	B. Prevalence - Treatment Coding (vs. 1 - 3 h)			
Contrast	**Beta**	**Std. Error**	**z**	**p**
4 - 6 h	0.80	0.54	1.47	0.14
7 - 9 h	3.58	1.08	3.33	**0.00***
10 - 12 h	1.22	0.54	2.24	**0.03**
13 - 15 h	1.34	0.62	2.15	**0.03**
16 - 18 h	2.71	1.10	2.47	**0.01***
19+ h	0.66	0.47	1.41	0.16
	C. Severity - Polynomial Coding			
Contrast	**Beta**	**Std. Error**	**t**	**p**
Linear	1.96	0.66	2.96	**0.00***
Quadratic	−1.65	0.61	−2.69	**0.01***
Cubic	−0.08	0.69	−0.12	0.91
4th degree	−0.73	0.73	−1.00	0.32
5th degree	−1.76	0.72	−2.45	**0.02***
6th degree	0.86	0.66	1.31	0.19
	D. Severity - Treatment Coding (vs. 1 - 3)			
Contrast	**Beta**	**Std. Error**	**t**	**p**
4 - 6 h	0.64	0.94	0.68	0.50
7 - 9 h	3.40	0.89	3.82	**0.00***
10 - 12 h	1.73	0.90	1.93	0.06
13 - 15 h	2.28	0.99	2.30	**0.02***
16 - 18 h	3.72	1.12	3.32	**0.00***
19+ h	1.77	0.84	2.12	**0.04**

*bold face: $p < 0.05$; *$p < 0.025$.*

most severe. The increased frequency and severity of injuries on the right side of the body can be attributed to the asymmetrical playing posture of oboists, where the right thumb is statically loaded by the weight of the instrument.

Risk Factors

Gender

Numerous studies have found female musicians to have a higher rate of injury than males (Roach et al., 1994; Zetterberg et al., 1998; Steinmetz et al., 2010; Paarup et al., 2011; Ranelli et al., 2011; Nawrocka et al., 2014; Kok et al., 2018). We hypothesized that female oboists would similarly report a higher rate of injury compared to their male counterparts. This study likewise found that females were slightly more likely to report a PRMD than males (76.3% compared to 70.8%), however, this was not a statistically significant effect. We did find, however, that females reported significantly more severe injuries than males. The higher rate and/or severity of PRMD among females is most often attributed to a lack of upper body strength in females compared to males.

Playing Hours

The relationship between playing hours and PRMD is complex. Our hypothesis that increased playing hours would contribute to injury was partially confirmed by the linear regressor in our logistic regression analysis - a higher number of hours of oboe playing time per week significantly increases PRMD severity – however there was no similarly statistically significant linear effect on PRMD prevalence. However, we did find a significant negative quadratic effect (inverted "U" shape) for both PRMD prevalence and severity, indicating that the relationship between playing hours and PRMD prevalence and severity was more complex than we had anticipated. In fact, the 1-3 h and 19+ h groups had the least prevalent and the least severe PRMDs on average. This is likely because those who played very few hours per week may not be playing for long enough hours to develop symptoms, while those who do not have symptoms in the first place are less likely to have to limit the time they spend on the oboe, and may therefore play for upwards of 19 h (or alternatively, due to a form of survivorship bias, individuals who are less prone to injury do not have to limit their practice time). Finally, confirming our observation of multiple peaks in **Figures 7**, **8**, we found a significant fifth degree polynomial relationship, suggesting significant fit for a two-peak and three-trough shaped regressor. In fact, those playing 7-9 and 16-18 h per week reported a significantly higher prevalence and severity of injuries than the 1-3 h per week group (see **Tables 3B,C**). This result speculatively suggests that although longer playing hours can contribute to PRMD frequency and severity (hence the higher rate in the 16-18 h group), the existence of PRMD in the first place may also force musicians to decrease their playing hours in order to manage their injury (explaining why those practicing 7-9 h were also highly likely to report injuries). Because this complex relationship was not *a priori* hypothesized, future work should investigate the relationship between playing hours and injury more thoroughly.

Career Level

We hypothesized that the varying demands of different career levels would have an effect on PRMD prevalence and severity, as students and professionals both typically have heavier playing-related demands placed on them than amateurs. Students were found to have a slightly higher rate of injury when compared to professionals and amateurs, while professionals reported more severe injuries than either students or amateurs. However, these effects were not statistically significant.

No known studies have sought to directly compare PRMD prevalence and severity between amateur, student, and professional musicians. This is likely because studies typically target one group or another, and usually end up studying a homogeneous group of students, or professional musicians, or amateurs, but rarely a combination. One study found amateurs to have a one year PRMD rate comparable to the rate established in the literature of professional musicians, but did not also

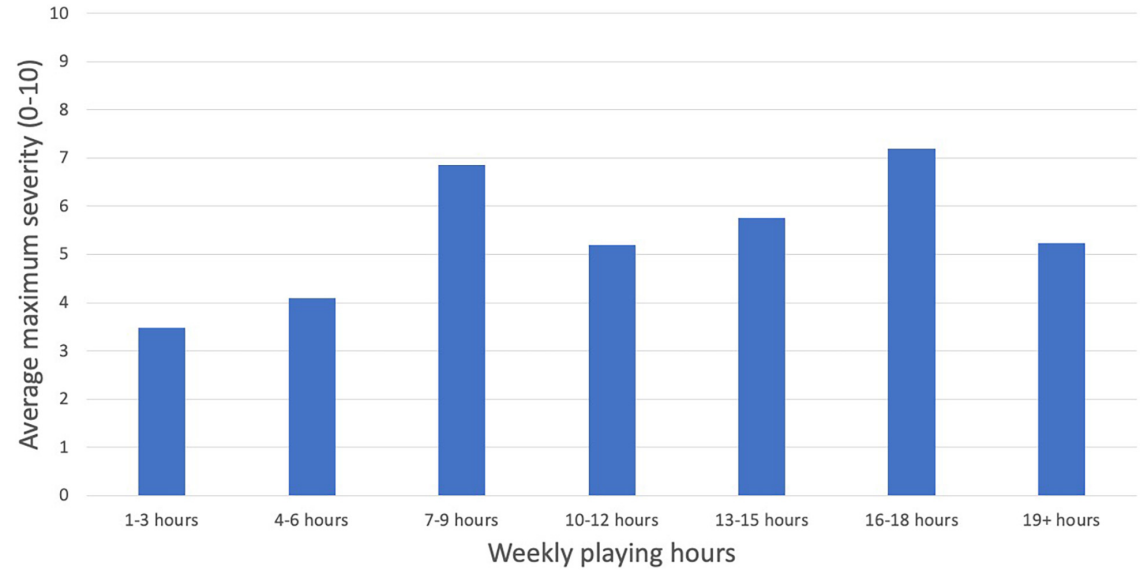


FIGURE 8 | PRMD average maximum severity (scale of 1 to 10) by weekly playing hours.

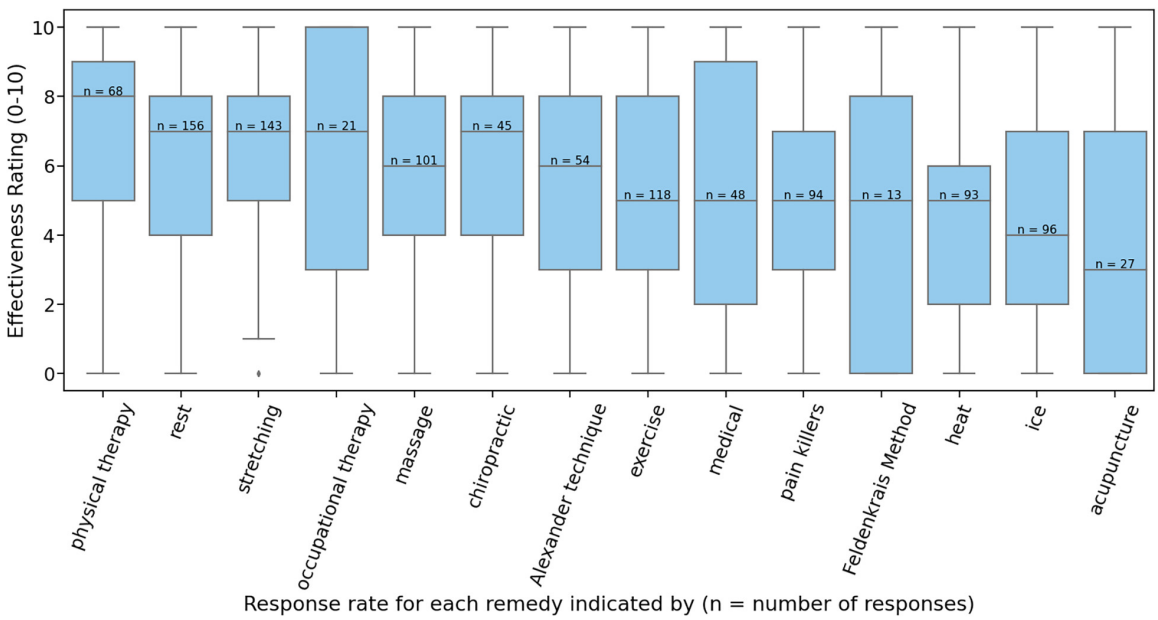


FIGURE 9 | Effectiveness ratings (scale of 0 to 10) of treatment methods.

survey professionals to directly compare the effects of career level (Kok et al., 2018). In order to more definitively ascertain the effect of career level on injury in musicians in general, more research is recommended.

Age

Previous studies have had mixed results regarding age and musicians' PRMD. Our study found no significant link between age and PRMD among this sample of oboe players, which echoes the results of a few previous studies (Crnivec, 2004; Rohwer, 2008; Kenny et al., 2018). The few papers that link age with PRMD do not agree on the nature of the relationship: one study found that increased age was associated with increased rates of PRMD (Berque et al., 2016), while another paper found that both the youngest and oldest musicians were more likely to be injured than others, though in their study the youngest and oldest musicians also reported the highest practice times, so the injuries could be related to time spent playing the instrument rather than age (Abreu-Ramos and Micheo, 2007).

TABLE 4 | "Other" treatment methods responses and ratings.

Method	Effectiveness rating	# of respondents
Instrument modifications (e.g., Fhred, WRIST, neckstrap, special thumb support)	8, 7, 8, NA, 10, 6	6
Body Mapping, body awareness	10, 9, 8,	3
Technique/hand position corrections	8, NA, NA	3
Jaw or embouchure exercises	10, 5	2
Osteopathy	NA, 10	2
Ultrasound therapy on fingers & hands	8, 10	2
Yoga	10, 10	2
Acu-magnetic treatment (related to acupuncture)	8	1
Alternating hot and cold water	7	1
Change of activity	3	1
Compression glove	10	1
Electric impulse therapy	10	1
Energy healing	10	1
Marijuana	4	1
Mindfulness	10	1
Pilates	10	1
SalonPas® pads while sleeping	10	1
Surgery	10	1
Wrist brace	7	1

Years of Playing Experience

Based on several studies that found that players with less experience are more likely to be injured (Yeung et al., 1999; Davies and Mangion, 2002; Ranelli et al., 2011; Nawrocka et al., 2014; Kok et al., 2018; Selms et al., 2020), we hypothesized that fewer years of playing experience would likewise correspond with higher PRMD prevalence and/or severity. However, we found no significant relationship between years of playing experience and injury prevalence or severity.

Treatment Methods

As not every respondent had experience with all of the treatment methods listed, there was a great deal of variability in the response rate for each method. This response rate variability makes it difficult to meaningfully interpret much of the data. For example, only 13 respondents indicated having had experience with Feldenkrais, while 156 were able to rank the effectiveness of rest. Even for those methods that had higher sample sizes, there was a great deal of variability in perceived effectiveness rankings. There is no strong evidence of any particular therapy being universally beneficial for everyone, as in almost every case there was a group of respondents ranking the effectiveness of the therapy as "0 (no effect)." It is highly likely that the effectiveness of particular methods at treating PRMD is largely dependent on the individual and the particular characteristics of the PRMD at hand. It is worth noting that physical therapy and occupational therapy were among the highest-ranking, and their relative success at alleviating PRMD may be attributed to the more targeted nature of these methods.

Based on the written-in responses in the "other: please specify" section, future studies on treatment method efficacy should consider investigating options such as instrument modifications (e.g., neck strap, instrument pegs), changes to playing technique, and body mapping.

In the literature, there are mixed results in studies exploring the effects of exercise on PRMD prevalence. Some studies have found no association between exercise and PRMD (Brandfonbrener, 1997; Kreutz et al., 2008; Baadjou et al., 2015). Other studies have found increased exercise is associated with less risk of PRMDs (Roach et al., 1994; Yeung et al., 1999; Ranelli et al., 2011). In one study, increased exercise was associated with higher rates of knee pain (Zetterberg et al., 1998). Three studies examined the effect of targeted exercise programs on the rate of PRMD in a group of musicians, and all reported a reduction of injuries at the end of the program (de Greef et al., 2003; Lopez and Martinez, 2013; Chan et al., 2014). All these exercise studies examined a diverse population, consisting of a mixture of string, woodwind, brass, and other musicians. The effect of posture has been explored with sample of saxophone players, and it was found that a rounded upper back and/or backward pelvic tilt correlated strongly with higher pain ratings, and a rounded back, backward pelvic tilt, and excessive curve in the low back all corresponded with higher rates of PRMD in the right wrist (Shanoff et al., 2019). Since the oboe, like the saxophone, has been found to be prone to PRMDs in the right wrist due to static loading of the right thumb (Nemoto and Arino, 2007), it is likely that postural issues will have a similar effect on PRMDs among oboe players.

Study Strengths and Limitations

An important strength of this study was its ability to reach the largest sample of oboists of any comparable study (n = 223). This was aided by the strong online presence of communities of oboists and double reed players. The survey was filled out on a volunteer basis, rather than randomized, and so it is possible that this lack of randomization affected the results, since respondents who have dealt with injuries in the past may be more willing to participate. This study was able to gather valuable information on the perceived effectiveness of various PRMD treatments. However, since the effectiveness of these treatments appears to vary so much based on the individual and the type of injury at hand, it would be advisable for future studies to delve deeper into this issue.

CONCLUSION

This study set out to establish the prevalence and nature of PRMD among oboe players, any risk factors that were associated with higher rates of injury, and a ranking of the effectiveness of various treatment methods. We observed the following:

1. The overall lifetime prevalence of PRMDs in this sample of oboists was 74.9%.
2. The most common injuries were on the right side of the body (right thumb, wrist, hand, and forearm were the most common).
3. Of those respondents who provided recovery information about their injuries, only 26.1% of injuries were listed as "completely recovered".

4. Females reported significantly more severe injuries than males.
5. The relationship between weekly playing hours and PRMD prevalence and severity was complex, with those playing 7-9 and 16-18 h per week reporting significantly more prevalent and severe injuries than those playing 1-3 h per week.
6. While the perceived effectiveness of treatment methods for PRMD varied a great deal between individuals, a few treatments (physical therapy, rest, stretching, occupational therapy, massage) tended to be ranked more highly than others.

With a sample of 223 oboists, this study was able to offer a more nuanced understanding of the nature, prevalence, risk factors, and treatments of PRMD in oboists. The results confirm and expand on much of the existing research on PRMD among woodwind players.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Toronto Research Ethics Board. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HMM conceived of the project, designed and implemented the survey, analyzed data, and wrote and gave critical review of the manuscript. SKL and AER contributed to data analysis. MHT contributed to survey design, analysis plan, and manuscript preparation. All authors reviewed and approved the final version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.772357/full#supplementary-material

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BRIEF RESEARCH REPORT
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A Short Performance Anxiety Scale for Musicians

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Given the prevalence of debilitating anxiety associated with music performance, there is a need for rapid, pinpointed assessment of the extent to which an individual experiences music performance anxiety (MPA). A short, five item scale, the Mazzarolo Music Performance Anxiety Scale (M-MPAS), was developed to capture retrospective self-reported estimates of the frequency, intensity and aversion tendency associated with performing music. 102 musicians completed the scale, as well as an established MPA inventory. The M-MPAS was found to be internally reliable (Cronbach's alpha = 0.894) with all items being statistically relevant to the overall scale. Furthermore, the M-MPAS was correlated with the relevant factors of an established MPA measure (r = 0.791), suggesting that the new scale exhibited good construct validity. M-MPAS is easy to score, with a scale range of 0–30. A score of 11 or above is suggested as the range in which a diagnosis of potential high MPA can be made, but more research into this and the psychometric robustness of the scale is called for. Nevertheless, the reliability and validity demonstrated in the present study, along with the brevity of the M-MPAS suggest that the newly proposed scale may offer considerable triaging benefits for pinpointed assessment of the extent to which an individual experiences MPA.

Keywords: performance anxiety, music, psychometrics, experience, severity, avoidance, frequency, intensity

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INTRODUCTION

Music performance anxiety (MPA) is "the experience of persisting, distressful apprehension and/or actual impairment of performance skills in a public context, to a degree unwarranted given the individual's musical aptitude, training, and level of preparation" (Salmon, 1990, p. 3). The condition affects 15–25% of musicians, with even higher rates in younger musicians (Robson and Kenny, 2017; Fernholz et al., 2019). This makes the diagnosis and management of MPA a key concern that has attracted considerable research interest. There are currently several psychometric tools that assess MPA, but there has been a neglect in the rapid assessment of the nature of MPA episodes, an issue this paper proposes to address through the reporting of a newly developed instrument.

In his review of MPA literature, Taborsky (2007) proposed that "numerous factors may influence the intensity of anxiety, often resulting in increased heart rate, state anxiety, and other physical symptoms" (p. 22). But Taborsky's review reveals that the perception of the *global intensity* of MPA is not a significant matter in the design of the MPA measures currently available. While psychometric methods require a broad sweep of various, specific response items to facilitate a good estimate of the psychological construct under investigation, it is still surprising that direct questioning of global MPA intensity is not requested. There is compelling literature on small and even single-item measures as providing good approximations of aspects of psychometric

constructs, particularly as initial screening tools (Williams and Smith, 2018; Casu and Gremigni, 2019; Turon et al., 2019). Otherwise, the psychometric scale relies on gathering data regarding a large number of possible individual facets that contribute to the MPA experience, and in doing so could become inordinately long, potentially redundant, or risk missing one or more key facets even before a diagnosis of MPA is made. As shown in **Table 1**, the most frequently used MPA assessment tools require between 15 and 58 items to be rated by the individual. A direct, simple interrogation of global MPA intensity would by-pass the need for such specificity as an initial step, and return to the root of MPA, which, as Salmon's (1990) definition infers, is concerned with *experience*.

Of course, intensity alone is not sufficient to capture the experience of MPA. If an MPA episode is particularly long, then this would increase the MPA experience in comparison to a short MPA episode. Similarly, if MPA episodes occur frequently, at a given level of intensity, the overall experience of MPA would be more problematic than, for example, a single episode among many performances. A small number of MPA measures (Papageorgi, 2007, AMPAS; Papageorgi, 2021, MPAS; Sheriff and Yoong, 2015) have been cited that gather data about frequency of aspects of MPA episodes, however none have been cited that explicitly probe global indication of MPA experience (see **Table 1**). Frequency and intensity information is commonly gathered in extant (non-MPA) psychometric scales, both as simple global scales, and as fully fledged psychometric dimensions (e.g., Swain and Jones, 1993; Wisniewski et al., 2006; Kozel et al., 2008; Walker et al., 2010; Schneider and Stone, 2014; Van Lancker et al., 2016).

The studies cited that gather responses on global items tend also to include a third concept, which can be characterized as the burden of the experience, in other words, the extent to which the experience (in this case of MPA) creates a sense of seeking to avoid future such experiences. After all, one individual may experience considerable negative impact of MPA even with relatively low frequency and intensity of episodes while another may experience less negative impact even with the same frequency and intensity of episodes. Measuring the aversiveness tendency of the MPA experience was therefore considered essential. An early example of an MPA measure that explicitly makes this distinction is the MPAS (Wolfe, 1989; see **Table 1**), where helpful, adaptive anxiety and unhelpful, maladaptive anxiety were included as separate factors. This can be summarized in global terms as the impact that MPA has on aversion from performing, a commonly reported factor in MPA measures.

While such simple, global items may allow for rapid assessment of MPA, we acknowledge that they cannot replace comprehensive, multidimensional diagnostic tools. But the availability of global indications of MPA, and consequent rapid assessment of MPA experience would serve the research and clinical community. Furthermore, very short assessment tools can be sufficiently reliable, making their value potentially high. This paper therefore takes a first step in developing a short scale that assesses MPA experience. The aim of the study was to present a first step toward the rapid, reliable and pinpointed initial measure of MPA experience.

METHODS

Participants

A total of 102 musicians (37 male and 65 female) from Australia volunteered to participate in this study by completing one online questionnaire. 79 were current students, studying music in a conservatoire or tertiary setting. The remaining 23 participants were former music students who were not currently studying music at a tertiary level. The sample was composed of 33 pianists, 22 woodwind players, 15 vocalists, 13 guitarists/bass guitarists, 8 string players, 6 percussionists, 4 brass players, and 1 harpist. Participants' ages ranged from 18 to 60 years, with an average of 24.39 years (SD = 8.49). Participants had learned their instrument for an average of 11.23 years (SD = 4.76).

Materials

Mazzarolo Music Performance Anxiety Scale

Self-reported MPA was measured using a newly developed five-item scale – the Mazzarolo Music Performance Anxiety Scale (M-MPAS). By covering the areas of intensity, frequency, and aversion, these questions aimed to enable a simple, quick, and effective way to measure MPA. The development of the scale followed the line of argument presented in the Introduction, with additional items added to allow reverse scoring and to emphasize the critical outcome of MPA, aversion of performance. The scale uses a seven-point Likert-type scale ranging from 0 = "Strongly disagree" to 6 = "Strongly agree" in response to five statements: (1) for each of the five items: "I experience strong nerves/anxiety before I perform," (intensity) (2) "I frequently experience nerves/anxiety before I perform (frequency)," (3) "I avoid performing in order to alleviate my nerves/anxiety," (aversion), (4) "I feel positive before my music performances," ("negative" aversion, with reverse scoring used for this statement), and (5) "I don't want to go ahead with my music performances because of my nerves/anxiety" (aversion) (see **Table 2**).

Kenny Music Performance Anxiety Inventory

The K-MPAI was used to assess the construct validity of the M-MPAS. It was selected because it is in wide usage among researchers, is considered reasonably comprehensive and has strong psychometric properties (Chang-Arana et al., 2018; see also **Table 1**). It consists of 40 items and encompasses eight dimensions of MPA: (1) Proximal somatic anxiety and worry about performance, (2) Worry/dread (Negative cognitions) focused on self/other scrutiny, (3) Depression/hopelessness (Psychological vulnerability), (4) Parental empathy, (5) Memory, (6) Generational transmission of anxiety, (7) Anxious apprehension, and (8) Biological vulnerability. Of these, factors 1, 2, 3, and 7 are most directly related to the *experience* of MPA, which we argue are necessary for diagnosis, while 4, 5, 6, and 8 are concerned with etiology. The items of the K-MPAI are answered on a seven-point Likert-type scale (0 = "Strongly

TABLE 1 | Sample of commonly cited, published MPA measures.

Source	Name of measure	Items	Components	Relevant global measures*	Notes
Brodsky et al. (1994)	Music Performance Stress Survey (MPSS)	25	(1) Physical conditions, (2) Related symptoms, (3) Involvement in interventions for musicians' occupational medical and psychological problems, (4) Somatic symptoms, (5) Emotional attitudes (6) Effects on career	a, f, i	Psychometric properties not reported
Cırakoğlu and Şentürk (2013)	Performance Anxiety Scale for Music Students (PASMS)	24	(1) Fear of stage, (2) Avoidance, (3) Symptoms	a	
Kenny et al. (2004)	Kenny Music Performance Anxiety Inventory (K-MPAI – also the K-MPAI-R)	40	(1) Proximal somatic anxiety and worry about performance, (2) Worry/dread (Negative cognitions) focused on self/other scrutiny, (3) Depression/hopelessness (Psychological vulnerability), (4) Parental empathy, (5) Memory, (6) Generational transmission of anxiety, (7) Anxious apprehension, (8) Biological vulnerability	a	
Lehrer et al. (1990)	Music Performance Anxiety Questionnaire (MPAQ)	32	(1) Planning to cope with anxiety symptoms, (2) High standards and a judgmental attitude about performance, worry about anxiety and its (3) Effects on performance, (4) Concern with the reactions of important others, (5) Concern about distraction in oneself and in the audience	a	
Osborne and Kenny (2005)	Music Performance Anxiety Inventory for Adolescents (MPAI-A)	15	(1) Somatic, (2) Cognitive, (3) Behavioral	a	Anxiety experienced by adolescent musicians
Papageorgi (2007, 2021)	Adolescent Musicians' Performance Anxiety Scale (AMPAS)	20	(1) Negative outcome expectancies, (2) Negative experiences in performance, (3) Evidence of pre-evaluation anxiety, (4) Experience of physiological symptoms of anxiety, (5) Concern about others' judgments, (6) Negative perception of anxiety	a, f	
Sheriff and Yoong (2015)	Music Performance Anxiety Scale (MPAS)	58	(1) Causes/Situational factors; (2) Temporal occurrence; (3) Cognitive manifestations; (4) Affective manifestations; (5) Behavioral manifestations; (6) Somatic manifestations; (7) Autonomic Arousal	a, f, i	More validation required; scale is not publicly available
Wolfe (1989)	Music Performance Anxiety Scale (MPAS)	55	(1) Adaptive anxiety (helpful); (2) Maladaptive anxiety (harmful); (3) Music performance anxiety: (3a) Cognitive and (3b) Emotional components)	a	

**None of the measures contained items explicitly about global frequency, intensity, and few contained items explicitly on global aversion (of music performance). Where some measure of these qualities were identified, they are labeled accordingly: f, frequency; i, intensity; a, music performance aversion. For more detailed overviews of MPA measures, see, for example, Osborne and Kenny (2005), Goren (2014), Burin and Osório (2016), Brugués (2018).*

disagree" to 6 = "Strongly agree"). Answers with a higher score indicate greater anxiety and psychological distress in the context of music performance.

Procedure

The Human Research Ethics Advisory Panel of UNSW Australia approved the study. Students studying Music were invited to participate in the study via email. These students were encouraged to forward the email to any other musicians over the age of 18 who might be interested in participating. Participants entered data using Qualtrics survey software[1]. They were informed that their answers would be de-identified and only be used for research purposes. To reduce bias due to order effects, factor presentation order of the K-MPAI was

[1]www.qualtrics.com

TABLE 2 | Mazzarolo Music Performance Anxiety Scale (M-MPAS).

	Strongly disagree	Disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Agree	Strongly agree
1. I experience strong nerves/anxiety before I perform	0	1	2	3	4	5	6
2. I frequently experience nerves/anxiety before I perform	0	1	2	3	4	5	6
3. I avoid performing in order to alleviate my nerves/anxiety	0	1	2	3	4	5	6
4. I feel positive before my music performances	6	5	4	3	2	1	0
5. I don't want to go ahead with my music performances because of my nerves/anxiety	0	1	2	3	4	5	6

After an introduction, the M-PAS items list is preceded by the following instruction: "The following statements will ask you about your experience with music performance anxiety. To what extent do you disagree or agree with each of the following statements?".
Numerals in the matrix are not shown to the participant/client, but are used for scoring by the researcher/therapist. The score is calculated as a simple sum of the 5 numerals. Scores can range from 0 (lowest MPA experience) to 30 (highest MPA experience).

TABLE 3 | M-MPAS item-total statistics.

M-MPAS statements	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Squared multiple correlation	Cronbach's alpha if item deleted
1. I experience strong nerves/anxiety before I perform	11.39	41.053	0.808	0.700	0.857
2. I frequently experience nerves/anxiety before I perform	11.05	43.73	0.693	0.596	0.881
3. I avoid performing in order to alleviate my nerves/anxiety	12.89	37.206	0.79	0.665	0.862
4. I feel positive before my music performances	12.59	46.165	0.663	0.443	0.888
5. I don't want to go ahead with my music performances because of my nerves/anxiety	12.98	39.128	0.773	0.663	0.864

Cronbach's alpha = 0.894.

randomized. In addition to completing the M-MPAS and K-MPAI, participants provided background information and completed other tasks that are not reported here.

RESULTS

Internal Consistency of the Mazzarolo Music Performance Anxiety Scale

Cronbach's alpha was calculated with the M-MPAS items to examine the reliability of the instrument. The results revealed a Cronbach's alpha value of 0.894, which indicates good internal consistency within the M-MPAS (Ponterotto and Ruckdeschel, 2007). The Item-total Statistics table presents the value that Cronbach's alpha would be if a particular question was deleted from the scale. **Table 3** shows that the removal of any question would result in a lower Cronbach's alpha. Since all such models produce lower Cronbach's alpha values, none of the questions within the M-MPAS should be removed, though Question 4 is the worst performing (Cronbach's alpha of the scale = 0.888 when omitted).

Construct Validity of Mazzarolo Music Performance Anxiety Scale

A Pearson product-moment correlation was performed between the M-MPAS and the scores of items taken from 4 factors of the K-MPAI that investigated MPA symptoms (proximal, worry/dread, memory, and anxious apprehension). Two responses could not be used for this analysis as those belonged to participants who had not completed the K-MPAI. The results showed that there was a strong, positive correlation between the reduced K-MPAI and M-MPAS scores ($r = 0.797$, $n = 100$, $p < 0.001$) and had a large effect size (Cohen, 1992).

Diagnostic Criteria

Cut-off publications for K-MPAI vary. Paliaukiene et al. (2018) used scores above 130 to designate a "high MPA" group. This figure was based on the principle of one standard deviation above the mean. For clinical diagnosis, based on Youden's Index, 104 has also been proposed (Kenny, 2015). Therefore the cut-off above which high MPA would be initially diagnosed via the M-MPAS was estimated through a linear regression with the overall K-MPAI score for the four experience related factors. This

score was scaled from a range of 0–148 (using 24 items) to a range of 0–240 (for the 40 items upon which published cut-offs are based). The least squares linear regression equation to estimate the conversion from K-MPAI to the M-MPAS for the present dataset explained 62.89% of the variance, and can be expressed as:

$$M - MPAS = 0.1444 \times \text{K-MPAI} - 4.0623$$

The K-MPAI cut-off of 104 (out of 240) can therefore be estimated as 11.0 (out of 30) on the M-MPAS.

DISCUSSION AND CONCLUSION

The M-MPAS was developed to address the need for a rapid, preliminary assessment of an individual's Music Performance Anxiety (MPA). The five item scale gathers data on the global frequency and intensity of MPA episodes, as well as on the negative impact (aversion to future music performance) of the experience, and deliberately avoids matters concerned with etiology. The correlation analyses revealed that a strong relationship existed between the relevant, experience focused factors of the K-MPAI, suggesting strong construct validity of the M-MPAS (Cook, 1979). These K-MPAI factors may be viewed as capturing in greater depth the essence of the MPA experience, but consist of more items and time requirements than the M-MPAS (24 versus 5 items). Furthermore, we made an initial estimate of the cut-off above which an individual may be diagnosed as having high MPA. The five item scale has a possible range of 0–30, with scores at or above 11 proposed as an indicator of potential high MPA. The study has several limitations, and will need further investigation before it could be adopted for clinical use. For example, the question wording for three of the items (1, 3 and 4) referred to feelings experienced prior to, rather than during, performance. Ideally information about different stages of the performance episodes would be desirable, but for the sake of clarity, brevity and simplicity, we chose the antecedent time framing as the point of focus for these items. The reliability and validity analyses suggest this limitation is tolerable, but future work may seek to investigate the psychometric impact of modifications that identify and improve possible weaknesses of the scale. Access to an instrument that allows rapid, initial assessment of MPA is a matter of urgency given the prevalence of performance anxiety in a discipline that should above all be bringing joy and passion to its creators.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the ethics committee has not approved distribution of the data collected. Requests to access these datasets should be directed to Emery Schubert, e.schubert@unsw.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Research Ethics Advisory Panel of UNSW Australia. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IM designed the study, collected and analyzed the data, and wrote the drafts of the manuscript. ES assisted with the design of the study, analysis, and editing of the manuscript. Both authors were involved in determining the concept and rationale of the study. The study commenced while IM was conducting Honors research and considerably reworked as part of her Doctoral research program.

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Temporospatial Alterations in Upper-Limb and Mallet Control Underlie Motor Learning in Marimba Performance

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Sound-producing movements in percussion performance require a high degree of fine motor control. However, there remains a relatively limited empirical understanding of how performance level abilities develop in percussion performance in general, and marimba performance specifically. To address this issue, nine percussionists performed individualised excerpts on marimba within three testing sessions spaced 29 days apart to assess early, intermediate, and late stages of motor learning. Motor learning was quantified *via* analyses of both the temporal control of mallet movements, and the spatial variability of upper-limb movements. The results showed that temporal control of mallet movements was greater in the intermediate compared to the early learning session, with no significant additional improvements revealed in the late learning session. In addition, spatial variability in the left and right elbows decreased within the intermediate compared to the early learning session. The results suggest that temporal control of mallet movements may be driven by reductions in spatial variability of elbow movements specifically. As a result, this study provides novel evidence for kinematic mechanisms underlying motor learning in percussion which can be applied towards enhancing musical training.

Keywords: percussion, motor learning, sensorimotor, motor control, acceleration, upper-limb

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INTRODUCTION

Musicians have a unique challenge when learning the various movements underlying sound-production. Indeed, a significant amount of temporal and spatial coordination of the upper-limbs is required to perform successfully. Percussion performance is a unique musical context because many sound-producing movements share commonalities with non-musical motor tasks (i.e., supination/pronation and flexion/extension of the shoulders, elbows, and wrists). Indeed, these movements are consistent with those executed during activities of daily living such as reaching and grasping. As a result, a percussion practice/performance context can be useful to further understand how complex musical movement patterns develop and change over time, while remaining relevant within the broader sensorimotor control literature. To this end, the present study examined four-mallet marimba performances at three time-points to study motor learning in music.

Instrumental techniques are known to influence sound production in percussion. In a seminal study within this research area, Dahl (2004) investigated drumstick kinematics when performing accented and unaccented notes wherein movements were measured predominantly along the vertical movement axis. The results showed that drummers used wrist and arm movements to adjust stick height and striking velocity when performing stroke techniques such as taps, full-, up-, and down-strokes to yield the desired aural outcome (e.g., playing loud vs. quiet). Further, drummers raised the stick to a greater vertical preparatory height in anticipation of performing an accented relative to unaccented note. Dahl (2004) further reported that when the stick reached its maximum height, the downstroke was created *via* a whiplash-like movement of the wrist. In contrast, unaccented (i.e., soft) strokes were produced with reduced movements of the hand and arm along the vertical axis. Dahl (2004) surmised that limb and drumstick movements were thus intimately linked with sound production (see also Dahl et al., 2011). Nevertheless, sound production in marimba performance can also be influenced by additional factors, such as grip technique.

The grip of the drumstick is a key factor underlying motor control in percussion. A relaxed grip allows for the stick to rebound freely off the drumhead with greater velocity, while a restricted grip facilitates control to stop the stick at a desired rebound height, resulting in a duller sound (e.g., Dahl and Altenmüller, 2008). Performance tempo has also been shown to influence stick and hand movements. At slower tempos, drummers can utilize the time in between strokes to increase their dynamic range, whereas preparatory movements tend to decrease when performing at faster tempi (e.g., Dahl et al., 2011). This work in conjunction with the findings reported above highlight that stick movements and hand position/grip are critical for sound production, thus implicating upper-limb movement patterns as significant contributors to sound production in percussion.

Literature from alternate musical contexts such as piano may further illustrate how upper-limb movements (e.g., elbows, wrists, hands, and fingers) contribute to sound preparation and production. For example, classical pianists organize proximal upper-limb motions in a way that minimizes biomechanical load and muscular effort to the distal muscles (e.g., Furuya and Kinoshita, 2007, 2008). More specifically, organizing movements of the upper-limbs in a proximal-to-distal fashion coincided with increased elbow pronation and supination when performing keystrokes specifically at faster tempi (i.e., Furuya et al., 2011). Expert pianists also optimize the use of gravity during downward arm swings when striking piano keys wherein the effective utilization of the elbow lowered muscular force load at distal limb segments compared to novice performers (i.e., Furuya et al., 2009). Based on the piano kinematics literature cited here, it can be gathered that movements of the elbow may be particularly critical for performance contexts involving melodic instruments like the marimba (cf. non-melodic instruments like the snare drum).

Studies examining the limb kinematics of percussionists at various skill levels have only recently begun to uncover how performance experience refines movement patterns. When performing fast repetitive drumming movements, expert drummers demonstrated greater temporal accuracy which occurred *via* utilizing low-mass distal joints, resulting in whiplash-like movement of the stick towards the drumming surface compared to novices (i.e., Altenmüller et al., 2020; see also Dahl, 2004). Movement smoothness in drummers' strokes has also been shown to increase at faster tempi while muscular co-articulation linearly decreased in line with slower performance tempo (i.e., Gonzalez-Sanchez et al., 2019, see also Furuya et al., 2012). Further, expert drummers presented with reduced wrist muscle co-contraction resulting in more temporally succinct playing, which was hypothesised to reflect more efficient performance practices (i.e., Beveridge et al., 2020). Naturally, deliberate motor practice alters the capacity to execute movements.

However, studies contrasting expert and trainee musicians provide only a snapshot of movement execution as a function of experience. Critically, such findings cannot account for how movement patterns were acquired and subsequently refined over time. As mentioned above, achieving such understanding has the potential to advance mechanistic knowledge of complex skill execution, as well as advance theories of motor learning in musical contexts. This pursuit may contribute to the development of optimization factors for motor learning in percussion performance which can be used to aid in the training of musicians. To this end, the present study examined motor learning in percussion where upper-limb movements executed within four-mallet marimba performances were assessed from both temporal and spatial perspectives at three time-points [i.e., session (S) 1, S2, and S3]. Briefly, the marimba is a melodic percussion instrument (e.g., a piano with wooden bars) that is played using mallets. By utilizing a marimba approach in the present study, novel insight regarding the development of sound preparation and sound-producing movements occurring along performance axes not previously investigated in alternate percussion investigations (i.e., anteroposterior, and mediolateral) can be examined to further advance pedagogical applications for motor learning in music.

To meet these goals, two main hypotheses were developed and tested. From a temporal perspective, analyses rooted in the frequency domain were utilised to quantify how movements of the mallets changed over time. More specifically, the first (i.e., velocity) and second (acceleration) derivatives of mallet position data were computed. The time-series data for each mallet during each session (i.e., S1, S2, and S3) were converted into a frequency-domain representation using the pwelch method (i.e., relative peak power). Relative peak power reflects the relative amplitude of a particular rate of motion in the acceleration profile and has been utilised to study sensorimotor control of reaching movements (i.e., de Grosbois and Tremblay, 2016, 2018; de Grosbois et al., 2019). In this frequency domain representation, greater peak power values are indicative of high temporal control. As a result, it was hypothesised that relative peak power would increase linearly across the learning sessions (i.e., S1 vs. S2 vs. S3). To assess motor learning from a spatial perspective, variability in limb movements (i.e., hands, wrists, elbows, and shoulders)

were computed and compared across testing sessions. In general, reductions in spatial variability of upper-limb movements are considered favourable relative to increases in spatial variability in musical contexts (e.g., Furuya et al., 2009, 2011). It was thus hypothesised that spatial variability of upper-limb movements would reduce across sessions concomitant with the predicted increases in relative peak power. Successfully confirming the hypotheses outlined here would provide novel insight into kinematic factors underlying motor learning in music, which can be leveraged towards pedagogical applications to the training of percussionists.

MATERIALS AND METHODS

Participants

Nine participants (# of females = 4) completed the protocol described below. Participants were recruited from the Percussion Department in the Faculty of Music at the University of Toronto. All participants were pursuing degrees in percussion performance and had an average of 9.3 years (SD = 2.1) of percussion experience at the time of participation. All participants self-reported to be right-handed. The study was approved by the University of Toronto Research Ethics Board and participants provided informed written consent prior to the commencement of participation.

Apparatus

Participants performed their excerpts on a Musser Deluxe Studio Grand Rosewood M245 marimba (Ludwig Musser, Elkhart, IN, United States). Motion capture technology was used to gather kinematic data and compute the velocities and acceleration profiles of the markers affixed to the upper-limbs and mallets. The setup included eight Vicon Vero (Vicon Motion Capture, Oxford, United Kingdom) motion capture cameras. Twenty-seven markers were affixed to the limbs of the performers in line with the upper-limb model written in Vicon BodyLanguage (e.g., Murray, 1999). Five markers were positioned on the upper half of the torso including the spinous process of the seventh cervical vertebra, the right scapula, the spinous process of the tenth thoracic vertebra, the jugular notch where the clavicles meet the sternum, and the xiphoid process of the sternum. Markers were further positioned on the left and right limbs including on the acromion-clavicular joints (i.e., used to measure shoulder movements), three inches apart on the upper arms, the lateral epicondyle approximately at the elbow joints (i.e., used to measure elbow movements), the midpoint of the forearms, the thumb side of the radial styloid (i.e., used to measure wrist movements), the little finger side of the ulnar styloids, and just below the third metacarpus on both hands (i.e., used to measure hand movements, see Murray, 1999; Cutti et al., 2005). One marker was positioned at the central point of the ball of each mallet (i.e., four in total). These markers were subsequently used to track movements of each mallet. Given the considerable range of upper-limb and mallet motion during the performance, the markers were sampled at 100 Hz to ensure they could be continuously sampled by the motion capture cameras (see **Figure 1**).

Procedure

A total of three testing sessions were completed across a 12-week academic semester at early (i.e., S1), intermediate (i.e., S2), and late (i.e., S3) assessment time-points. All testing sessions were separated by 29-day intervals starting from the first session. This interval was chosen to equate the number of formal lessons between participants. That is, each participant had practice sessions with percussion department faculty members where performance-related feedback and instruction were provided. Separating the testing sessions by 29 days ensured that all participants had an equal number of formal lessons between each assessment time-point. The pieces performed during the testing sessions were part of the individual participant's curriculum which culminated in an end-of-term evaluation performance. As a result, each participant played an individualised excerpt in each of their early, intermediate, and late testing sessions (i.e., nine excerpts in total). This approach was deemed necessary to study the development and refinement of performance-level motor skills (see section "Discussion").

There were additional procedural differences between participants. To study performance-level kinematics, participants often performed several trials until they achieved a performance that was representative of their ability to play the piece. More specifically, participants were asked whether they would be satisfied if the performance (i.e., the previous trial) had been given to a concert audience. The minimum number of trials required to achieve the representative trial ranged between 2 and 10 trials, with an average of 3 and a standard deviation (SD) of 2.1. The single representative trial obtained in each session was subject to formal data analysis procedures described below. The length of each trial (i.e., performance) also varied across participants, with an average trial length of 18 s (SD = 4 s; range = 14–25 s). Lastly, the tempo of each piece varied between participants with a mean of 87.8 beats per minute (BPM) and a standard deviation of 14.7 (range = 72–115 BPM). Within participants, tempo was always consistent across testing sessions (i.e., each participant performed the piece at the same tempo across sessions). Due to the individualised excerpts and the procedural variability described in this section, data analysis procedures focused on the velocity and acceleration domains to ascertain consistent kinematic patterns across participants.

Data Analysis

Data Reduction—Frequency-Based Mallet Analyses

Acceleration data was computed *via* the positional motion capture data along the three orthogonal cardinal axes (i.e., x, y, and z). Given that the mallets used were unique to each participant, the markers on the mallets were not precisely consistent across participants and sessions. As a result, resultant acceleration was chosen as the primary substrate for the frequency-domain analyses. These resultants were computed as the square-root of the sum of the squared values of each axis, at each time-point. Data from each axis, and the resultant were filtered with a 2nd order lowpass Butterworth filter using a cut-off frequency of 10 Hz. Notably, this filter was applied both before and after the computation of the resultant to minimize the

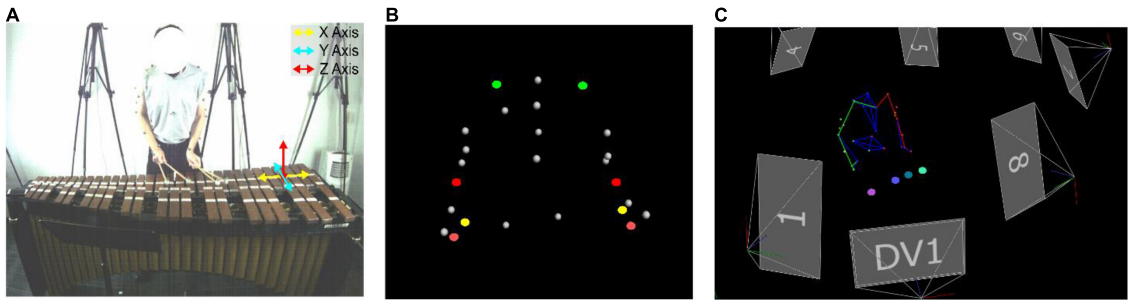


FIGURE 1 | The direction of the movement axes **(A)** are shown. Marker placements (i.e., green = shoulders, red = elbows, yellow = wrists, and salmon = hands) are shown in panel **(B)**. Mallet numbers (i.e., seafoam green = LH1, teal = LH2, purple = RH3, pink = RH4) are shown in panel **(C)**.

impact of the amplification of noise due to the computation of the resultant acceleration (e.g., Elliott and Hansen, 2010).

The resultant acceleration traces for each participant, mallet, and session were further summarised using frequency-domain analyses. First, a frequency-domain representation of each resultant was computed using the Welch method (i.e., Welch, 1976) as implemented in the SciPy library within Python (Van Rossum and Drake, 1995). The following parameters were implemented when using the Welch method: (1) A 1-second sliding window; (2) A 50% overlap between successive windows; (3) Any linear trend was removed from each window; (4) A Hanning truncation was applied to the window; and (5) Median estimates of power-spectral density were returned. Note that median estimates were returned to minimize the potential influence of artefacts in the signal that may have persisted beyond the signal filtering completed in the first step. Ultimately, this resulted in normalised estimates of the contributions of specific frequencies to the resultant signal. Because participants each played unique pieces, these estimates were further normalised as relative values of the total power to facilitate comparisons across and within participants (see Warner, 1998).

These computed power-spectra-densities were further summarised by extracting two primary measures: (1) The maximum relative amplitude of the largest peak on the spectrum (i.e., relative peak-power); and (2) The width of this peak at 50% of its height (i.e., peak width). The amplitude measure (i.e., relative peak power) represents the relative contribution of the dominant oscillation frequency contributing to the resultant signal. Peak width provides some evidence of the differences in the temporal consistency of the performance, with wider widths indicating varying frequencies contributing to the signal, or at least, increases in temporal variability. Both of these measures were extracted using the find_peaks() function with the Scipy library in Python.

Data Reduction—Spatial Variability Analyses

To determine the impact of training on upper-limb movements, spatial variability was computed along the three orthogonal cardinal axes (i.e., x, y, and z). In line with the objective approach for studying temporal performance characteristics in the mallets, spatial characteristics were assessed by obtaining the average standard deviation of individual limb segment movements along each movement axis. Specifically, the standard deviation for movements of the hands, wrists, elbows, and shoulders along each of the x, y, and z axes from the representative trial were computed for each participant. These standard deviation values were then averaged across the nine participants to obtain the mean standard deviation for each movement axis and session (e.g., right elbow variability along the x axis: S1 = 128.3 mm; S2 = 86.8 mm; S3 = 84.1 mm). These values were subject to formal data analysis.

Statistical Contrasts

The analysis of limb acceleration was completed on both the relative peak power and the peak width estimates obtained *via* the frequency domain analysis, which was completed on the resultant accelerations of the individual mallets. Both dependent variables were examined using a 3 Session (S1 vs. S2 vs. S3) × 2 Hand (Left vs. Right) × 2 Mallet (Thumb vs. Pinky) repeated measures ANOVA. *Post-hoc* analyses of main effects or interactions involving the continuous variable of Session were completed using single degree-of-freedom polynomial contrasts. Otherwise, *post-hoc* pairwise comparisons were completed, and a Bonferroni correction was applied, resulting in an adjusted alpha threshold of $p = 0.02$. If a violation of sphericity was observed, The Greenhouse-Geisser correction was applied to the degrees of freedom before evaluating statistical significance.

The analysis of spatial variability was completed for the standard deviation of movements from all limb segments under study (i.e., hands, wrists, elbows, and shoulders). Standard deviation values were submitted to separate repeated measures ANOVAs for each limb segment and movement axis with session as the within subjects factor (i.e., S1 vs. S2 vs. S3). Only the limb segments that resulted in a significant effect of session were reported below. Main effects of session were followed up with Bonferroni corrected *t*-tests with a corrected alpha threshold of $p = 0.02$ as *post-hoc* procedures.

RESULTS

Frequency-Based Mallet Analyses

The acceleration analysis for relative peak power failed to reveal a main effect of session, hand, or mallet (i.e., all *p*

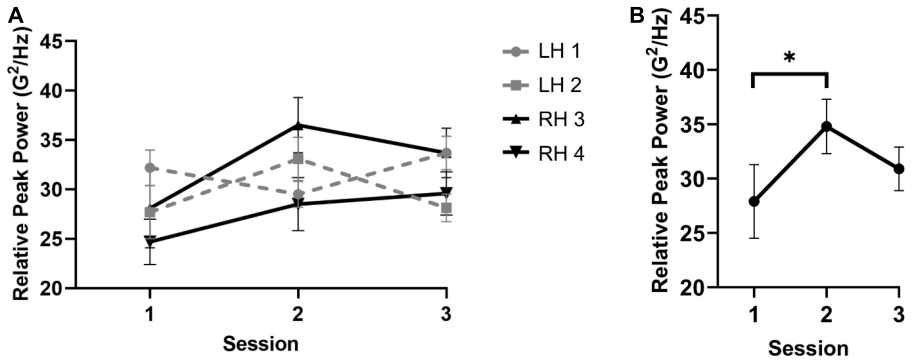


FIGURE 2 | Results for the frequency-based analysis of mallet movements. The overall pattern of effects for peak power and the significant mallet × session interaction is shown in panels **(A,B)**, respectively. The analysis revealed that relative peak power increased specifically for the thumb mallets between sessions 1 and 2. *indicates significance at the Bonferroni corrected alpha threshold.

values > 0.06). However, a significant interaction between session and mallets was observed, $F(1.4,11.2) = 6.8$, $p = 0.017$, $\eta_p^2 = 0.39$ (see **Figure 2**). Follow-up simple effects analyses showed a significant modulation only for mallets 2 and 3 (i.e., thumb) across sessions, $F(2,16) = 5.5$, $p = 0.02$, $\eta_p^2 = 0.41$. The resulting polynomial contrast conducted across sessions and collapsed between mallets 2 and 3 showed a significant negative quadratic trend across sessions, $F(1,16) = 8.83$, $p = 0.009$, $\eta_p^2 = 0.36$. Examination of the quadratic trend indicated that the greatest increase in relative peak power occurred for most participants in S2 ($M = 34.8$ G^2/Hz, $SD = 6.4$) relative to S1 ($M = 27.9$ G^2/Hz, $SD = 9.3$). These results likely indicate that the relative contribution of the dominant rate of acceleration increases specifically between S1 and S2. In other words, performance variability at the peak frequency contributed to the performance overall to a greater extent during S2. No significant effects were observed for the peak width. In the absence of significant scaling of the peak width, the increase in relative peak power likely reflects a reduction on task-irrelevant temporal variability in the thumb mallets specifically. Thus, participants may be constraining movement degrees of freedom within the intermediate stages of learning to focus on executing unique mallet movements in line with temporal accuracy constraints.

Spatial Variability Analyses

The only significant effects of Session were observed in the elbows. Indeed, spatial variability of elbow movements yielded significant effects of Session for both the left, $F(2,16) = 4.8$, $p = 0.02$, $\eta_p^2 = 0.38$, and right, $F(2,16) = 6.5$, $p = 0.009$, $\eta_p^2 = 0.45$ elbows along the mediolateral x axis. For left elbow position variability, *post-hoc* contrasts revealed greater variability in S1 ($M = 117.7$ mm, $SD = 30.5$) compared to S2 ($M = 83.6$ mm, $SD = 21.7$), $t(8) = 3.1$, $p = 0.01$, 95% CI = [8.9, 59.4]. In the right elbow, position variability was greater in S1 ($M = 128$ mm, $SD = 33.5$) compared to S2 ($M = 86.8$ mm, $SD = 29$), $t(8) = 3.4$, $p = 0.01$, 95% CI = [13.2, 69.8]. Results for both elbows are shown in **Figure 3**. This pattern of effects may indicate that improved spatial variability in elbow movements may be linked to the reduced temporal variability in the mallets. This hypothesis was further considered below.

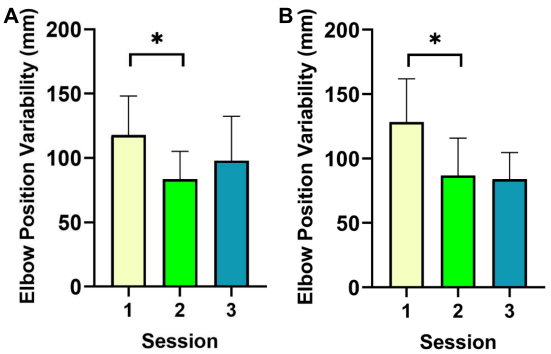


FIGURE 3 | Results for spatial variability of elbow movements are shown. Results for both elbows [i.e., left elbow **(A)**, right elbow **(B)**] revealed reduced spatial variability between S1 and S2. *indicates significance at the Bonferroni corrected alpha threshold.

DISCUSSION

This study investigated how upper-limb movement patterns in a percussion context are acquired and refined from spatial and temporal perspectives at three time-points representing early, intermediate, and late phases of motor learning. The results indicated that high spatial and temporal variability in limb movements and mallet acceleration within early learning stages was subsequently reduced in intermediate stages. The strongest effects for temporal variability were observed between S1 and S2, which was unexpected due to the anticipated linear nature of improvement hypothesised above. Instead, the kinematic changes observed specifically within S2 suggest that a reduction on task-irrelevant temporal variability occurs following only one month of training, and predominantly occurs for the inside mallets (i.e., thumb mallets 2 and 3). Spatial alterations in elbow variability likely contributed to these temporal effects. That is, reductions in spatial variability followed a similar trajectory as the

temporal effects observed in the mallets. Such findings provide critical insight into the development of sensorimotor control underlying motor learning in music.

As previously mentioned, temporal data obtained from mallet acceleration revealed that the most consistent change in relative peak power overall was between S1 and S2. Relative peak power was used to quantify movements of the individual mallets across the three testing sessions, wherein increases in relative peak power indicated a greater isolation of the predominant temporal rate of performance (e.g., de Grosbois and Tremblay, 2016, 2018). A unique finding of the present study was that changes in relative peak power were primarily driven by movement alterations occurring at the thumb mallets (i.e., mallets 2 and 3), which was not observed in the outer mallets (mallets 1 and 4). This effect may provide novel insight into the time course of motor learning in four-mallet marimba performance. That is, the control of inner vs. outer mallets follow unique learning trajectories, with motor control of the inner mallets developing more rapidly compared to the outer mallets. Such a hypothesis may be supported by differences in visual feedback of outer and inner mallet trajectories.

Asymmetries are a common constraint in motor behaviour. Indeed, it is well known that manual asymmetries exist within the upper-limbs, with humans often showing clear hand dominance (e.g., Oldfield, 1971; Sainburg and Kalakanis, 2000). Asymmetries can further be found within the visual system wherein visual feedback of the moving limb gathered by the dominant eye may be critical for the online control of pointing movements (i.e., Manzone et al., 2018; Loria et al., 2019). The learning asymmetries between the outer and inner mallets were consistent with the asymmetries literature, and suggest the presence of dominant (i.e., inner) vs. non-dominant (i.e., outer) mallets. Such an effect may arise because the outer mallets are often in the peripheral visual field during the performance, thus limiting the quality of visual feedback required to refine trajectories over time (e.g., Sivak and MacKenzie, 1990; Proteau et al., 2000; Loftus et al., 2004; King et al., 2010). As a direction of future pursuit, alternative interventions that manipulate the availability of visual feedback in peripheral and central vision in four-mallet marimba performance can further evaluate visuomotor contributions to learning.

The results also indicated that the greatest reduction in spatial variability occurred between S1 and S2 in both elbows along the mediolateral movement axis. Reduced spatial variability of elbow movements has previously been shown to delineate experienced vs. inexperienced drummers, with the former showing lower variability overall (e.g., Altenmüller et al., 2020). The novel contribution of this investigation is that reductions in elbow spatial variability coincided with increases in the relative peak power (i.e., the predominant performance frequency) of mallet movements. As a result, it may be postulated that decreased spatial variability across sessions likely served to decrease task-irrelevant variability at the level of the mallet. This pattern may suggest that a decrease in elbow movement variability results in greater control of distal thumb mallet movements specifically. Support for this hypothesis may be found in cello performance, wherein precise spatial control of right elbow and shoulder movements was associated with lower bow movement variability underlying sound production (i.e., Verrel et al., 2014; Gonzalez-Sanchez et al., 2019). As a result, the coupling of spatial and temporal control may be one mechanism underlying motor learning in marimba specifically and music performance in general.

The results also have implications for the development of movements not directly related to sound production. Contrary to the stated hypotheses, relative peak power did not increase linearly during training but appeared to plateau between S2 and S3 for the thumb mallets (see **Figure 2**). This pattern likely reflects changes in practice foci during the motor skill acquisition process. Following S2, participants likely reached optimal sensorimotor and kinematic stability related to the movements underlying sound production (i.e., effective gestures), and thus emphasised the development of expressive gestures. Previous work has clearly demonstrated the vital role of expressive gestures, including how such gestures can be leveraged to influence the perceived aural quality of a performance (e.g., Davidson, 1993; Schutz and Lipscomb, 2007; Broughton and Davidson, 2016; Wanderley and Vines, 2016). Although the present study focused on motor learning of sound-producing movements, the results may be interpreted as evidence that expressive gestures emerge one month into training once sensorimotor learning of sound-producing movements has occurred.

Prior to concluding, it is pertinent to highlight some of the limitations of this study. Most critically, kinematic changes observed during testing cannot be linked directly to specific feedback or approaches to training provided during individual lessons. In addition, this study examined a small sample where only the percussion students at the host institution who were actively practicing marimba repertoire were involved. Lastly, all participants performed unique excerpts. Regarding the potential mechanistic impact of this study, however, it is important to consider that the observed reductions in temporal and spatial variability did occur across different musical pieces, thus highlighting the potential stability of the effects reported here. In addition, all participants were actively preparing their pieces for an end-of-term evaluation performance, which supports the external validity of this study. However, it is recommended that future investigations test the hypotheses proposed here using a larger sample of students from multiple percussion departments and music schools.

Nevertheless, this study still provided valuable insight into the motor skill acquisition process in percussion performance which to date has been limited. This study demonstrated that high temporospatial variability in early learning stages was reduced within intermediate stages when performance motions stabilised. The rate of change between temporal and spatial learning also appeared to be linked. Following one month of training, a relatively permanent change in elbow and dominant thumb mallet movements occurred that was stable over time. Therefore, participants may be constraining elbow movement degrees of freedom within intermediate phases of learning to focus particularly on temporal characteristics and the development of expressive gestures. These findings may also be relevant

for other contexts such as sports where elbow movements are critical to task success including overarm throwing in baseball (e.g., Hore et al., 2005; Hore and Watts, 2011). Importantly, this study represents a first step towards understanding mechanisms of motor learning in marimba performance which can be leveraged in future pedagogical approaches to enhance the training of musicians.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Toronto Research Ethics Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TL designed the study, collected and analysed the data, and wrote the manuscript. MT analysed the data and wrote the manuscript. JG designed and conducted the frequency-based analysis, and wrote the manuscript. AH secured the funding, helped to recruit participants, and wrote the manuscript. MHT secured the funding and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Exploring the Impact of the Somatic Method 'Timani' on Performance Quality, Performance-Related Pain and Injury, and Self-Efficacy in Music Students in Norway: An Intervention Study

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The importance of including performance-related body mechanics into music education to improve performance quality and prevent performance-related injuries has been stressed by many researchers recently. However, it is unclear how this information could be delivered most effectively. The somatic method 'Timani' provides a practical solution by combining expertise in music performance and functional body mechanics with the goal of achieving a more efficient playing technique. Since no in-depth study has been conducted to assess the method before, we explored the impact of this method on young musicians' performance through an online, 4-week-long Timani intervention with a mixed-methodology design. 17 students (mean age = 19.17 years) were recruited from the Norwegian Academy of Music. They participated in two group workshops at the beginning and the end of the project and received four individual Timani sessions administered by certified teachers. We collected survey data at the workshops about performance-related pain and self-efficacy, and qualitative feedback after each session. In addition, all sessions were observed by the researcher and semi-structured interviews were conducted with the teachers about the perceived outcomes and their experiences with teaching the method online. Our findings show that the intervention had a positive impact on a physical, professional, and to some extent, psychological and behavioral level. The improvements included better posture when playing, enhanced control and dexterity in the upper extremities, and improved breathing mechanisms. The seven students who had performance-related pain pre-intervention reported a reduction in the discomfort. The positive results were achieved by the dual expertise of the teachers in music performance and functional body mechanics, the structure of the sessions, the communication, and the pedagogical tools used. Both students and teachers felt that administering the sessions online was satisfactory and produced good results.

Timani is a promising method to establish healthy playing and singing habits thus improving performance quality and preventing performance-related problems and has great potential in reducing pre-existing injuries and pain. Also, it can be effectively taught online which has further implications for the logistics of delivery.

Keywords: musician's health, intervention, somatic method, young musicians, performance quality, performance-related pain and injury

INTRODUCTION

Playing a musical instrument or singing is often romanticized as a purely artistic pursuit, overlooking the fact that it is as much of physical activity as well as a creative and aesthetic one. Musicians have to perform extremely complex motor movements when playing or singing, which requires very refined patterns of muscle activation (Furuya and Altenmüller, 2015). They are often called the athletes of the small muscles (Quarrier, 1993), yet their knowledge and education about body mechanics and their preparation for the physical side of the task is less than satisfactory, and rarely comparable to those pursuing sports on a high level (Chan and Ackermann, 2014).

While there are initiatives to include biomechanical analysis in musical performance (Kjelland, 2000; Visentin et al., 2008; Kelleher et al., 2013), the majority of musicians are relying on their primary instrumental or singing teacher when learning the complex coordination and posture needed for music-making. This educational process, however, places much more attention on the auditory output than the physical movements the musician uses to achieve it (Chan and Ackermann, 2014). Moreover, the information shared on lessons about the performance-related body mechanics is rarely based on an up-to-date anatomical understanding or founded on biomechanical principles; teachers are likely to replicate their own education (Mills and Smith, 2003) or base their tuition on their own personal experience as musicians and educators (Visentin et al., 2008), which subsequently, might result in less-than-ideal body mechanics and instrumental technique in some students.

This missing piece in professional music tuition can contribute to various performance-related problems (Visentin et al., 2008). One subtle and often overlooked outcome is that inefficient body mechanics and posture can negatively affect the sound production, lead to limitations in the technical skill, and thus, inhibit musical expression and hinder musicians to reach their full potential (Ueno et al., 1998; Baadjou et al., 2017; Shoebridge et al., 2017).

Yet, working on playing-related body mechanics and posture is rarely used as a tool to enhance performance quality, the topic comes to the forefront of the conversation much more often when it leads to a performance-related injury that thwarts the instrumental or singing skill (Steinmetz et al., 2010). This is not surprising, given the high prevalence of such injuries in this population in all age groups from college-level music students (Cruder et al., 2020) to adult professionals (Kok et al., 2016).

However, young musicians might downplay the consequences of such injuries (Stanhope, 2018) and the possibility of honing their skills might motivate them more to engage with intervention programs rather than the idea of injury prevention. Musicians generally tend to take a task-specific view and are more motivated to do additional physical exercises when they perceive it as directly related to their instrumental technique (Ackermann et al., 2002) and are interested in practical, and instrument-specific physical and somatic education (Stanhope, 2018). Shoebridge et al. (2017) also highlight that the right posture, which allows efficient coordination with minimal effort, needs to be achieved in a dynamic performance context.

Yet, the majority of the interventions and preventative programs presented in the literature are usually underpinned by the narrative of avoiding getting injured or aiming for better overall health and do not include task-specific exercises. The focus is often on improving general strength and endurance through exercise and fitness programs, sometimes even focusing on one specific body part, such as the trunk or the upper extremities (Stanhope et al., 2020). Apart from the fact that the evidence is not consistent in terms of the safety and effectiveness of these interventions and they can possibly worsen the condition of the musician (Stanhope et al., 2020), and despite the reported positive outcomes in terms of flexibility, ease of the movements, and muscle strength, some of these interventions were unable to show a significant positive effect on the endurance and perceived exertion in performance and practice situations (Chan et al., 2014a,b).

In addition to exercise programs, several somatic methods have been tested on musicians with the goal of relieving performance-related problems and enhancing the body mechanics and instrumental technique when playing. These methods are developed with the general population in mind and tailored to the specific needs of musicians. Examples of this in the literature include Alexander Technique (AT) (Kleinman and Buckoke, 2013; Klein et al., 2014), Feldenkrais Method (FM) (Lee, 2018), Body Mapping (Buchanan and Hays, 2014) and yoga and yogic breathing (Khalsa and Cope, 2006; Lee et al., 2016).

These studies have various outcome measures and methodologies with varying quality. Some are only descriptive and do not include any experimental data (Lee, 2018), with the aim to provide some guidelines for teachers to incorporate the methods into music lessons. What they all have in common, however, is that they are generally taking a more holistic approach and stress the importance of improving general posture and alignment over targeting specific muscle groups or general strength and endurance (Schlinger, 2006).

Although these methods are gaining more and more popularity among musicians, there is not much data available on how they translate these methods' ideas to dynamic performance situations. From the 12 controlled trial AT studies

Klein et al. (2014) reviewed, most used AT sessions away from the instrument as an intervention and allowed the participants to incorporate the learned material into their playing on their own. Similarly, providing general group ATM (awareness through movement) sessions is the core component of most FM interventions for musicians (Beacon et al., 2017; Paparo, 2021) with few direct links introduced between the FM methods and playing mechanics.

The general difficulty is that many of these methods have been developed for commonly held postures and performed movements, such as sitting or walking, while musicians need to use additional instrument-specific body mechanics for sound production. When interacting with the instrument, general alignment and movement patterns change; Doyle (1984) found that after a short AT intervention, 98.6% of both the experimental and control group of violinists still changed their head and neck posture when taking the instrument up, following their habitual movement patterns.

Extrapolating from this, to make an intervention more effective, it seems necessary to correct and practice the body mechanics and posture in a dynamic performance context. This approach is currently lacking from the literature, with most of the interventions working with exercises away from the instrument and only little available data on how to transfer the embodied experience of alignment and effective body mechanics to a dynamic playing situation.

The somatic method 'Timani' seems to meet many of these needs and challenges. It was created by pianist, massage therapist, yoga teacher, personal trainer, and Kinetic Control Movement Therapist Tina Margareta Nilssen based on the clear understanding of the needs, challenges, and motivations of performing musicians. It complements traditional music tuition by educating musicians on efficient instrument-specific body mechanics, aims to improve performance-related movement control, and provide practical, music- and instrument centered sessions. It is positively framed by putting the emphasis on the enhancement of the playing mechanics, but also supports musicians with existing playing-related injuries. Detailed information is provided about the method itself in the "Materials and Methods" section.

The method is relatively new, therefore there is little data available. The Norwegian Academy of Music's Centre for Excellence in Music Performance Education (CEMPE) produced an unpublished report (Breian and Jørgensen, 2015) based on a 3-month long intervention with six participants, concluding that the method helped with avoiding performance-related injuries, and the participants found it highly relevant to their own instrumental practice. There are two additional Master theses (Danielsen, 2013; Skorstad, 2015) and a Bachelor thesis (Brænden, 2015) written on the topic with similar results, but a more thorough and deeper examination of the method is deemed necessary.

The present study is the first large-scale study exploring the impact of Timani on individual musicians. The method can serve both as an intervention for injuries and as an educational, preventative strategy, similarly to other methods reported in the literature, where there is no clear differentiation made between treatment and preventions (Stanhope et al., 2020). Therefore, we did not selectively choose participants with or without performance-related problems but decided to include young musicians from the Norwegian Music Academy's (NMH) talent program (TUP), and BA and MA classes, who are preparing for their professional careers for two reasons. Firstly, the method aims to establish healthy body mechanics for practice and performance, which is more effective in younger musicians because they have fewer established habits (Cruder et al., 2020). The importance of delivering health-related interventions in this generation is stressed in the literature (Spahn et al., 2014; Rickert et al., 2015) to shape their future practice behaviors which can have a significant impact on their careers. Secondly, research shows that there is a high percentage of performance-related musculoskeletal disorders (PRMDs) and other performance-related problems already in college-level music students and the problems are most frequent in the 1st and 2nd year Masters students (Cruder et al., 2020). This means that the selected participants are highly vulnerable to obtaining PRMDs or other performance-related health problems in the close future, so can hugely benefit from getting support during their professional education in establishing healthy habits.

We aimed to explore the impact of the intervention on performance-related problems, performance quality, and since the method provides practical solutions to support the playing technique, we also hypothesized that it would influence performance-related self-efficacy. Furthermore, we also wanted to list and assess the pedagogical tools used to achieve the outcomes.

Originally, the intervention was planned to run in-person in Oslo, but due to the Norwegian Government's COVID19 regulations, the study had to be moved online. This change was challenging but also provided an opportunity to gather information about how this somatic method can be taught in a virtual environment.

Following the events of 2020 and 2021, the research exploring online teaching exploded as it became the primary way of education during the pandemic, and researchers explored several different angles and settings (Saikat et al., 2021). However, to the best of our knowledge, no studies are yet available on how somatic methods can be taught online, which seems extremely sensitive in terms of the need for personal contact. Somatic methods often use physical touch to guide the student or client, and the teachers also need to be able to observe the movements closely and from different angles. In the absence of these basic conditions, teaching somatic methods online can be challenging.

Under the given circumstances, therefore, an additional research question was added to the study, namely, examining the effectiveness of online education in the case of Timani.

Our research questions were the following:

(1) How can Timani support instrumental technique, the body mechanics when playing an instrument and the self-efficacy of the musician?
(2) Can Timani be effective in reducing performance-related problems?

(3) What tools and strategies are used to contribute to the outcomes?
(4) Can Timani be effectively taught online?

The study is the result of a collaboration between the Musician's Health and Movement Institute (Oslo) and the University of York (United Kingdom).

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MATERIALS AND METHODS

Procedure

This is the first large-scale research study examining the effects of Timani on individual musicians. The exploratory nature of the study prompted a mixed methodology approach with strong qualitative elements. The main data collection was performed during a 4-week long intervention program and an opening and closing workshop. The participants filled out a questionnaire at the beginning of the first workshop and at the end of the closing workshop. The questionnaire collected basic demographic data and focused on two main areas: performance-related pain, injury or difficulties, and performance-related self-efficacy. Two validated scales were used to measure these constructs, the Musculoskeletal Pain Intensity and Interference Questionnaire (Berque et al., 2014) and the Music Performance Self-Efficacy Scale (Zelenak, 2014). To gather more information about the participants' overall experience, self-constructed questions were added to the closing questionnaire, focusing on the participants' engagement with the material, perceived outcome, and practice behaviors.

The intervention itself provided the participants with four, 45 min long individual Timani sessions online (one session each week) from a certified Timani teacher, which were observed by the researcher. Out of the 68 administered lessons, the researcher observed 63 (some sessions ran parallel) with her camera and microphone turned off to avoid any interference with the teaching process. The targets of these observations were the following: perceived effectiveness of the Timani exercises (i.e., changes in the posture and instrumental technique of the student), pedagogical tools, communication, feedback from the student, and use of the online environment. After each session, all participants were asked to fill out a short form with two open, qualitative questions regarding their experiences with the lesson, and their experiences with the online environment, which resulted in 68 short entries. To add an additional viewpoint, the teachers who administered the lessons were also interviewed after the conclusion of the project about their pedagogical approaches, the perceived impact and effectiveness of their teaching, and the use of the online space.

The research was conducted in two languages: Norwegian and English. The choice of language in different situations was informed by the level of understanding of the participants. The teachers and the researcher are bilingual, which allowed the lessons to be conducted in the participant's first language in each case to maximize clarity, and they were encouraged to provide the written qualitative feedback in the same language. The interviews with the teachers were conducted in English and the observational notes were taken both in English and Norwegian. The translations of the qualitative data were done by the researcher.

Participants

The participants for this study were recruited from the Norwegian Academy of Music (NMH) and its talent program for young musicians (TUP). The initial call for participants was made through the Academy, but the interested participants and their guardians were asked to contact the Musician's Movement and Health Institute directly. Nineteen students were recruited, but due to scheduling difficulties and a drop-out, the study was completed with 17 students [mean age: 19.17 years, 9 females, 8 males; 9 attending the talent program, and 8 students from the Norwegian Academy of Music's (NMH) Bachelor and Masters programs in performance]. More information about the participants is shown in **Table 1**.

Ethical Considerations

The participants were all young musicians, seven of them minors. Ethical approval was obtained from the Arts and Humanities Ethics Committee at the University of York, and the Norwegian Research Council was notified of the project in alignment with the regulations. In order to protect the personal data of the participants, the researcher did not obtain the full names or email addresses of the participants or, in the case of minors, the email addresses or full names of the parents or caregivers. All communication, including sending out the information sheets, collecting the signed consent forms, and scheduling the lessons was done by the four teachers assigned to teach the students. Moreover, all students entered the Zoom calls only using their first names. This way, the researcher did not obtain or store

TABLE 1 | Participant demographics.

	Instrument	Gender	Age	Program
(1)	Violin	F	14	TUP
(2)	Violin	F	14	TUP
(3)	Cello	M	12	TUP
(4)	Cello	F	13	TUP
(5)	Saxophone	M	18	TUP
(6)	Saxophone	M	19	TUP
(7)	Trombone	M	16	TUP
(8)	Trombone	M	17	TUP
(9)	Organ	M	15	TUP
(10)	Cello	F	22	NMH
(11)	Flute	F	21	NMH
(12)	Flute	F	22	NMH
(13)	Clarinet	F	20	NMH
(14)	Harp	F	30	NMH
(15)	Piano (jazz)	F	24	NMH
(16)	Organ	M	24	NMH
(17)	Conducting	M	25	NMH

any personal information and was not in direct contact with the participants or the guardians of the participants. However, the participants and guardians were encouraged to communicate with the teacher in case any question or concern arose, so these could be forwarded to the researcher anonymously.

Timani – The Method

Timani is a recently established somatic method for musicians that has been developed since 2007 by the Norwegian pianist, Massage Therapist, yoga teacher, Kinetic Control Movement Therapist and personal trainer Tina Margareta Nilssen.

Timani provides an analytical tool to recognize playing-related, compensatory movement patterns, and an approach to change less effective habits into more sustainable and functional movement patterns, teaching anatomy and using targeted, practical exercises. For the most part, the exercises are initially carried out away from the instrument, and then immediately integrated into the playing or singing with awareness of both the body and the produced sound.

The knowledge about anatomy and the more than 100 exercises are designed to help musicians understand and overcome challenges related to pain, injury, technical issues, sound production, or even just to enhance one's playing to access higher potential as a musician. By focusing on the physiological aspects of playing or singing, it is aimed to enable musicians to make the most effective use of their bodies while practicing and performing. The method is used by musicians worldwide – from soloists to entire ensembles, and from students to established professionals – whether they have already experienced performance-related pain or injury or want to prevent them arising in the first place. Timani is also becoming increasingly popular in schools and colleges, taught by an ever-increasing network of teachers in 15 countries.

In a standard Timani session the students get: (1) a simple analysis of their playing or singing, and an anatomical explanation of relevant muscles related to the analysis, (2) targeted exercises (normally 1 – 3 exercises per session) to access and coordinate muscles or increase sensory stimuli (enhancing proprioception) that can expand one's movement options while playing, and (3) implementation of the new awareness or activation while playing or singing. The exercises normally don't require any equipment but are performed with conscious awareness of a body part, muscle, or movement in order to activate and become aware of new movement options that are made available for using while playing or singing.

The foundation of Timani is based on seven pillars:

(1) Relevant anatomy for musicians – Knowing basic anatomy and biology that provides an understanding of the complexity of muscular action and movement needed for playing or singing. One learns about key muscles that are important for musicians and exercises to differentiate and coordinate these muscles for the purpose of performing music. For example, learning about and becoming aware of the function of the intrinsic muscles of the hand can create more clarity of how to balance these muscles for more effective movements. Or learning which muscles to relax and which muscles to use for controlling shoulder movement can offload some of the muscles that usually tends to compensate for a lack of stability in the area.
(2) Movement analysis for musicians – Learning how to observe certain movement patterns and be able to determine if the coordination is sustainable or straining for your body.
(3) The fascia system – Fascia is an important tissue in the body that connects us from top to toe. To gain an effortless technique, some basic understanding of fascia is needed, as it provides elasticity and connection in our movements.
(4) Healthy natural breathing – Accessing healthy breathing is dependent on the functioning of the whole body. Learning which muscles are involved in breathing and how to access better lung capacity and breath control is essential for winds and singers.
(5) Getting to know ground force reaction – Some of the exercises are aimed at creating a new relationship to contact with the floor (feet), the chair (sit bones), and the instrument (fingers, hands, and arms). These are based on developmental movements and the natural way that we trained our movements in early developmental stages.
(6) Brain-body connection – The brain plays an essential role in the movement as movement happens as a communication between the sensory and motor system, each of which participates equally in developing accurate movement skills.
(7) Awareness – Awareness can make us more connected to the musical intention and the physical experience of playing. What we are not aware of, we cannot control or change. Awareness and focus are essential to creating changes in already automatic movement patterns.

The Teachers

The four teachers in this study were all certified and experienced Timani teachers who received their education in the method Timani from the Musician's Health and Movement Institute. They had a dual role, firstly, they acted as teachers throughout the study, administering the online lessons, secondly, they took up the role of participants after the study was concluded and were interviewed by the researcher. The semi-structured interview schedule used for these interviews were constructed based on the observations and were directed at the pedagogical approaches used, the perceived success of the teaching, and the adaptation to the online environment. They received an information sheet and signed a consent form before the interviews were scheduled.

Expertise of the Researcher

The researcher is a professional flutist with an MA performance degree. In preparation for this study, she completed 6 months of the first year of the Timani teacher qualification at the Musician's Movement and Health Institute prior to the data collection and observed Timani classes to gain a better understanding of the method itself.

Analysis

Following Creswell's (2003) criteria for mixed-method research designs, four main steps were taken into consideration during designing the study and analyzing the data: implementation, priority, integration, and theoretical perspective. Implementation refers to the sequence in which the methods are used in the overall design, priority addresses the question of which source of data is chosen to be superior in case there are opposing concepts emerging, integration is the process of connecting data from different sources, and the theoretical perspective governs whether the theory informs the analysis from the beginning, or it is emerging during the research process. In our research design, the survey at the beginning and the end of the intervention served as a frame for most of the qualitative data collection: the observations and the feedback from the students. The last part of the data collection, the semi-structured interviews with the teachers, were informed by the observations and the feedback as presented in **Figure 1**. Priority was given to the qualitative data because not all concepts targeted by the inquiry are measurable reliably in a quantitative way, such as perceived performance quality.

Integration is one of the most important processes in triangulation in mixed methodology research (Fielding, 2012). In the process of integrating different types of data, two main approaches were taken. Firstly, the data obtained from the surveys, the observations, and the feedback were integrated after the conclusion of the data collection. Two topics for the qualitative analysis were signposted by the survey, performance-related self-efficacy and performance-related pain intensity and interference, therefore, qualitative data which seemed to be linked to these concepts were highlighted and collected into a separate category whenever possible to allow for the triangulation. Secondly, the qualitative data from the observations and the feedback were used to inform the semi-structured interview schedule, thus, we obtained more information about the already emerged categories, while allowing the interviewees to introduce new topics.

In our theoretical approach, we had our target topics to examine, therefore the theory, namely that the Timani intervention will have an impact on the participants' instrumental playing, self-efficacy, and performance-related pain, explicitly informed the analysis. However, there were some new and unexpected topics emerging, which were included in the final analysis.

RESULTS

The findings of this study came from the triangulation of the four different sources: the lesson observations, the qualitative feedback from the students, the main questionnaire administered at the beginning and at the end of the research, and the interviews with the teachers.

In the following section, the findings from each of these sources will be presented, and afterward, used to create a coherent model. Each of these sources highlights the intervention from a different angle, providing information on the student's personal experience, the teachers' experience, an outsider view, and a measurable, quantitatively shown change. The data answering the third research question about the online environment will be presented separately, under a different subheading.

Survey Data

Two validated questionnaires were used in the pre-and post-intervention survey, measuring performance-related self-efficacy and performance-related injury.

The Music Performance Self-Efficacy Scale (Zelenak, 2014) has four subscales, mastery experiences, vicarious experiences, verbal/social persuasion, and psychological state. While the repeated measures ANOVA showed no significant differences between the pre-and post-measures in the overall score, there was a significant difference in the subscale 'vicarious experiences' before the intervention ($M = 59.587$, $SD = 27.902$) and after the intervention ($M = 77.267$, $SD = 18.339$) ($t = 2.337$, $p < 0.05$).

The Musculoskeletal Pain Intensity and Interference Questionnaire (Berque et al., 2014) collects data about lifetime, 12 months, 1 month, and past week prevalence, and participants who experienced performance-related pain in the past month are invited to fill out questions about the pain intensity and its interference with their mood and everyday life. Out of the 17, 12 participants reported experiencing performance-related pain in their lifetime, and 7 suffered from it in the month preceding the data collection. We analyzed the data coming from this subset and found that there was a significant difference between the measure before the intervention ($M = 3.387$, $SD = 1.580$) and after the intervention [($M = 1.397$, $SD = 1.639$); $t = 4.216$, $p = 0.006$].

We added self-constructed questions to the final survey, inquiring about the participants' overall experience with the intervention, their practice behavior during the 4 weeks, if they intended to use the gained knowledge in their private practice in the future, and how well it complements their instrumental tuition.

All 17 participants felt that the intervention had a positive impact on them; the qualitative entries about the overall experience were focused on professional outcomes, but also reported physical and psychological changes. In some form, all participants noted that they achieved better performance results with less effort, increased endurance, and enhanced sound production.

> *I have found more stability and a smoother and bigger sound. And the pianissimo became more transparent as well and it does not sound so low.*

> *I feel that I'm finding my own tone more and more, and I can actually get the sound that I want without wearing myself out.*

Many noted that they felt more confident when performing, experienced less anxiety, and were able to focus on their performance goals and musical expression more.

> *I felt inner calmness when I played. Also, less nerves.*

The questions directed at the practice behavior during the intervention showed that four participants practiced the

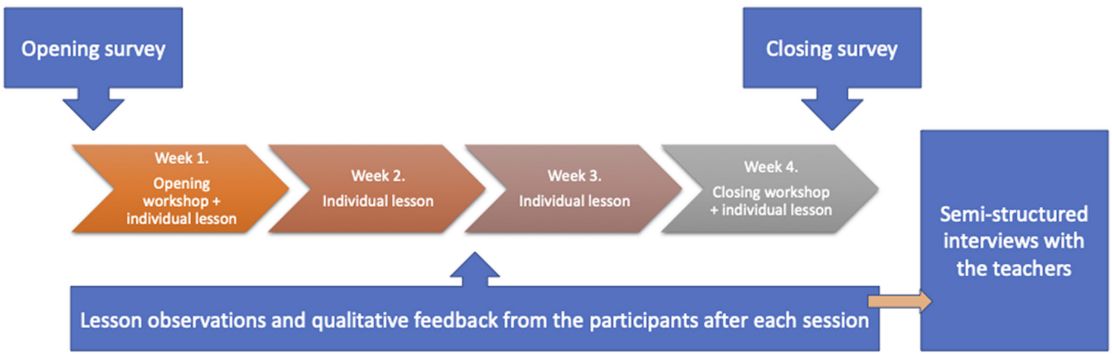


FIGURE 1 | The process of the data collection.

subscribed Timani exercises every day, 10 participants every other day, and 3 participants twice a week. All 17 participants had the intention to continue with the exercises, some even sharing plans to seek out further lessons. When asked about how they can incorporate the new information into the lessons with their primary instrumental teachers, the participants shared that they gained a new insight into how to solve specific performance problems they have already been working on in their lessons. Moreover, they felt that with the help they received during the intervention, they will be able to meet their teachers' expectations better.

> *We work very often to get a freer sound, and we always work to have enough air, but I feel that we never take the body as a starting point with my instrumental teacher. We work according to what we hear and try different things, but often there is a lot of focus on visualizing a story or character you want to play out. I have actually learned a whole new lesson about how breathing works in the sessions and it helped me a lot.*

> *I think that the exercises give me a better technique and stability, which gives me the surplus to perform the musical things my teacher asks for.*

There were differences in the participant's plans for using the exercises in the future: some said that they will return to them from time to time, while others were planning to use them frequently.

> *I will definitely use this in the future. Timani provides an insight into how the body works when we are playing, which in turn gives more back from the hours you put into practicing.*

Qualitative Feedback

Each participant was invited to answer two open questions immediately after each session, one asking about their general experience with the lesson, and the other regarding their experience with being taught online. Thus, each participant submitted four pieces of feedback, resulting in 68 short entries, the lengths spanning from a single sentence to full paragraphs. Most participants described the exercises done on the lesson, following with their experience with them and the resulting changes. Some of the entries touched on more than one topic, while others focused on only one specific experienced outcome. Twelve entries were only descriptive or too general (e.g., "*The Timani lesson was very good today*"), therefore we excluded them from the analysis.

After conducting qualitative analysis, six categories were established: (1) grounded, (2) easy to play, (3) improved sound production, (4) psychological benefits, (5) physical benefits, and (6) embodied knowledge.

The first category included 33 comments about feeling more balanced and supported, getting better contact with the chair or the floor, and positive bodily sensations. Twenty-four comments regarding the second category highlighted how the playing itself became less laborious, more natural, and required less effort in general. The third category included 19 pieces of data talking about improvements in the sound production and instrumental technique, such as more stable and even sound, which was easier to control. Some participants noted that the changes following the exercises were more noticeable in the musical output than in bodily sensations. The fourth category links closely to the second research question about performance-related pain: participants were reporting reduced tension and reduced sensations of pain while playing in 17 entries. The fifth category, labeled "psychological benefits," collected 12 comments about feeling calmer and more self-confident but also feeling seen and understood. The final group of themes included all 11 comments about the embodied learning experience; some participants stated that it was "cool to learn things about the body," and they appreciated that they received practical knowledge which supported their playing. Some representative quotes for each category can be found in **Table 2**.

Two additional overarching meta-categories were formed, which both included the original six groups of themes. These deal with the timeline of the experiences, with some reporting "revelations," i.e., immediate changes in the experience, while others gradual development.

Observations

During the intervention, the researcher took notes about every lesson focusing on the content, the communication, the feedback from the participant, the pedagogical tools, the perceived outcome, and the use of the online environment, producing

over 120 pages of documentation. These were organized and analyzed in two different ways: firstly, the learning process of each participant across the four lessons, and secondly, week by week, looking at the overall progress of all participants. While the lessons' contents varied greatly depending on the instrument and the participants' needs, there were some typical characteristics. The teachers choose more postural exercises (both with and without the instrument) in the first lessons and tended to move toward addressing finer motor movements in the later ones. However, they always linked the content with the participants' articulated wishes and technical issues and provided them with practical solutions.

The observational notes identified similar categories to the qualitative feedback: physical and professional benefits (i.e., changing in playing posture and enhanced sound production) were frequently perceived. The participants seemed to play more freely and naturally with fewer mistakes, and the breathing mechanisms of the wind players notably improved: they played through longer phrases without any visible effort.

These outcomes were achieved by various tools, which were sorted into four categories: first and foremost, the educational content, which was based on the dual expertise in music performance and performance-informed body mechanics with a strong focus on the musical outcomes as well as biomechanical ones. Secondly, the constructivist and flexible structure of the sessions that alternated between instrumental playing and physical exercises, thirdly, the communication, which was student-centered and age-appropriate, and lastly, the pedagogical tools used, namely, demonstrations and visual aids.

The structure of the sessions was characterized by alternation between playing and physical exercises, which allowed the participants to test the impact of each exercise on the instrument and observe any changes which took place. This process was supported by student-centered and open communication: teachers asked for the student's feedback after each segment of the session. A large proportion of these questions directed the students' attention toward their own bodily sensations after each exercise and each short playing session, stressing that there is no right or wrong answer. This eliminated any desire to please the teacher by giving the "right" response, helped their concentration and cultivated self-exploration and curiosity toward their own body mechanics, and enhanced the students' autonomy and agency. It also provided the teacher with clear feedback, and they could make the judgment whether the exercise was appropriate for the student. Moreover, the teachers avoided abstract language or metaphors as much as possible and used visual aids, such as skeleton models, anatomical pictures, and short videos to clarify their points. Demonstrations of the exercises were also frequent in the sessions to support the oral description of the activity.

Interviews

The four semi-structured interviews were conducted immediately after the conclusion of the intervention study. The interview schedule included questions about the teachers' backgrounds, the pedagogical tools used, including lesson planning, the communication with the students, especially in relation to their age, the perceived outcome, and their experience with the online environment. A thematic qualitative analysis was performed on the transcribed interview texts, which produced the following themes: personal experience, positive impact, communication, and planning.

All teachers highlighted their own personal experience with the method, stating that it proved to be a concise, relevant, and positive approach for enhancing their own professional playing experience, and articulated the need to support other musicians with their newly found knowledge:

> *I started realizing for myself how much of a difference it made. And . . . you just can't keep it to yourself.*

The listed positive impacts of the intervention appeared to happen on different levels, firstly, they observed immediate changes in postural alignment, body mechanics, and playing quality. They were, however, much more hesitant to make claims about the long-term impact of the intervention, stating that it is highly dependent on the participants' personality and circumstances.

> *Sometimes, you can do an exercise once and they go like: wow! And they go home, and they do that every day, and it sort of just clicks, and with other students, you can have this 'aha', and then they have forgotten.*

The interviews, however, identified another type of long-term impact which, to some of them, seemed even more important, namely, making the knowledge available:

> *Now it is natural that this knowledge exists, they have tried it [. . .] and if they have any problems they will know what to do. Because then they have this sense that there are answers, there are people who know. So, if I need something, there is somewhere that I can go. And that's even more important to me than just solving a shoulder problem if you know what I mean.*

TABLE 2 | Qualitative feedback categories.

	Category and frequency	Quotes
(1)	Grounded (33 comments)	"After the exercise, I felt more grounded, and stopped fidgeting around."
(2)	Easy to play (24 comments)	"It is much easier to play now, and I even get a better sound."
(3)	Improved sound production (19 comments)	"I feel like I got access to a steady and big sound in my playing without pushing and using a lot of extra force."
(4)	Physical benefits (17 comments)	"The usual tension in my arms was gone, and my fingers felt very relaxed."
(5)	Psychological benefits (12 comments)	"I loved the class today, it made me so calm and connected to the music!"
(6)	Embodied knowledge (11 comments)	"It is so cool to learn these things, I feel my entire body much better."

Following the theme "structure" identified by the observations, the teachers were asked about planning the sessions. They all seemed to take a constructivist and flexible approach with little pre-determined material. They prepared supporting material, such as anatomical pictures, the exercise manual available to all Timani teachers, and some general ideas based on the previous sessions, but most of the teaching content was informed by the feedback and playing of the participants.

> *I have found it more difficult for me to teach, and I don't often get good results with the student if I think that I know how it should go in the lesson. Because it's kind of like. . . expectations on me, some unspoken expectations on them, and I prefer to sort of just take it as it comes.*

When asked about the communication, they all reported having no difficulty with interacting with the participants, and that they could get their ideas across. They all felt that this specific age group, especially the minors, sometimes required a slightly different vocabulary to make it more age-appropriate but this did not change the content of the sessions. However, they noted that the way they communicated was impacted more by the personality of the participant than their age.

> *I feel that it is more person-dependent rather than age-dependent.*

Overall Model

The integration of all the data resulted in an overarching model, which has two main parts: the impact of the intervention and the tools used to achieve it. The model is presented in **Figure 2**.

The impact of the intervention resulted in physical, professional and, to a certain extent, psychological, and behavioral changes. The performance-related pain and discomfort reduction as a result of the intervention was shown quantitatively but also was supported by the participant's feedback. The observational data, the feedback and the teachers' interviews all supported the hypothesis that Timani can improve the dynamic posture when playing.

Professional and technical benefits were shown by all qualitative data including enhanced sound production, more efficient playing technique, and more control and dexterity in the performance-related movements after the intervention.

There were some comments about psychological changes from the participants both during the lessons and in the written feedback about feeling calmer and experiencing less anxiety after the intervention. Also, many noted in the qualitative feedback that as the result of the intervention, they feel more self-confident that they can reach their performance goals. These comments were linked in the data to the quantitatively measured self-efficacy, which showed a significant change in the subscale "vicarious experiences."

Due to the length of the intervention, we can only report some behavioral changes which took place during the intervention and cannot provide longitudinal data. The teachers' interviews reinforced that whether someone includes the Timani exercises into their instrumental playing practice is highly dependent on the participants' personality and circumstances. However, the qualitative data from the closing survey shows that all the participants have the intention to engage with Timani exercises in their daily practice.

Online Environment

Teaching the method online had both advantages and disadvantages, and some of these were highly dependent on the individual's environment and opportunities. Probably most important of all, in online learning, both the teacher and the student are dependent on the right infrastructure, including a strong internet connection and functional devices. Apart from a few occasions, these basic requirements were met. In the qualitative feedback, many participants mentioned that being able to study from the comfort of one's home is a positive aspect. However, the observational data showed that this might be a disadvantage in cases where the student lacked privacy and was distracted by family members moving or talking in the background.

The other challenge, which was both observed and commented on by the participants, stemmed from the visuals the teachers are getting on the student. Ideally, the teacher should be able to observe the student from different angles. In a traditional, personal setting, this is easily solved: the teacher can change position while the student is playing. In this online environment, the student had to be asked to change the camera position and repeat the excerpt to capture the ideal angle, which, in some cases, disturbed the flow of the lesson. It seems that these difficulties did not result in the decreased quality of the lesson delivery, in fact, one of the participants noted that they were positively surprised how easy it was to follow the guidance from the teacher. The same positive feedback was repeated in the qualitative forms:

> *Honestly, I'm very impressed by how well the teacher spotted small details through the screen.*

While most Timani exercises can be done without equipment or external physical guidance, there are a few exceptions and some basic needs to be met. One of the most frequent problems was the quality of the chairs available in the students' homes and the practice rooms they signed in from, and the available space needed for the exercise.

The online environment also had some advantages such as the lack of traveling which made the scheduling easier and being able to learn from the comfort of one's home. Also, the teachers were able to use various teaching materials tailored to the content of the lesson on the spot. As an example, they were sharing screens to show anatomical pictures or short videos to enhance their teaching, which was very well received by the participants.

Based on the observation and the qualitative questions, we concluded that the online format was an efficient method for teaching Timani.

DISCUSSION

The analysis and integration of the different types of data support the idea that the somatic method Timani can benefit instrumental technique, posture, and body mechanics. We found

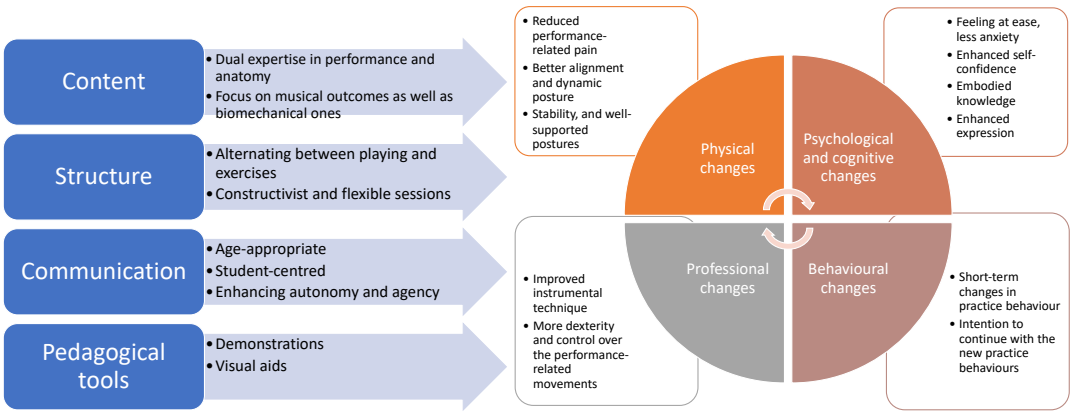


FIGURE 2 | Overall model.

limited evidence to support our hypothesis that it can enhance performance-related self-efficacy, but the data suggest that it can decrease playing-related pain and discomfort. Moreover, the online delivery was satisfactory, and even created additional advantages for both the students and the teachers.

The final model summarizing the overall findings shows the positive impact on four different levels: physical, professional, and to a certain extent, psychological, and behavioral. These different layers deeply influence each other, and in some cases, overlap, and some suggestions of these effects are going to be made in the following paragraphs.

On a physical level, the findings show a positive change between pre-and post-intervention in terms of performance-related pain, posture, and body mechanics. The word 'posture' in this context refers to dynamic skeletal alignment both in an inactive and performance situation (Krasnow et al., 2001), while 'body mechanics' or 'biomechanics' is used to describe the active interaction with the instrument, i.e., movement patterns and coordination skills associated with the performance.

The students who had performance-related pain at the beginning of the study reported a decrease in their discomfort, which – in the qualitative data - they linked to the biomechanical and postural changes prompted by the exercises. The close relationship between posture, body mechanics, and performance-related problems is well established in the literature (Steinmetz et al., 2010). A biomechanically correct posture allows the loads to evenly distribute between the skeleton, musculature and joints which decreases the possibility of overloading and overuse (Chan and Ackermann, 2014), and it can also reduce performance-related fatigue (Hafez, 2019), therefore is an important factor in preventing playing-related physical injuries (Chan and Ackermann, 2014).

The importance of postural alignment and correct body mechanics as a means to treat and prevent performance-related problems cannot be understated, however, these tools can have a significant impact on healthy musicians as well: participants without pain also reported feeling more grounded and more at ease. Many linked these positive embodied feelings to psychological changes as well, such as 'feeling calmer and more focused' and reduced anxiety. Enhancing embodiment through somatic methods can result in reduced levels of performance anxiety; the phenomenon has been shown in several interventions using the Alexander technique (Hoberg, 2008; Klein et al., 2014).

More generally, modulating the body's position can have a meaningful impact on mood regulation (Veenstra et al., 2017) and plays a part in reducing anticipatory anxiety (Lipnicki and Byrne, 2008; Weineck et al., 2020) and mental health in general (Domingues, 2018), moreover, it can improve interoception (Weineck et al., 2020). While many studies use gross postural differences to examine the phenomenon, such as slumped or erect and standing or supine conditions, it is quite possible that smaller changes in the posture might lead to similar benefits, which, given the high levels of performance anxiety and other mental health concerns in this population, might be a valuable tool.

Both physical and psychological effects were often observed and/or reported in connection with the performance quality, given that in Timani, the new movement coordination, muscle activation, and posture is immediately translated to the instrument. The corrected posture or body mechanics led to various performance outcomes, such as more dexterity in the upper extremities, better sound production and breathing mechanism, resulting in superior performance. This observation is also supported by the literature: the importance of body mechanics in instrumental playing was proposed as early as 1952: Polnauer (1952) argues that fully understanding the biomechanical process of the sound production would not only help avoid injuries, but also shorten training time, and improve musical skill and quality. His ideas were repeated more recently as well, linking posture to sound and performance quality (Ueno et al., 1998; Kreutz et al., 2008; Shoebridge et al., 2017).

More specifically, there is evidence of the relationship between breathing mechanisms and postural alignment: Ackermann et al. (2014) showed that variations in posture change the expansion of the chest and abdomen when playing a wind instrument, therefore, it is quite possible that which misalignments in the body can lead to reduced breathing capacity and disrupted air control (Chan and Ackermann, 2014). In Baadjou et al.'s (2017)

study, clarinetists reported better sound quality and 'feeling of more space or capacity to breathe' (p. 106) after a postural correction. The reported and observed dexterity and more controlled and coordinated fine motor movements in the fingers and the arms can also be a result of the enhanced body mechanics: a more supported trunk leads to decreased muscle activation in the upper extremity, relieving unnecessary tension (Baadjou et al., 2017).

These positive performance outcomes prompted another notable change. In the qualitative data, many participants commented on becoming more self-confident in reaching their performance goals. This was prompted by gaining access to previously unknown, practical, and replicable tools that had an impact on their playing. Since self-efficacy is defined as a belief that the individual is able to perform the required task and reach the desired outcome (Bandura et al., 1977; Ritchie and Williamon, 2010), during the data integration process, we linked these qualitative entries about self-confidence to the results of the Performance-Related Self-Efficacy scale. It is quite interesting that while the qualitative entries frequently mention the topic when measured quantitatively, we were only able to show a significant difference in the PRSE in the subscale 'vicarious experiences.' The term refers to the process when the individual is enhancing their self-efficacy by observing others completing a task and modeling it (Hendricks, 2015). There might be several reasons why the participants showed improvement in this specific sub-scale, but the frequently used demonstrations in the sessions can be viewed as a contributor.

In conclusion, it seems that the intervention prompted changes in posture and body mechanics which supported the participants on three levels, physical, psychological, and professional, further signposting the importance of the inclusion of body mechanics in music education and professional practices.

Yet, resources such as postural analysis and instrument-specific and performance-informed body mechanical corrections are generally not readily available for musicians, even though there is a clear interest expressed toward the topic: in Ioannou and Altenmüller's (2015) 68.7% of the student participants expressed that they believed that basic knowledge in anatomy and physiology would be a necessary part of music education, and 43.4% expressed that this knowledge would help them in avoiding performance-related problems.

In sports performance, the analysis of occupational biomechanics is a frequently used technique to enhance performance and has given rise to valuable insights over the years (McGinnis, 1999; van der Kruk et al., 2018; Taborri et al., 2020). In music, in spite of the success in incorporating the tool into music education and performance in a handful of studies (Kjelland, 2000; Visentin et al., 2008; Kelleher et al., 2013), the primary source of information about the instrumental or singing technique, including the posture and the specific movement patterns needed for the sound production, is the instrumental or singing teacher, whose primary focus is the auditory output, rather the supporting body mechanics (Chan and Ackermann, 2014). However, all musical tasks, such as the musical expression or specific techniques, are underpinned by a unique muscular activation and in the absence of specific anatomical knowledge, teachers often use their own technique or their education as a model (Mills and Smith, 2003; Visentin et al., 2008). Also, their access to new potential approaches and ideas can be restricted due to the relative isolation they work in, and the prevailing model of master-apprentice tuition (Haddon, 2009). While in some cases this can be an effective model for music tuition, it does not necessarily account for anthropometric differences. As an example, differences in the length of the neck can have implications for the headrest used in violinists, or the facial structure might inform the shape of the ideal mouthpiece. Therefore, replicating the teacher's specific technique might not always be ideal for the student.

Moreover, in instrumental or singing lessons, metaphors are often used to communicate and describe the desired movement coordination, and these can be interpreted in many ways. As an example, instructions such as 'play with a heavy arm' can provide useful insights for some students, but others might over-activate muscles in the bowing arm to achieve the effect, which can result in inferior sound production and control. With this in mind, it seems necessary for musicians to access anatomically informed support regarding their posture and body mechanics when playing to avoid injuries and enhance their instrumental or singing technique. The challenge is to translate efficient biomechanics into a dynamic playing situation, which needs combined expertise in performance and anatomy (Shoebridge et al., 2017).

The characteristics of the Timani sessions in our research demonstrated how these two can be blended and administered in an efficient and personal manner. The observational data and the interviews with the teachers provided an insight into the tools used to achieve the noted positive physical and professional outcomes.

The structure of the sessions, namely, alternating between exercises and playing created an atmosphere similar to an instrumental teaching session which the participants seemed to be very comfortable with. Research shows that music students favor practical, instrument-specific and individual injury prevention programs (Stanhope, 2018), and are more likely to be engaged with the material when they find it relevant and directly related to their instrumental playing (Ackermann et al., 2002), and the sessions seemed to satisfy this need.

Also, excessive focus on postural corrections divorced from the playing can be a barrier to achieving positive results: in Shoebridge et al.'s (2017) study musicians felt that such postural interventions separated them from the expression, and they were "losing sight of performance as the goal of coordination" (p. 832). In the observed Timani sessions, the relevance of the exercises to the playing was made clear by observing the quality of the sound and the ease of expression supported by the new movement behavior as well as the change in the instrumental technique and the overall physical sensations in the body. In a sense, all the physical work done in the sessions was informed by the performance goals. As a result, many participants reported that they were able to focus on the music more once their movement patterns and postural alignment was optimized.

This positive framing, placing the physical activity in the context of enhancing performance skills seemed to inspire and motivate the participants greatly. When the narrative is framed negatively, i.e., avoiding injury, the strongest predictor

for engaging in some kind of physical activity seems to be experiencing symptoms or witnessing another musician suffering from an injury (Stanhope, 2018).

Opposing this, in our study, the participants seemed intrinsically motivated and enthusiastic, highlighted the professional benefits most frequently in their feedback, and diligently engaged with the exercises, including them in their practice routine. This behavioral benefit was consistent across the sample in the course of the intervention, but to examine whether this behavioral change is permanent, a longitudinal study would be necessary. According to the teachers' interviews, the long-term outcome varies depending on the client's personality, physical needs, and playing situation, but it seems promising that the participants in this study all had the intention to continue learning and practicing Timani exercises.

The oscillation between playing and physical exercises might have additional benefits. In exercise programs where the content of the intervention is divorced from the playing-related movement behavior, the positive effect might not translate well to practice and performance situations, especially the exertion levels (Chan et al., 2014a). Moreover, when discussing dynamic-playing related postures, Shoebridge et al. (2017) highlighted the importance of "rebalancing the self with the instrument and performance environment" (p. 821).

When probing further into the structure and the content of the sessions, the teachers described the procedure of leading the session and choosing appropriate material as a flexible and constructivist process. From an epistemological viewpoint, constructivism means that the knowledge is formed through the learner's active interaction with the educational material, rather than a process of acquiring knowledge that exists outside the learner as an abstract entity (Shively, 2015). A constructivist approach also implies student-centeredness by actively involving the students in their own learning process, which was achieved by verbal and non-verbal communication, characterized by repeated open questions and adjusting the taught material based on the participant's feedback in the sessions. Allowing the participant's experience to guide the session steps away from the traditional master-apprentice model, and provides autonomy and agency for the student. Moreover, it seems to cultivate curiosity and engagement with the material.

In conclusion, this preliminary study suggests that Timani may have a significant impact on musicians' performance-related body mechanics, and as a result, on the sound production, and additionally, might influence psychological states and practice-related behaviors. Its most unique characteristics, namely, that the postural alignment and motor coordination are taught in the context of instrumental playing seems to motivate musicians to engage with the physical exercises. Moreover, since it is created and taught by performing musicians or therapists with a special interest in working with musicians, it has a clear understanding of the challenges and difficulties of playing or singing on an advanced level, and the shortcomings of the generally provided educational frameworks. It aims to fill this gap with anatomical knowledge, but without losing sight of the performance goals. As the study demonstrated, it can have a very beneficial effect on young musicians, including the reduction of performance-related pain, the enhancement of instrumental technique, and providing accessible tools to reach one's musical potential.

Limitations

This has been an exploratory study with the aim of capturing multiple angles of the intervention. Therefore, some of these measures could have been more in-depth to provide more detailed information. We were also relying strongly on the participant's self-report, which carries the risk of bias: young students might want to please the teachers and be less outspoken about their experiences. Nevertheless, the observational data supported the qualitative feedback from the students.

Also, performance is a complex phenomenon, and it is hard to measure its quality. The individual's perception of their own playing can be influenced by several factors, such as the environment or their relationship to the teacher. The chosen method of self-report and observations might over- or underestimate the changes in quality and cannot be fully objective. In the future, to obtain more objective, quantitative measures, the scope of the inquiry will probably need to be narrowed down to a certain instrument type and/or specific techniques.

CONCLUSION

The somatic method Timani brings a new approach to the field of musicians' health and wellbeing. Among its many unique characteristics, the ability to transfer the impact of the physical exercises directly to the instrument seems to enhance motivation by experiencing immediate results in the playing technique itself. Musicians can easily merge these techniques directly into instrumental practice since the equipment needs are low, and the knowledge provided is practical and relatable.

While the importance of preventing PRMDs and other performance-related problems in this vulnerable population is indisputable, the method also highlights the role of body mechanics and posture in performance quality and offers a new avenue to enhance playing technique. This positive framing seems to increase the motivation to engage with the method among young musicians.

More research is needed to explore the long-term impact of the method and test its effectiveness in different ages and professional levels.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Arts and Humanities Ethics Committee

of the University of York. Written informed consent to participate in this study was provided by the participants, and in the case of minors, by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AD responsible for the research design, the data collection and analysis, and the writing of the majority of the manuscript. TN organized the intervention, recruited the participants and the teachers, collected consent forms, and contributed to the manuscript with the description of the method and other corrections. Both authors contributed to the article and approved the submitted version.

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BRIEF RESEARCH REPORT
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Illuminating Music: Impact of Color Hue for Background Lighting on Emotional Arousal in Piano Performance Videos

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This study sought to determine if hues overlayed on a video recording of a piano performance would systematically influence perception of its emotional arousal level. The hues were artificially added to a series of four short video excerpts of different performances using video editing software. Over two experiments 106 participants were sorted into 4 conditions, with each viewing different combinations of musical excerpts (two excerpts with nominally high arousal and two excerpts with nominally low arousal) and hue (red or blue) combinations. Participants rated the emotional arousal depicted by each excerpt. Results indicated that the overall arousal ratings were consistent with the nominal arousal of the selected excerpts. However, hues added to video produced no significant effect on arousal ratings, contrary to predictions. This could be due to the domination of the combined effects of other channels of information (e.g., the music and player movement) over the emotional effects of the hypothesized influence of hue on perceived performance (red expected to enhance and blue to reduce arousal of the performance). To our knowledge this is the first study to investigate the impact of these hues upon perceived arousal of music performance, and has implications for musical performers and stage lighting. Further research that investigates reactions during live performance and manipulation of a wider range of lighting hues, saturation and brightness levels, and editing techniques, is recommended to further scrutinize the veracity of the findings.

Keywords: color, music, performance, lighting, emotion, arousal, red, blue

INTRODUCTION

Music is known to influence emotion in its audience, resulting in common use in many scenarios to manipulate an audience's mood, such as in shopping, exercise and film (e.g., Cohen, 2010). Furthermore, Huron (2015) has suggested that emotions conveyed by music are enhanced when non-music modalities projected from the same source exhibit emotions that are congruent

with the emotion nominally depicted by music. This may be particularly significant in stage lighting. Colored stage lighting regularly accompanies musical performances, from Broadway musicals, to worship bands at mega churches, to sold-out world tours of pop superstars. But what effect does the addition of colored lighting actually have on the emotions conveyed by music to an audience?

The impact of colors on emotion perception have been shown in internet web design (Demir, 2020) and physical spaces (Kurt and Osueke, 2014). Kurt and Osueke (2014) found that spaces with a dominant red color were more likely to be described by as "excitement inducing," aligning with the view of Birren (1950), who suggested that warmer hues, such as red and yellow, can increase arousal in an individual more than cooler hues, such as blue and green.

In music research Bresin (2005) asked participants to judge how well certain colors fit particular performances of two melodies using rating scales. Overall, red best reflected music expressing anger (high arousal) while blue was most associated with music expressing love (low arousal). Building on this work, Palmer et al. (2013) investigated cross-modal associations between music, color, and emotion. In this study, a significant relationship between all three mediums was observed; suggesting that a cross-modal relationship between color and music was mediated by common emotional associations. For example, "happier" music was associated with a "happy" color (yellow). Musical features also played a role, such as slower music associated with the color blue, because it was mediated by the low arousal emotion of sadness (see also Whiteford et al., 2018; Sugawa et al., 2021). Schubert et al. (2019) asked participants to describe pieces of music with a number of icon-based rating scales, including representations of temperature, color, feelings, and shapes. In this study, slower music was also consistently described as "blue."

The impact of stage lighting was investigated by Hsiao et al. (2017) who tracked the aesthetic choices made by five professional stage-lighting technicians. They found that the arousal level of the music had a significant relationship with both the choices in saturation and hue made by the technicians. They also found that as the arousal level of the music rose, so did the frequency of red lighting color choice, whilst the opposite result followed the frequency of blue lighting. While the effect of some hues upon arousal are consistent, we have not found research that investigates the more implicit impact of hue upon the emotion expressed by music performance, and yet this is a situation where impact on hue might be having a (currently poorly understood) effect.

The aim of this study was to investigate the effect of hue on an audience's perception of the level of expression in piano performances. It was hypothesized that (audio/video recorded) performances projected with red hue would be rated higher in arousal than the same performance viewed under a blue hue. To collect a wide range of data and control for possible variables such as habituation and distraction, this study consisted of two experiments: (1) a grouped by color experiment; and (2) a grouped by congruency experiment.

EXPERIMENT 1 (COLOR GROUPING): METHOD

Stimuli

Four videos were filmed of four different solo "classical" piano pieces (performed by author JM). Stimulus details and abbreviations for each of these excerpts are presented in **Table 1**. The nominally high (BeethovenH and ÉlégieH) and low (BachL and PreludeL) arousal pieces were chosen to reflect previous research suggesting a) music generating high arousal is commonly faster, louder and features shorter, more staccato phrases, whilst b) music generating low arousal is commonly slower, softer and features longer, more legato phrases (Bigand et al., 2005; Livingstone and Thompson, 2006). Two sets of the four recordings were prepared by digitally adding a blue hue filter to one set of stimuli and a red hue filter to the other (see 'Method for coloring videos' sections in **Supplementary Material**).

Participants

The 53 people (41 female, 11 male, 1 non-binary; age range 18–35, M = 21.4, SD = 4.1) participated in Experiment 1. Mean age was 21.4 years, range 18–35, SD = 4.1. Of the 53 participants, 44 played a musical instrument/sang, of which 18 had received lessons for 1-5 years, 8 had received lessons for 6–9 years and 15 had received lessons for 10 or more years. Common instruments played included piano/keyboard (18), voice (11), woodwind (e.g., flute/clarinet/saxophone) (6) and guitar (4). The remaining 9 participants did not play an instrument or sing (that the sum of instrument counts is greater than 53 because some participants reported playing more than one instrument). 26 of the participants listened to the audio from speakers, whilst 27 listened on headphones. All participants reported normal hearing. 33 participants reported watching the videos on a laptop screen, 8 on a computer monitor, 10 on a smartphone and 2 on a tablet.

Procedure

An online survey was created using the Qualtrics[1] survey platform. Participants were sorted into two groups at random. The first group viewed all excerpts under a blue filter (blue condition). The second group viewed all the excerpts under a red filter (red condition).

Each group was asked to watch the allocated videos, presented in a randomized order, and to rate the arousal, valence, enjoyment and familiarity of the piece for each excerpt. Arousal was rated on a scale from 0 ("no arousal" e.g., calm) to 10 ("very high arousal" e.g., excited). Valence was rated on a scale from 0 ("negative") to 10 ("positive"). Enjoyment was rated on a scale from 0 ("did not enjoy") to 10 ("enjoyed"). Familiarity of the piece was rated on a three point scale: unfamiliar (1), somewhat familiar (2), or very familiar (3).

Once they had completed these questions, participants were asked to provide demographic and computer/audio technical information. The experimental protocol was approved by the

[1]https://www.qualtrics.com

TABLE 1 | Excerpt details and abbreviations.

Abbreviation	Full title of piece	Composer	Bar Numbers	Duration	Nominal arousal level
BachL/Bach Siloti LOW	"Andante" from the Sonata for Violin Solo in A Minor	Johann Sebastian Bach (Transcribed by Alexander Siloti)	1-11	1 m 2 s	Low
PreludeL/Rach. Prelude LOW	Prelude in D major Op. 23 No. 4	Sergei Rachmaninoff	1-19	1 m 10 s	Low
BeethovenH/Beethoven HIGH	Sonata Op. 27 No. 2 'Moonlight', 3rd Movement	Ludwig Van Beethoven	1-14	0 m 27 s	High
ÉlégieH/Rach. Élégie HIGH	Élégie Op. 3 No. 1	Sergei Rachmaninoff	63-82	0 m 38 s	High

Two versions of the abbreviations are used, a very short one followed by a slightly longer one, the latter being used to aid in more easily reading graphs of data. All clips commence at the beginning of the work. Clip durations are shown in minutes (m) and seconds (s). Duration of each clip was determined by identifying ostensibly natural cadence points.

University of New South Wales Human Research Ethics Advisory Panel B (approval HC210217).

EXPERIMENT 1: RESULTS AND DISCUSSION

Arousal ratings were consistent with the nominal arousal level of all four stimuli, regardless of condition (**Figures 1A–C** shows the results for valence and enjoyment ratings). Responses were compared for each excerpt between the red condition and the blue condition. As detailed in the **Supplementary Material Table 2**, arousal ratings were statistically identical across condition for each extract. 44 out of 53 participants reported viewing all the videos in full, 9 viewed all at least in part, and none indicated not viewing. As all participants would therefore have glimpsed the red or blue hues at the very least, this should have been enough to trigger a color association, thus strengthening the reliability of arousal ratings. Whilst the lack of difference across the two conditions seemed decisive, the hypothesized change may have been hidden due to participant habituation to the color of the video. Since they viewed each performance with the same coloring, it is possible that the impact of the color on perception of arousal in the music, if indeed there was one, was diminished (Thompson and Spencer, 1966; Rankin et al., 2009). Experiment 2 was therefore designed to validate Experiment 1 by investigating whether color habituation led to the lack of support for the hypothesis.

EXPERIMENT 2 (CONGRUENCY GROUPING): METHOD

Stimuli

The stimuli for Experiment 2 were identical to Experiment 1, with the exception that the participants were shown the videos in different combinations to those of Experiment 1 (see "Procedure").

Participants

A total of 53 new participants (34 female, 19 male; age range 18–64, M25.8, $SD = 10.8$ years) were recruited in Experiment 2. This includes one participant who completed the survey twice. Their second response was excluded from the analysis. 45 participants played a musical instrument/sang, of which 18 had received lessons for 1-5 years, 6 for 6-9 years, and 17 for 10 or more years. The remaining 4 participants reported less than 1 year of lessons. Instruments played included 24 piano/keyboard, and 8 participants did not play or sing. 33 of the participants listened to the audio from speakers, whilst 20 listened on headphones. All reported normal hearing. 32 participants reported watching the videos on a laptop screen, 8 on a computer monitor, 10 on a smartphone and 3 on a tablet.

Procedure

Participants undertook a survey identical to that of Experiment 1, except that instead of only viewing the videos under either a red or blue filter, they saw a combination of stimuli with each hue (**Figure 2**). The participants were again sorted into two groups at random. The first group viewed the excerpts in the "congruent condition" with nominally high arousal excerpts paired with red lighting and low arousal excerpts paired with blue lighting. The second group viewed excerpts in the 'incongruent condition': high arousal excerpts with blue light treatment and low arousal excerpts with red light treatment.

EXPERIMENT 2: RESULTS AND DISCUSSION

Means were calculated for the ratings of arousal, valence and enjoyment for each condition and are presented in **Figures 1D–F** (see **Supplementary Material Table 3** for additional statistical analyses). Once again, nominal arousal conditions were consistent with participant ratings of arousal for each piece, regardless of condition (**Figure 1D**). Also evident was that once again, there was no difference in arousal ratings due to condition. The congruent group rated the stimulus BachL as more enjoyable than the incongruent group, and very small trends in the same condition could be observed for all pieces (**Figure 1F**), which could be explained by color congruence with mood facilitating cognitive fluency (Belke et al., 2010), and hence greater enjoyment. However, neither this result nor the valence ratings were statistically different.

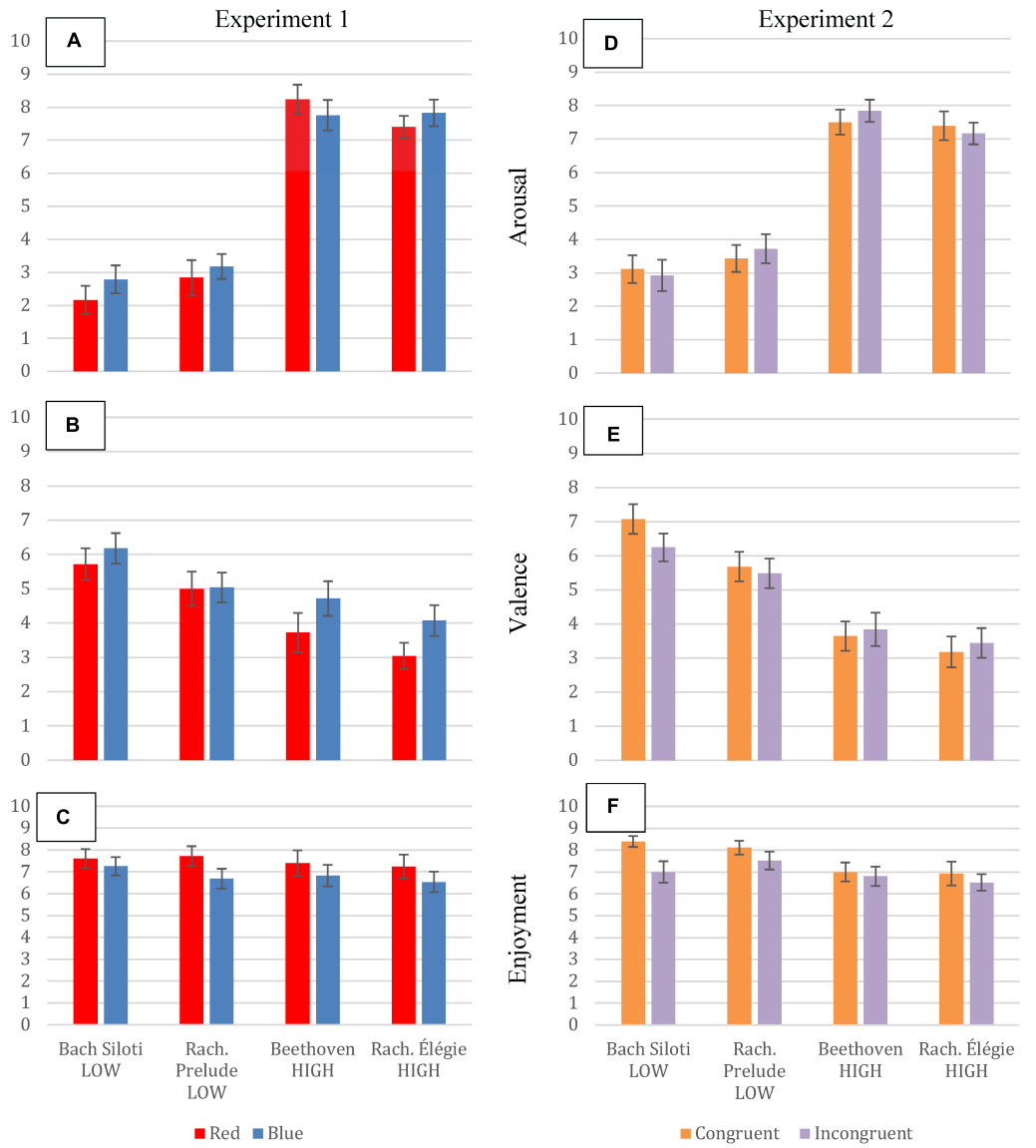


FIGURE 1 | Error bar plots of mean arousal, valence and enjoyment ratings (respectively) in Experiment 1 **(A–C)** and Experiment 2 **(D–F)**. Error bars = ± ±1SE.

Familiarity ratings (lower half of **Table 2**) showed little overall difference in ratings between conditions, once again eliminating this variable as a possible confound (in line with the results of Experiment 1 - see top half of **Table 2**). Participants watched all (46) or some (7) of the videos, with participants who only watched some citing reasons such as lack of time, limited attention, and again, an assumption that they had already understood what they needed to answer the questions, hence listening to a smaller portion of each excerpt. This time, when asked what they thought the study was about, 3 of the 53 participants correctly guessed that the study was testing the effect of colored lighting. A separate analysis was run, excluding the responses of these partcipants. However, there was no significant change to the results. Despite the revised design we still found no evidence to suggest that there was any difference in arousal ratings due to manipulating color. We also ran an analysis for the effect of condition with Experiment 1 and 2 data combined ($n = 53$ per condition). Again, arousal ratings were not significantly higher in the red compared to blue condition (**Supplementary Material Table 4**). The *a priori* statistical power of this analysis was better than 0.8 ($N > 102$, single-tailed, independent-sample t-test).

GENERAL DISCUSSION

The results of this study did not support the hypothesis that hue affects arousal perception of music performance. Several studies used to build our hypothesis measured the level of arousal through direct inspection of color itself (Kurt and Osueke, 2014; Demir, 2020), or based by pairing color and music (Bresin, 2005;

TABLE 2 | Mean ratings of familiarity (Experiment 1 and 2).

Experiment 1

BachL		PreludeL		BeethovenH		ÉlégieH	
Red Condition	Blue Condition	Red Condition	Blue Condition	Red Condition	Blue Condition	Red Condition	Blue Condition
1.52	1.57	1.24	1.43	2.08	1.93	1.28	1.43

Experiment 2

BachL		PreludeL		BeethovenH		ÉlégieH	
Congruent Condition	Incongruent Condition	Congruent Condition	Incongruent Condition	Congruent Condition	Incongruent Condition	Congruent Condition	Incongruent Condition
1.30	1.44	1.33	1.16	2.04	2.16	1.37	1.20

Familiarity of the piece was rated on a three-point scale: unfamiliar (1), somewhat familiar (2), or very familiar (3). See ***Table 1*** *for abbreviations of the four music excerpts played.*

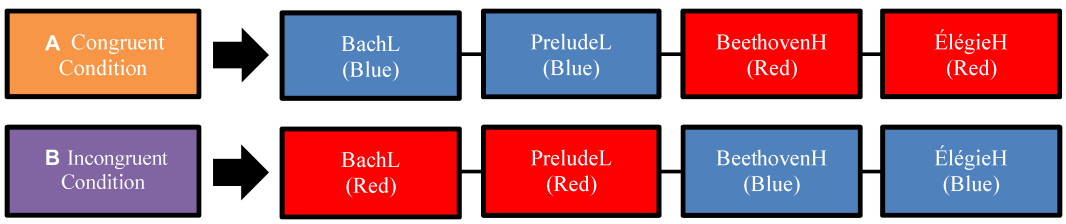


FIGURE 2 | Example of sequences of videos viewed in each condition for Experiment 2. **(A)** Shows an example of the video pipeline in the congruent condition as viewed by participants; **(B)** shows an example of the video pipeline in the incongruent condition as viewed by participants. The actual sequence of the four excerpts (the four boxes) was presented in a different random order for each participant.

Palmer et al., 2013; Schubert et al., 2019). To our knowledge this is the first study that did not intentionally draw participant attention to the presence of colors, rather directing focus to the arousal of the performance. And so perhaps the effect of color, being more implicit, is also small, and the emotions perceived through the auditory channel of the music itself has a far stronger effect.

This apparent dominance of the auditory channel in communicating emotion is also in line with previous studies that explore the relationship between auditory and visual stimuli when communicating emotion. Iop and Pauletto (2021) presented different colored images of doors with a variety of knocking sounds, and found that the aural modality (i.e., the knocking sound) dominated over the visual modality (i.e., the door color) in determining participant perception of emotion. The authors suggested that this was due to the perceived presence of a human at the source of the sound, as opposed to the color of an inanimate object, the door.

Similarly, the emotion in the present study may have been perceived to have come from the human produced sound. With this scenario, the background hue would not be perceived as created by the performer/composer, but rather just another aspect of the environment through which the sound emanates. Non-vocal instrumental musicians can express and convey emotion to a listener, with theories attributing this capacity to empathy and emotional contagion processes because of the resemblance of the music to the characteristics of the human voice (Juslin, 2019) and of shared mental architecture in music and empathy processing (Schubert, 2017). Hence, an empathetic response may dictate the channel that dominates response (whether the musician or the performed music, rather than a background color). This would include multimodal channels of communication, including the body movement of the performer (Broughton and Stevens, 2009). Such an interpretation is still consistent with the ethological signaling theory promoted by Huron (2015): both the signals and cues presented by a performer (i.e., the movements made as the music is performed, including facial expressions) are part of the process of communicating emotion clearly and unambiguously, whereas color manipulation of the video may have had a more ancillary impact.

CONCLUSION

This research sought to better understand the effect colored lighting has on the perceived emotional expression of a musical performance, especially relating to the impact of specific hues on arousal. The study did not provide evidence that visual color manipulation of piano performance impacts arousal ratings of the music: that a performance under a red light would be rated higher in arousal than the same performance under a blue light.

As a novel study into color and arousal, there were several limitations. Firstly, the only aspect of color changed within the videos was the hue (red versus blue). It is known that not only

hue, but also saturation and brightness can contribute to levels of arousal and valence in emotion (Bresin, 2005; Palmer et al., 2013; Hsiao et al., 2017). Consequently, further research could examine these aspects also, perhaps combining the changing of hue, saturation and brightness within different conditions to see if this enhances the color effect upon emotion when paired with music. Moreover, as it seemed that the effects of the lighting were dominated by other channels of information within the videos, such as the auditory expression of the music and physical expressions of the body of the performer, more stimulating lighting conditions (e.g., mid-performance changes to color, additions of multiple color/pattern combinations, etc.) could enhance these effects.

Another limitation was the online deployment and the consequent variety of different displays used by participants, as data collection was conducted during a "lockdown" due to COVID-19 in Sydney, making data collection in a reasonably well-controlled physical space not possible. It cannot be known from the current study certainty if this variability in screen sizes diminished the impacts of hue on arousal. It is also worth considering the influence of hue in a live performance environment, though this could come with a loss of experimental control because of the challenge of having two identical live performances. A possible solution is through application of immersive virtual environments. For example, Cha et al. (2020) explored participant reactions to color within immersive virtual environments and found a positive relationship between color and arousal, specifically with red as a higher arousal hue. Future research using an immersive virtual environment could better simulate a live environment without the loss of experimental control. Finally, future research could include physiological data collection such as measurement of Motor Corticospinal Excitability or Galvanic Skin Response, to accompany self-report from participants. These physiological measures may have some correlation with mental arousal states (see, e.g., Jola and Grosbras, 2013; Wang et al., 2014).

This study suggests that musicians and stage lighting technicians looking for the best choices in the hue of lighting to enhance the perceived emotional expression of a musical performance should make choices based on artistic discretion, since hue appears to be unlikely to have a significant impact on the overall mood of a music.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the data collected is confidential. Requests to access the datasets should be directed to ES, e.schubert@unsw.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by UNSW Human Research Ethics Advisory Panel. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JM was designed, conducted and documented the project in consultation with all authors. EH and AC edited the additional video and documented. JM, ES, GD, AC, and JZ revised and edited the manuscript. All authors checked all aspects of the design, assisted with the roll out of data, collection and analysis.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.828699/full#supplementary-material

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Acceptance and Commitment Coaching for Music Performance Anxiety: Piloting a 6-Week Group Course With Undergraduate Dance and Musical Theatre Students

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Treatments for students with problematic levels of music performance anxiety (MPA) commonly rely on approaches in which students are referred to psychotherapists or other clinical professionals for individual care that falls outside of their music training experience. However, a more transdisciplinary approach in which MPA treatment is effectively integrated into students' training in music/performing arts colleges by teachers who work in consultation with clinical psychologists may prove more beneficial, given the resistance students often experience toward psychotherapy. Training singing teachers, and perhaps music teachers at large, to use an evidence-based coaching strategy like Acceptance and Commitment Coaching (ACC) to directly manage students' MPA is one such approach. Building on the work of a previous study in which ACC was administered by a singing teacher to a musical theatre student with problematic MPA, we piloted the effectiveness of a six-session, group ACC course for a sample of performing arts students (N = 6) with MPA related to vocal performances, using a mixed-methods design. The coach here was also a singing teacher without a clinical background, and her training in ACC by a clinical psychologist was of a similar duration (8 h) as the previous teacher's (7 h). Similar to the musical theatre student, the students reported being significantly less fused with their MPA-related cognitions, more accepting of their MPA-related physiological symptoms, and more psychologically flexible while performing in general, and these improvements were maintained after 3 months. Furthermore, they appeared to lower their shame over having MPA and change how they thought in relation to one another. Of note, these improvements were similar to those shown by seven vocal students with MPA after they received Acceptance and Commitment Therapy from a clinical psychologist, but with larger reductions in shame and better acceptance of MPA, which suggests a non-clinical, group ACC intervention that includes supportive discussions to normalize MPA and challenges attempts to control it may be more helpful than individual psychotherapy. These results are promising and indicate a brief training in ACC (<10 h) may be sufficient for singing teachers to provide significant benefit for students with problematic MPA.

Keywords: music performance anxiety (MPA), acceptance and commitment coaching, acceptance and commitment therapy, psychological flexibility, group coaching, performing arts students, vocal performance anxiety

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INTRODUCTION

Music Performance Anxiety in University Settings

Music performance anxiety (MPA) is a form of social anxiety that commonly affects professional and student musicians. MPA symptoms can be categorized into cognitive symptoms, physiological arousal symptoms, behavioral symptoms (which include both avoidant behaviors and anxious behaviors), and distress/impairment over having MPA - for examples of each symptom category, see Shaw et al. (2020). The more categories of MPA symptoms a musician experiences, the more problematic their MPA will be. Given their younger age, university music students are more likely to experience problematic levels of MPA, because they often have less experience performing at elite levels compared to professionals (Papageorgi et al., 2013; Biasutti and Concina, 2014). Students in competitive music and performing arts schools are also sensitive to their comparisons to other students, and to comparisons to their own self-standards, when self-evaluating the quality of their music performances (Denton and Chaplin, 2016). Thus, prevalence estimates for university students with problematic levels of MPA are purported to be slightly higher than those for professional musicians (20–35% for students vs. 15–25% for professionals; Fishbein et al., 1988; Wesner et al., 1990; Schroeder and Liebelt, 1999; Kaspersen and Gotestam, 2002).

Available treatments for music students with MPA vary but can be classified into three general categories: (1) *medication-based treatments*, such as beta-adrenoceptor blocking agents aka "beta-blockers" (Nube, 1991), and benzodiazepines (James and Savage, 1984), (2) *psychotherapy-based treatments*, such as Cognitive Behavioral Therapy (Kenny and Halls, 2018), Acceptance and Commitment Therapy (Juncos et al., 2017), and Psychodynamic Therapy (Kenny et al., 2014), and (3) *alternative treatments that either promote relaxation and improved physical health*, such as biofeedback (Wells et al., 2012), yoga (Khalsa et al., 2009), meditation (Lin et al., 2008), hypnosis (Brooker, 2018), and the Alexander Technique (Hoberg, 2008), *or are expressive arts therapies*, such as music therapy (Montello et al., 1990), guided imagery alone (Esplen and Hodnett, 1999), and guided imagery with progressive muscle relaxation (Sisterhen, 2005). Typically, these treatments are administered by psychologists and mental health clinicians with training in psychotherapy for anxiety disorders. However, music students may not choose to work with a psychotherapist due to stigma and lack of time/access to therapy, and rather, they may prefer to consult with their teachers about how best to cope with MPA (Williamon and Thompson, 2006; Shaw et al., 2020). A few of the aforementioned treatments indeed have been administered by music teachers and showed promising results, i.e., Alexander Technique (Hoberg, 2008), and guided imagery with progressive muscle relaxation (Sisterhen, 2005). These studies highlight the growing interest in enlisting music teachers' participation in helping students manage MPA, as such an alternative treatment model may help to overcome the aforementioned hurdles preventing music students from seeking psychotherapy for MPA (Patston, 2014; Shaw et al., 2020).

Music Teachers as Music Performance Anxiety Practitioners

Given the close bond between music teachers and students, it is unsurprising music students may prefer to consult with them, rather than with a psychotherapist, about how to manage their MPA. One-on-one lessons afford students the privacy and individualized attention they would receive in psychotherapy, but without the stigma. It is inevitable that psychological issues related to a student's performances, and possibly issues of a more personal nature, will arise under such conditions, especially if the teacher-student relationship exhibits similar qualities known to correlate with good psychotherapy outcomes. Shaw et al. (2020) rightly point out such *relational* qualities known to correlate with effective psychotherapy outcomes also exist within the teacher-student dyad, i.e., a relationship marked by empathy, congruence, and unconditional positive regard, and a good working alliance marked by an agreement on the goals to be achieved and the methods to achieve them (Rogers, 1951; Bordin, 1979; Karver et al., 2006; Ardito and Rabellino, 2011). Thus, music teachers who notice these qualities in their relationships with students are likely to make a positive impact when individually coaching one with problematic MPA, and teachers who haven't yet noticed these qualities will want to prioritize building up the rapport and working alliance with a student(s) before starting this work. Of course, when faced with students' more personal issues unrelated to music performance, teachers must recognize them as falling more within the jurisdiction of a psychotherapist, and appropriate referrals must be made regardless of the strength of the relationship.

Classroom teachers also deal with a myriad of emotional and behavioral issues and are often encouraged to seek training in psychological methods to better equip them to handle such issues. One common example is Applied Behavioral Analysis, or "ABA," which is an evidence-based framework for addressing the needs of students with Autism and other neuro-developmental disorders, such as AD/HD (Cook et al., 2014; Makrygianni et al., 2018). With training in ABA, classroom teachers may cut down on students' disruptive behaviors, improve IQ scores, communication skills, adaptive behavior, and their social skills, with training ranging from 1.5 h to multi-day workshops - and teachers who participate are able to show a high proficiency in demonstrating specific ABA skills post-training (Sarokoff and Sturmey, 2004; Lerman et al., 2008; Makrygianni et al., 2018; Alberto et al., 2022). Other examples are the mental health training and certification program offered by the International Board of Credentialing and Continuing Education Standards (IBCCES) and the training in Mental Health First Aid offered in numerous countries, including the United States and United Kingdom (National Council for Mental Wellbeing, 2021). These programs offer training for special and general education teachers, and numerous other school staff, to help identify and support students struggling with common psychological problems, such as depression, anxiety, trauma,

suicidal ideation, substance abuse, and others (International Board of Credentialing and Continuing Education Standards, 2021; National Council for Mental Wellbeing, 2021). Classroom teachers can learn evidence-based solutions for handling their students' emotional and/or behavioral challenges, which helps to fill the training gap faced by many who regularly witness students' psychological struggles yet feel unqualified to help (Jorm et al., 2010; Glasper, 2017; Diaz, 2018).

In light of the similarities between the music teacher-student/psychotherapist–client relationship, and the increasing trend of training classroom educators to better handle students' mental health needs, it is important to start viewing music teachers as capable MPA practitioners, whether they work in the private studio, classroom setting, or both. While MPA is often understood as a problem occurring within the student, in that it reliably occurs in individuals who exhibit numerous risk factors for developing it, some of which include perfectionism, being female, age younger than 30, being classically trained (Mor et al., 1995; Sinden, 1999; Kenny, 2011; Kenny et al., 2012; Papageorgi et al., 2013), MPA is simultaneously occurring at a cultural level, in that it reliably occurs in contexts in which high standards for success are expected, e.g., conservatories and university music departments, competitive auditions for professional work. Thus, it would benefit music teachers – who already operate within these contexts – to receive training in managing MPA in order to offset the pressures facing students and to introduce a better balance into the training experiences offered by music and performing arts colleges. By outsourcing MPA treatment to psychotherapists, the problem is approached too idiographically and will continue to be perceived that way. Of course, psychological conditions must be treated at the individual level by psychotherapists with the requisite graduate-level education, adequate training, and a license to practice independently. However, problematic cases of MPA could be effectively managed institutionally, by teachers who work in music/performance arts colleges and are adequately trained by clinical psychologists to help students in such a transdisciplinary manner (Shaw et al., 2020).

Group Coaching as an Intervention Strategy by Music Teachers for Students With Music Performance Anxiety

Music teachers who wish to address their students' MPA but lack time for an individualized coaching approach (e.g., Shaw et al., 2020) may consider a group coaching intervention as an alternative that could impact a larger number of students. Group coaching is often discussed interchangeably with team coaching, but they are distinct. Team coaching seeks to address and change a team's dynamics, enabling them to work toward an enhanced self-coaching capability, whereas group coaching includes people seeking individual outcomes whilst exploring them within a group setting (Clutterbuck, 2009). Thus, group coaching requires the coach to have an understanding of group dynamics and dialogue processes, along with the ability to create a rapport and connection with each individual (Brown and Grant, 2010). There are advantages of group interventions over individual ones, in that they are often more cost-effective and facilitate change via interactive group processes that don't occur as readily, if at all, within individual settings, e.g., social comparison, social support, and providing supportive yet challenging feedback (Borek and Abraham, 2018). These and other helpful processes are even more likely to occur when groups are homogenous in their composition, mixed-gendered, and group sizes are small, i.e., five to seven members (Burlingame et al., 2003; Borek and Abraham, 2018).

Social comparison theory asserts that people self-evaluate through their comparisons to others, including *upward comparisons* to a group member of perceived higher status or skill and *downward comparisons* to someone of perceived lesser status or skill (Festinger, 1954). Such evaluations can be helpful when one's comparisons (whether upward or downward) lead them to be influenced by their peers in a positive, motivative way, but they become unhelpful when the comparisons involve discrepancies in skill or group status that are either too large, or non-modifiable, and when used in this maladaptive way social comparisons correlate with shame, perfectionism, and psychopathology (Allan and Gilbert, 1995; Walton et al., 2020). Applied to MPA, this might involve a student making an upwards comparison to a peer with less outward anxiety and concluding her peer is a better performer than she is. Social support is the provision of psychological and/or material help to group members, and it is associated with improved physical and mental health (Thorsteinsson and James, 1999; Borek and Abraham, 2018). It may include providing members with helpful information, giving someone a positive appraisal of themselves, providing emotional support, or providing help in learning specific skills (Borek and Abraham, 2018). Receiving supportive, but challenging, feedback from a group facilitator or a peer(s) after making an important self-disclose is another important group process that may lead one to personal change.

While the relational qualities may be similar between and a therapist/client, teacher/student, and arguably between a coach/coachee, these professions are not the same, and thus, group coaching must be distinguished from classroom teaching and group psychotherapy, in order to reduce the potential for unethical behavior on part of the music teacher. Whereas teaching is imparting information through instruction, coaching involves unlocking one's potential in order to maximize their performance (Whitmore, 2017). In classroom teaching, a student's personal or performance goals would be less important than the teacher's curriculum, however, identifying and working toward students' goals would be prioritized in group coaching. Psychotherapy is distinct from coaching in that it often adopts a pathology-focused approach and aims to resolve one's symptoms of psychological distress, whereas, coaching typically adopts a skills-focused approach and aims to enhance one's existing skills to unlock their potential (Hart et al., 2001; Grant, 2003; Cavanagh et al., 2006). Classroom teachers must avoid the diagnosis and treatment of mental health problems and again must refer a student with known,

or suspected, signs of a psychological disorder to appropriate psychotherapy providers.

Acceptance and Commitment Coaching as a Non-clinical Music Performance Anxiety Treatment

Recently, a non-clinical version of Acceptance and Commitment Therapy (or "ACT" – pronounced as the word "act") was individually administered by a singing teacher to a male, musical theatre student to effectively treat his problematic MPA, and the results were promising (Shaw et al., 2020). When administered in non-clinical (non-psychotherapeutic) settings, ACT is called Acceptance and Commitment Coaching (ACC) or Acceptance and Commitment Training (also abbreviated as ACT and said as the word "act"). ACT (Hayes et al., 1999, 2011) is part of the "third-wave" of behavioral psychotherapies, which is also referred to as the "mindfulness and acceptance-based wave" of psychotherapies. As such a therapy, ACT does not aim to reduce symptoms of anxiety or emotional distress. Rather, it promotes mindfulness and acceptance of those symptoms while simultaneously increasing one's commitment to behave in accordance with their personally held values. Such a dual skill set creates a more *psychologically flexible* behavioral repertoire, which is the overall aim of ACT and ACC (Hayes et al., 1999, 2011; Hill and Oliver, 2019). Paradoxically, a reduction of one's anxiety or other symptoms of emotional distress usually does occur within ACT treatments, but it is not the direct goal (Bach and Moran, 2008). Applied specifically to the treatment of MPA, ACT fosters both mindfulness and acceptance of physiological MPA symptoms, defusing or disentangling oneself from cognitive MPA symptoms, learning to identity more as an observer of one's MPA symptoms rather than taking them personally, identifying one's performance-related values, and making the commitment to increase actions reflective of one's values during performances, rather than over-engaging in avoidant or emotion-driven behavior (Juncos et al., 2014, 2017; Juncos and Markman, 2015). These six skills are collectively known as the "ACT Hexaflex" (**Figure 1**) and are thought to be ongoing behavioral processes that directly contribute to psychological flexibility (Hayes et al., 1999, 2011).

Shaw et al. (2020) compared their results in using ACC to those of previous ACT for MPA psychotherapy studies and found the musical theatre student who received the ACC intervention showed a nearly identical response as participants who received ACT psychotherapy (Juncos et al., 2014, 2017; Juncos and Markman, 2015; Clarke et al., 2020). That is, musicians in these studies appeared to become more accepting of their physiological MPA symptoms, less fused with their cognitive MPA symptoms, and less avoidant/more value-driven with their performance-related behavior, even while experiencing MPA. Further, the singing teacher who provided the ACC intervention had no formal education or training in psychotherapy, rather, she received approximately 7 h of individualized training by a clinical psychologist with expertise in using ACT to treat MPA. She also received post-graduate training in a popular coaching model, GROW (Goal, Reality, Options, and Will; Whitmore, 1992), that is widely used by executive coaches to improve work performance. The GROW model was used to provide further structure to the ACC intervention. The similarities in results between Shaw et al. (2020) study and those of previous ACT for MPA psychotherapy studies (Juncos et al., 2014, 2017; Juncos and Markman, 2015) suggest music teachers may be able to use ACC to effectively treat MPA in non-clinical settings, without needing to continually outsource this work to psychotherapists. If a non-clinical practitioner who is not a psychotherapist, e.g., a music teacher or performance coach, wishes to become competent in using ACT to treat MPA, they must first receive adequate training in it by a variety of means, i.e., attending online or in-person courses and/or workshops, individualized training from an ACT expert, extensive readings, peer consultation groups, or post-graduate study with ACT training included. The training should also include supervision from someone with expertise in the approach who can evaluate the practitioner's core competencies and readiness to practice ACT. Unlike the Alexander Technique, ACT does not require a certification to be used by clinical or non-clinical practitioners, which may increase the number of practitioners aiming to use it.

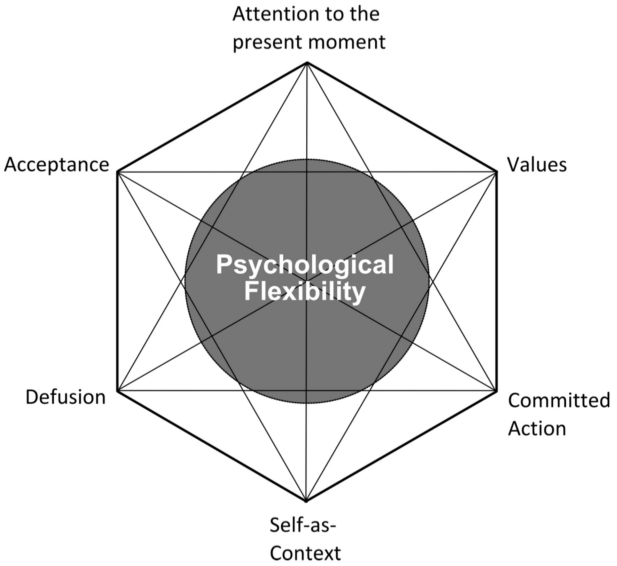


FIGURE 1 | The ACT Hexaflex (Batink et al., 2016).

Group Acceptance and Commitment Coaching for Music Performance Anxiety

Thus far, no studies have examined a group ACC intervention administered by a music teacher to treat MPA, yet there are several reasons why it may prove beneficial. Two previous ACT for MPA studies involved a group therapy component, and both treatments led to significant improvements in psychological flexibility and reductions in MPA: Juncos et al. (2017) study included six group performances (in addition to 12 individual

ACT sessions) in which the student vocalists performed in front of one another, whereas Clarke et al. (2020) study was entirely group-based and also had student vocalists perform in front of one another during one of their six sessions. The groups in both were of similar size (N = 7 in Juncos et al., 2017; N = 6 in Clarke et al., 2020). Moreover, group-based ACT psychotherapy treatments have shown similarly positive results in treating other anxiety disorders, including Social Anxiety Disorder (Kocovski et al., 2013), Generalized Anxiety Disorder (Avdagic et al., 2014), public speaking anxiety (England et al., 2012), and mixed anxiety disorders (Glaser et al., 2009). While individual ACC has already shown promising results when directly administered by a singing teacher to a student with problematic MPA (Shaw et al., 2020), a group ACC intervention may be more ecologically valid due to its cost-effectiveness.

From a group coaching perspective based on ACC, the coach would aim to mitigate some of the unhelpful processes arising for students with problematic MPA, like excessive fusion with cognitive MPA symptoms, a lack of willingness to perform with physiological arousal MPA symptoms present, and excessive behavioral avoidance/lack of values-guided action. These patterns of inflexibility were targeted in Juncos et al. (2017) and Clarke et al. (2020) treatments. Resolving these processes would include teaching students with MPA to identify how they are stuck in those patterns of behavior, while also improving the Hexaflex processes considered the healthier counterparts to those patterns, e.g., training in defusion helps lessen the harmful impact of excessive fusion with one's MPA-related thoughts, increasing one's willingness to perform with physiological MPA symptoms lessens the impact of excessive behavioral avoidance within one's performances, and helping to identify one's performance values and elicit a commitment from the student to behave more in accordance with them helps discipline one's behavior so it is more values-based and less emotion-driven.

Aims of the Current Study

Continuing with the research initiated by Shaw et al. (2020), this study aimed to preliminarily investigate the effectiveness of ACC as a non-clinical MPA intervention, also when administered by a singing teacher without training or education in psychotherapy. Here, the ACC intervention will be delivered via a group coaching course, rather than a single-subject methodology, to a small group of undergraduate dance and musical theatre students with homogenous levels of MPA related to their vocal performances skills. It should be noted this study did not aim to establish whether ACC has efficacy in treating MPA, as that would require a more well-controlled methodology. Rather, it aimed to determine whether a group ACC course would have ecological validity for use in music/performing arts colleges with students who experience problematic levels of MPA. ACT as a psychotherapy has already demonstrated efficacy in treating Social Anxiety Disorder (Kocovski et al., 2013; Craske et al., 2014; Herbert et al., 2018; Krafft et al., 2020), of which MPA would be considered a "performance-only subtype" according to the *Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition* (American Psychiatric Association, 2013). Thus, it stands to reason that ACC might be generally helpful for students with MPA. A mixed-methods design with combined qualitative and quantitative data was selected to allow for a continuous and thorough assessment of students' responses to the ACC course. The following five hypotheses were made for the study's quantitative data:

1) It was predicted there would be significant improvements in some of the measurable ACC Hexaflex processes, i.e., *mindful acceptance* of MPA-related physiological symptoms, *defusion* from MPA-related thoughts, and improvements in overall *psychological flexibility*, at post-coaching compared to pre-coaching, and these improvements would be maintained at a 3-month follow-up.
2) The group ACC intervention would lead to significant improvements in students' performance quality ratings at post-coaching when compared to their pre-coaching ratings, as adjudicated by three independent jurors.
3) Students' shame over having MPA would be significantly reduced during their performances, and also more generally as indicated by significant improvements in their social comparisons at post-coaching, and at a 3-month follow-up.
4) Although ACC does not aim to reduce symptoms of MPA, it was hypothesized the students' MPA levels would be significantly decreased at post-coaching, and at the follow-up, as previous ACT interventions have led to significant reductions in MPA (Juncos and Markman, 2015; Juncos et al., 2017; Clarke et al., 2020).
5) Lastly, the ACC intervention would yield clinically significant results similar to those observed after the ACT psychotherapy intervention was used in Juncos et al. (2017) with seven student vocalists undergoing training in classical singing. In other words, there would be visibly similar improvements on the total/subscale scores for questionnaires used here and in the 2017 study, i.e., BAFT, PHLMS, AAQ, KMPAI, and ESS.

MATERIALS AND METHODS

Participants

Ethical approval for the study was obtained from the Institutional Review Board at University of Wales Trinity St. David (UWTSD). The participants were second-year Professional Musical Theatre and Dance students (N = 6) from Performers College, an independent college in the United Kingdom specializing in performing arts and also where the primary author (SM) works as a vocal tutor. Four of the students were specializing in Dance Theatre, whereas two were specializing in Musical Theatre. Students from both specializations train together, while some classes and shows are more focused on either specialization. Five of the students were enrolled in a Bachelor's Degree track, and one was enrolled in a 3-year Diploma track. Four were female and two were male. Their ages ranged from 18-years-old to 20-years-old (M = 19.33, SD = 0.82).

Interested applicants responded to a screening assessment conducted online, and they were eligible to participate if they experienced distressing symptoms of MPA while singing, were in their second year of study, not currently receiving psychological or psychiatric treatment, not a current student of the primary author's, and if their Kenny Music Performance Anxiety Inventory (KMPAI) score was above the clinical cutoff (105). Six students met inclusion criteria and provided their consent to participate in the study.

Coach

SM served as the coach who delivered the ACC intervention. She was undertaking a Master's degree in Voice Pedagogy with the Voice Study Centre, a provider of postgraduate study accredited by the UWTSD, and this research project made up her Master's thesis. SM is trained in singing, acting, and musical theatre and has extensive vocal and instrumental performance experience. At Performers College, she teaches singing theory, technique, ensemble and solo singing, and she also maintains a private voice studio. Her work within higher education musical theatre training has led her to observe the debilitating effects of MPA on students firsthand, prompting her to research available MPA treatments and subsequently design an evidence-based, group coaching intervention for MPA that might readily be used by singing teachers of other student cohorts. Like the primary author in Shaw et al. (2020) study, she had no training or education in psychotherapy, and she received training in a popular coaching model, GROW (Whitmore, 1992), as part of her M. A. education. The third author (DW) helped her secure ethics board approval and provided supervision regarding some ethical matters inherent in coaching students with MPA, i.e., ensuring she was not functioning as a psychotherapist to the students, and that students were aware of available counseling resources through the British Association of Performing Arts Medicine (BAPAM). SM's coaching course only aimed to treat the students' MPA and did not target matters of a more personal nature.

Procedure

Training

As in Shaw et al. (2020) study, SM was trained in ACC by the secondary author (DJ), a clinical and performance psychologist with 16 years' experience in treating anxiety disorders and specific expertise in using ACT to treat MPA. DJ has conducted two single-subject designs with instrumentalists and a pilot study with vocal students ($N = 7$), in which ACT psychotherapy was investigated as a MPA treatment. He also provides training for singing and instrumentalist teachers, performances coaches, and other non-clinical professionals in using ACT/ACC to treat MPA and to enhance music performance. SM's training in ACC lasted approximately 8 h – it included attending a 5-h ACT for MPA online course taught by DJ in May, 2020, an additional 3 h of individualized ACC training on Zoom with DJ, and regular email correspondence during the ACC intervention about how students were responding and specific guidance for those students who appeared to need extra help. Their scores on the ACC self-report measures at the mid-way point informed DJ which students needed further help and what type of exercises would be helpful.

Group Coaching Course

An ACC group course using Hill and Oliver's (2019) book *Acceptance and Commitment Coaching: Distinctive Features* as a guide was created for the current study. This book features a six-session outline for coaches who wish to use ACC with clients (pp. 120–126), from which the course content was pulled. Additional content was taken from the secondary author's book, *ACT for Musicians: A Guide for Using Acceptance and Commitment Training to Enhance Performance Skills, Overcome Performance Anxiety, and Improve Well-Being* (Juncos and de Paiva e Pona, 2022) and from various other ACT resources referenced below. The six sessions targeted the same ACT Hexaflex processes addressed in previous ACT for MPA psychotherapy studies (Juncos et al., 2017), i.e., mindfulness of MPA symptoms, increased willingness toward/acceptance of MPA symptoms, defusion from MPA-related thoughts, observing one's MPA symptoms rather than defining oneself by them, identifying performance-related values, and committed action toward those values.

Regular exercises to increase mindfulness of MPA symptoms were used during sessions, e.g., "Mind watching" (Forsyth and Eifert, 2016), "Scanning a picture frame" (Juncos and de Paiva e Pona, 2022), "Hearing your thoughts" (Harris, 2009), and students were encouraged to practice at home in between sessions. Students strengthened willingness to have MPA symptoms and ultimately to become more accepting of them by discussing the futility of attempts to control MPA symptoms, and through group and individual exercises, e.g., "The difference between what I can and cannot control" (Forsyth and Eifert, 2016), and "Acceptance of performance-related thoughts and feelings" (Juncos and de Paiva e Pona, 2022). Defusion from MPA-related thoughts and unhelpful comparative thinking was taught through discussion, videos, and exercises, e.g., "Treating your mind like a separate entity and describing what it's doing," and "Thanking your mind for the thoughts it creates," (Juncos and de Paiva e Pona, 2022). Self-as-context and learning to take MPA less personally were improved through discussion. Students' performance-related values were identified through regular discussion, videos, and exercises, e.g., "Values checklist" (Harris, 2009), "Questions to to help identify your performance-related values (Juncos and de Paiva e Pona, 2022). Lastly, a commitment to performing more in accordance with students' performance values was strengthened by regular discussion and group exercises, e.g., "Passengers on a bus metaphor" (Hayes et al., 2011) and creating S.M.A.R.T. goals. Overall psychological flexibility was strengthened by using the "ACT Matrix" tool (Polk and Schoendorff, 2014) within the group setting, e.g., by having students come up with examples of *away moves* in relation to their attempts to control/avoid MPA symptoms, and *toward moves* in relation to their engaging in committed actions more often during performances. Students were given regular homework assignments to further strengthen ACC skills in between sessions. For a detailed outline of the six sessions, readers are directed

here: https://www.researchgate.net/publication/358271152_Acceptance_and_Commitment_Coaching_for_MPA_Course_Design_Sarah_Mahony.pdf.

In addition to ACC skills, students were taught to improve self-compassion for experiencing shame in relation to their MPA, and when overly engaged with unhelpful, comparative thinking, through group discussion, video, and group and individual exercises, e.g., "Working with difficult emotions," "Working with shame" (Neff and Germer, 2018), and "Acceptance of performance-related thoughts and feelings" (Juncos and de Paiva e Pona, 2022). Lastly, students were made aware during the last session of several skills from a Psychological Skills Training protocol that may further help to manage MPA, i.e., visualization, positive self-talk, and breath control (Hardy et al., 1996; Spahn et al., 2016). However, these skills were not directly taught to them, given the different theoretical stance PST has (compared to ACC) toward controlling vs. accepting symptoms of physiological arousal.

The six sessions were conducted entirely online through Zoom, as the ACC group course took place in the United Kingdom during the COVID-19 pandemic (November to December, 2020). Their sixth session took place at the beginning of winter break, shortly after their term had ended. Sessions lasted 1 h each and their content was delivered via power-point slides. Students were sent an information handout after each session and encouraged to keep a journal of their experience with the course. All sessions were recorded and the video/audio data, along with students' questionnaire data, was securely stored on SM's laptop following General Data Protection Regulation standards.

Performance Schedule

Students video-recorded two vocal performances at pre-coaching (Session 1), in order to assess for baseline performance quality: one with accompaniment and one solo (a cappella). Similarly, they gave another accompanied and solo video-recorded performance at post-coaching (Session 6). Due to potential latency problems with performing music virtually on Zoom, and to the UK's restrictions on social gatherings during the COVID-19 pandemic, their accompaniment was not live, rather, the students provided an instrumental back-up track for them to sing over. All students provided consent to be video-recorded. The primary author and other research participants served as each student's audience members. Students were instructed to select four songs that demonstrated their highest current singing proficiency, to achieve consistency of performance, and to select different songs to minimize any potential practice effects. Immediately after each performance, each student was instructed to complete an ESS questionnaire and remain in the audience for their peers.

Music Performance Quality

Video-recordings for performances from each participant were randomized and sent to be marked by three expert judges. All three judges had significant experience with teaching and assessment within various educational settings, including professional musical theatre training colleges. Additionally, they were all professional musical theatre creative, with credits in performance, directing and musical direction. The judges did not know the purpose of the study, nor the order in which the recordings were presented. Additionally, they were asked to use their expertise to imagine the performances under real-life conditions and score accordingly. To avoid unfair marking based on circumstances out of the group's control, judges were instructed not to take the following into account while scoring: appearance/outfit, lighting, camera angle, quality of video or sound, quality of internet connection, or location of performance.

The scoring criteria was adapted from the Associated Board of the Royal Schools of Music (ABRSM) singing exam marking scheme, a scoring criteria regularly used to adjudicate United Kingdom students' vocal performances. Each domain was scored from 1 out of 10 points (where 1 = *poor*, and 10 = *excellent*) and included the following areas: *Pitch/Intonation, Tempo and Rhythm, Vocal Tone and Projection, Musicality (Dynamics, Vocal Expression), Character and Storytelling, and Confidence and Stage Presence*. All students provided consent to have their performances adjudicated.

Self-Report Measures

Acceptance and Commitment Coaching-Based Process Measures

The Philadelphia Mindfulness Scale (PHLMS; Cardaciotto et al., 2008) was used to assess mindfulness. It is a 20-item measure comprised of two subscales: the Awareness subscale, which measures one's continuous monitoring of internal and external experiences, and the Acceptance subscale, which measures one's non-judgmental attitude toward one's experiences. It uses a 5-point Likert scale, and higher subscale scores indicate higher levels of each construct. Internal consistency for the test is adequate for both the Awareness subscale ($\alpha = 0.75$) and the Acceptance subscale ($\alpha = 0.82$).

The Acceptance and Action Questionnaire-2 (AAQ-2; Bond et al., 2011) is a 7-item measure that was used to assess acceptance and psychological flexibility. It uses a 7-point Likert scale, and higher scores indicate higher levels of psychological flexibility and acceptance. Furthermore, the AAQ-2 shows good internal consistency ($\alpha = 0.84$).

The Believability in Anxious Feelings and Thoughts (BAFT; Herzberg et al., 2012) was used to assess cognitive defusion, and it requires participants to indicate on a 7-point Likert scale how much they agree with each of 30 items. Higher scores on the BAFT reflect higher levels of fusion with one's anxious thoughts and feelings. It shows excellent internal consistency ($\alpha = 0.90$).

Symptom-Based Measures

The revised KMPAI (Kenny, 2009) is a 40-item measure used to assess psychological discomfort associated with MPA. It uses a 7-point Likert scale, and higher scores indicate greater levels of anxiety and MPA-related distress. The revised KMPAI shows excellent internal consistency ($\alpha = 0.94$). Its author also suggests a score of 105 or higher indicates clinically significant MPA (Ackermann et al., 2014).

The Experiential Shame Scale (ESS; Turner, 2014) is a 11-item self-report measure that assesses the degree to which one

identifies with physical, emotional, and social components of the emotion of shame, using a a 7-point Likert scale. Higher scores indicate higher levels of state shame. The last question was modified to reflect one's willingness to discuss their music performance at the moment the ESS is taken. The ESS has adequate internal consistency ($\alpha = 0.72$).

The Social Comparison Scale (SCS; Allan and Gilbert, 1995) assesses how one ranks themselves in relation to others, either favorably or unfavorably, in areas such as ability, inclusion, and desirability. Respondents rate how they feel about themselves on 11 dichotomous concepts using a 10-point, Likert scale. Higher scores indicate more favorable ratings compared to others. The SCS has excellent internal consistency ($\alpha = 0.91$).

Assessment Schedule and Qualitative Data Collection

Students completed the full battery of self-report measures (AAQ-2, BAFT, PHLMS, KMPAI, SCS) at baseline (Session 1), at the mid-way point (Session 3), at post-coaching (Session 6), and at a 3-month follow-up assessment. The KMPAI was also used as a screening measure, so each participant had two baseline KMPAI scores at the start of the ACC intervention. Students were also interviewed 1 week after the sixth session to assess their overall impressions of the coaching course and to elicit feedback about what might be done to improve it in the future. Interviews lasted 15 min each, followed a semi-structured format, and also took place/were recorded via Zoom. In total, the study's qualitative data included verbatim transcripts of each of the six ACC sessions and interviews, along with written reflections at the sixth session and the follow-up.

RESULTS

Changes in Psychological Flexibility

Within-group changes on mean scores for questionnaires measuring overall psychological flexibility (AAQ-II) and specific Hexaflex processes, i.e., defusion (BAFT), mindful acceptance and awareness (PHLMS *Acceptance* and PHLMS *Awareness*), were evaluated post-coaching and at the 3-month follow-up assessment, using paired *t*-tests. Significant improvements were observed within students' pre-coaching (Session 1) mean scores and scores at post-coaching (Session 6) and at the 3-month follow-up assessment on all but one questionnaire (PHLMS *Awareness*), thereby supporting Hypothesis #1. See **Table 1** for paired *t*-test results and *p* values for scores on these measures. Although no significant differences were observed within pre- and post-coaching (and at follow-up) scores on the PHLMS *Awareness* subscale, there was a trend toward improved mindful awareness at the follow-up assessment. Effect sizes were medium to large both at post-coaching and the 3-month follow-up point (see **Table 2**).

Changes in Music Performance Quality

The study's second hypothesis, that the ACC intervention would lead to significant improvements in students' performance quality, was not supported by the three judges' ratings. A repeated measures ANOVA was conducted with performance time (pre vs. post-coaching) and raters (Judges 1, 2, or 3) as within-subject variables, and judges' total ABRSM scores as the dependent variable. There was no significant main effect of time on the three judges' total scores: $F(1,5) = 0.65$, $p = 0.46$, nor were there significant main effects of time on the judges' scores for accompanied vs. a cappella performances: $F(1,5) = 0.17$, $p = 0.7$; $F(1,5) = 0.61$, $p = 0.47$, respectively. However, when looking at judges' scores on the combined technical subscales (Pitch/Intonation, Tempo and Rhythm, Vocal Tone and Projection, Musicality) vs. the combined non-technical subscales (Character and Story Telling, Confidence and Stage Presence) for students' a cappella performances only, the p -value for the effect of time on the students' non-technical scores [$F(1,5) = 2.07$, p = =0.21] was noticeably smaller than that for the combined technical scales [$F(1,5) = 0.27$, $p = 0.63$]. In particular, the effect of time on judges' Character and Story Telling scores for students' a cappella performances was approaching significant [$F(1,5) = 3.63$, $p = 0.12$] with good inter-rater reliability: ICC (2, 2) = 0.85. However, the effect of time on judges' scores on the same subscale for students' accompanied performances was not approaching significant [$F(1,5) = 1.55$, $p = 0.27$]. In general, when looking at the effect of time on judges' ratings for students' performances, the *p* -values tended to be smaller for students' a cappella performances than their accompanied ones, and for the non-technical subscales compared to the technical subscales (**Table 3**).

Changes in Shame Over Having Music Performance Anxiety

Within-group changes on mean scores for a questionnaire measuring state shame (ESS) administered immediately after students' accompanied and a cappella performances at both pre- and post-coaching were evaluated, using paired *t*-tests. Significant improvements were observed in students' ESS scores at post-coaching for both types of performances, thereby supporting Hypothesis #3a. ESS scores for students' post-coaching accompanied performances [$M = 2.82$, $SD = 0.85$] were significantly lower than ESS scores at their pre-coaching accompanied performances [$M = 5.13$, $SD = 1.1$; $t(5) = -6.39$, $p < 0.05$], and similarly, ESS scores for their post-coaching a cappella performances [$M = 2.47$, $SD = 0.64$] were significantly lower than ESS scores at their pre-coaching a cappella performances [$M = 4.53$, $SD = 1.38$; $t(5) = -4.42$, $p < 0.05$]. See **Table 2** for effect sizes related to changes in ESS mean scores. Within-group changes on mean scores for a questionnaire measuring the tendency to make unfavorable (upward) comparisons between oneself and others (SCS) were also evaluated, using paired *t*-tests. Significant improvements were observed in students' SCS scores at post-coaching [$M = 58$, $SD = 15.14$; $t(5) = 5.37$, $p < 0.05$] and at the 3-month follow-up [$M = 64.5$, $SD = 14.61$; $t(5) = 6.76$, $p < 0.05$], when compared to students' SCS scores at pre-coaching [$M = 34.17$, $SD = 17.89$]. Thus, Hypothesis #3b was also supported. See **Table 2** for effect sizes related to changes in SCS scores.

TABLE 1 | Descriptive data and mean scores for ACC-based measures, as well as results of paired *t*-tests comparing pre-coaching means (Session 1) to means at post-coaching (Session 6) and at a 3-month follow-up.

Schedule	Self-Report Measures			
	BAFT	***PHLMS* (Aware)**	***PHLMS* (Accept)**	***AAQ-II***
	M = 50.1[a]	*M* = 36.65[b]	*M* = 30.19[b]	*M* = 17.34[c]
	SD = 16.88	*SD* = 4.93	*SD* = 5.84	*SD* = 4.37
S1 (Pre)	*M* = 82.83	*M* = 36.67	*M* = 20.67	*M* = 29.5
	SD = 16.1	*SD* = 6.53	*SD* = 6.09	*SD* = 8.14
S6 (Post)	*M* = 44	*M* = 38.17	*M* = 30.5	*M* = 22.67
	SD = 7.75	*SD* = 4.12	*SD* = 6.89	*SD* = 10.19
	t(5) = –6.97*	*t*(5) = 0.74	*t*(5) = 3.43*	*t*(5) = –3.88*
FU	*M* = 44.17	*M* = 41	*M* = 30.67	*M* = 23.5
	SD = 6.85	*SD* = 4.34	*SD* = 7.58	*SD* = 7.92
	t(5) = –6.1*	*t*(5) = 1.92	*t*(5) = 2.96*	*t*(5) = –2.88*

Normative means and standard deviations for the [a]BAFT, [b]PHLMS, and [c]AAQ-II, were taken from non-clinical samples of undergraduates used in each measure's validation study.
**Statistically significant result at $p < 0.05$ level compared to S1 mean.*
S, session; FU, follow-up.

TABLE 2 | Effect sizes for changes in scores on self-report measures from Session 1 to Session 6 and to 3-month follow-up, using Hedges' *g*.

	Self-Report Measures						
	BAFT	**PHLMS (Accept)**	**AAQ-II**	**KMPAI***	**SCS**	**ESS (Accomp.)**	**ESS (A Cappella)**
S6	*g* = 3.07	*g* = 1.52	*g* = 0.74	*g* = 1.87	*g* = 1.44	*g* = 2.35	*g* = 1.91
FU	*g* = 3.07	*g* = 1.46	*g* = 0.75	*g* = 2.48	*g* = 1.86	n/a	n/a

**KMPAI scores from Session 1 were used as a baseline comparison, rather than students' scores at the screening assessment.*
S, session; FU, follow-up.

Changes in Music Performance Anxiety Symptoms

Within-group changes on mean scores for a MPA-based measure (KMPAI) were evaluated at post-coaching and at the 3-month follow-up, using paired *t*-tests. Significant reductions were observed between students' pre-coaching scores [$M = 161.83$, $SD = 19.66$] and their scores at post-coaching [$M = 117.67$, $SD = 26.91$; $t(5) = -6.36$, $p < 0.05$] and at the follow-up assessment, [$M = 106.17$, $SD = 24.83$; $t(5) = -6.85$, $p < 0.05$] thereby supporting Hypothesis #4. Students' mean KMPAI score at the 3-month follow-up (106.17) fell very close the author's recommended cutoff score (105) for determining clinically significant levels of MPA (Ackermann et al., 2014). Furthermore, an independent samples *t*-test showed there were no significant differences between students' KMPAI scores at the screening assessment [$M = 160.5$, $SD = 26.81$] and at Session 1 [$M = 161.83$, $SD = 19.66$; $t(10) = -0.1$, $p = 0.46$].

Similarities Between This Study's Results and Those From Juncos and Colleagues' ACT for Music Performance Anxiety Psychotherapy Study

For a visual inspection of the shared questionnaire results from both studies, the reader is guided from **Figures 2** to **11**. Similar to Juncos et al. (2017) study, all students in this study (6 of 6) made clinically significant improvements on *at least one* of the shared self-report measures after coaching, whereas all students (7 of 7) made such an improvement in Juncos and colleagues' study. Here, a *clinically significant* improvement meant a student's score fell outside the normative range for a questionnaire before coaching and within that range after coaching ended - either immediately afterward (at Session 6) or at the 3-month follow-up point. Such a metric is commonly used when assessing change in single-case designs (Kazdin, 2011). The PHLMS *Awareness* subscale was excluded when conducting this analysis, as students' mindful awareness was not predicted to improve after the ACC coaching. For the KMPAI, a clinically significant improvement meant either of the students' baseline scores fell above the recommended cutoff score (105) and below the cutoff at either Session 6 or at the follow-up.

Looking first at the graphs for ACC-based questionnaires common to both studies, **Figure 2** shows the current students' BAFT scores and should be viewed alongside **Figure 3**, which shows the 7 vocal students' BAFT scores from Juncos et al. (2017) study. **Figure 2** shows the majority of the current students' scores (5 of 6) fell above the BAFT's normative range prior to ACC intervention, whereas none of their scores fell within that range at post-coaching (Session 6) or at the follow-up. Similarly, **Figure 3** shows all the students' BAFT scores (7 of 7) in Juncos et al. (2017)

TABLE 3 | Results of ANOVA tests for the main effect of time on three judges' ABRSM subscale scores for students' accompanied and a cappella performances, and results of Intraclass Correlation Coefficient analyses using a two-way random model with absolute agreement among the judges.

	Technical subscales			Non-technical subscales	
P/I[1]	**T&R[2]**	**VT&P[3]**	**M[4]**	**CH&ST[5]**	**C&SP[6]**
Accompanied					
$F(1,5) = 0.1$	$F(1,5) = 0.25$	$F(1,5) = 0.63$	$F(1,5) = 0.02$	$F(1,5) = 1.55$	$F(1,5) = 0.3$
$p = 0.76$	$p = 0.64$	$p = 0.47$	$p = 0.89$	$p = 0.27$	$p = 0.61$
ICC = 0.79	ICC = 0.72	ICC = 0.9	ICC = 0.85	ICC = 0.88	ICC = 0.89
A Cappella					
$F(1,5) = 0.58$	$F(1,5) = 0.00$	$F(1,5) = 0.03$	$F(1,5) = 0.87$	$F(1,5) = 3.63$	$F(1,5) = 0.93$
$p = 0.48$	$p = 1.00$	$p = 0.87$	$p = 0.39$	$p = 0.12$	$p = 0.38$
ICC = 0.71	ICC = 0.69	ICC = 0.82	ICC = 0.84	ICC = 0.85	ICC = 0.87

[1]Pitch/Intonation; [2]Tempo and Rhythm; [3]Vocal Tone and Projection; [4]Musicality (Dynamics, Vocal Expression); [5]Character and Storytelling; [6]Confidence and Stage Presence.

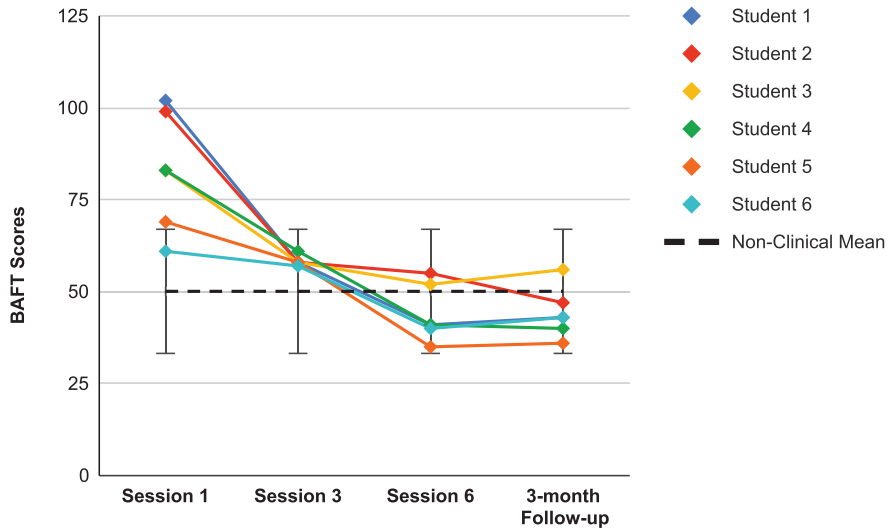


FIGURE 2 | Believability in Anxious Feelings and Thoughts scores for the current students, from pre-coaching (Session 1), midway (Session 3), post-coaching (Session 6), and the 3-month follow-up, with the non-clinical mean (50.10) and bars spanning one standard deviation up/down (*SD* = 16.88; Herzberg et al., 2012).

study fell above the normative range at baseline or at the beginning of ACT psychotherapy, and all of their scores fell within the normative range (or better) at post-treatment (Session 12). BAFT scores falling above that range indicate higher levels of fusion with MPA-related thoughts and feelings. **Figures 4**, **5** show the current students' AAQ-II scores and the vocal students' AAQ-II scores from Juncos et al. (2017), respectively. **Figure 4** shows the majority of the current students' scores (5 of 6) fell above the AAQ-II's normative range prior to receiving ACC, whereas the majority (4 of 6) fell within the normative range at Session 6 (or better) and half were within that range at follow-up (3 of 6). Similarly, **Figure 5** shows the majority of the vocal students' AAQ-II scores (6 of 7) fell above the normative range at baseline or at the beginning of ACT psychotherapy, whereas the majority (5 of 6) fell within the normative range at post-treatment and also within that range (or better) at the 3-month follow-up (4 of 6). AAQ-II scores falling above the normative range indicate higher levels of psychological inflexibility. **Figures 6**, **7** show the current students' PHLMS *Acceptance* subscale scores and the vocal students' PHLMS *Acceptance* subscale scores from Juncos et al. (2017), respectively. **Figure 6** shows the majority of the current students' scores (4 of 6) fell below the PHLMS *Acceptance* subscale's normative range prior to receiving ACC, whereas the majority (5 of 6) fell within the normative range at Session 6, and the majority (5 of 6) also fell within that range (or better) at the follow-up. Similarly, **Figure 7** shows the majority of the vocal students' PHLMS *Acceptance* subscale scores (4 of 7) fell below the normative range at baseline or at the beginning of ACT psychotherapy, whereas all the students' scores fell within the normative range (or better) at Session 12 and the majority of scores (5 of 6) were within that range (or better) at the 3-month follow-up. PHLMS *Acceptance* scores falling below the normative range indicate lower levels of acceptance of MPA symptoms.

Looking next at the graphs for symptom-based questionnaires common to both studies, **Figure 8** shows the current students' KMPAI scores and should be viewed alongside **Figure 9**, which

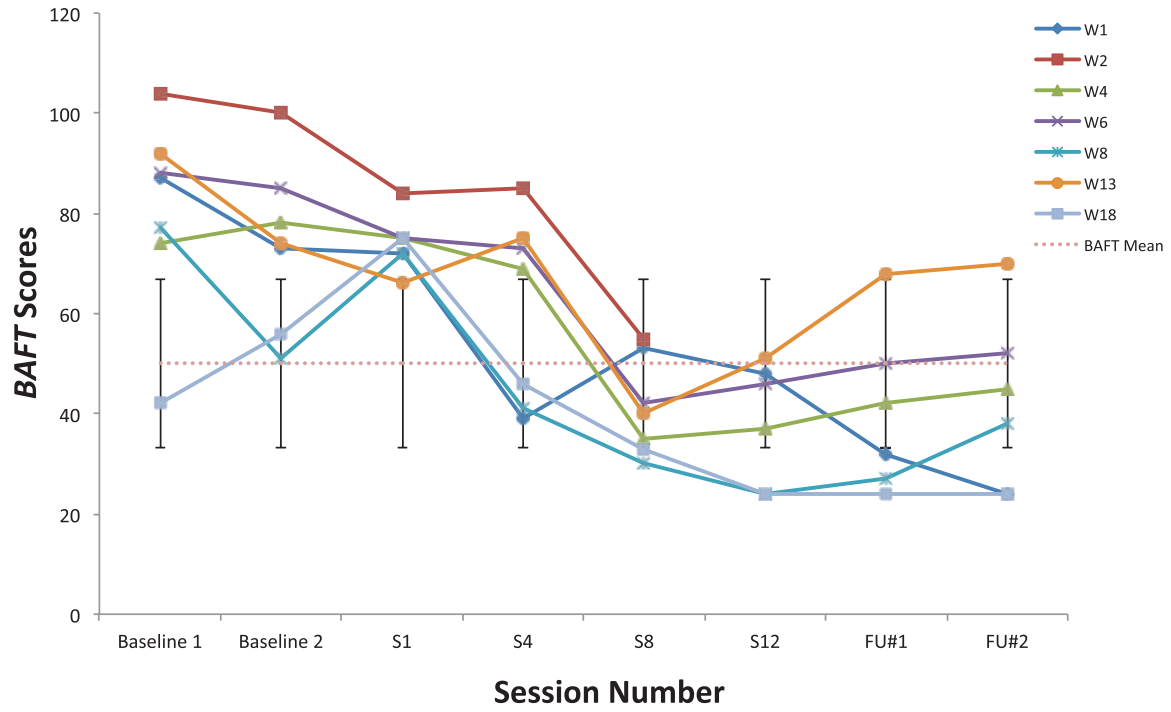


FIGURE 3 | Believability in Anxious Feelings and Thoughts scores for seven vocal students (Juncos et al., 2017) showing scores from the baseline period to post-treatment, 1- and 3-month follow-up points, also with the non-clinical mean (50.10) and bars spanning one standard deviation up/down (*SD* = 16.88; Herzberg et al., 2012).

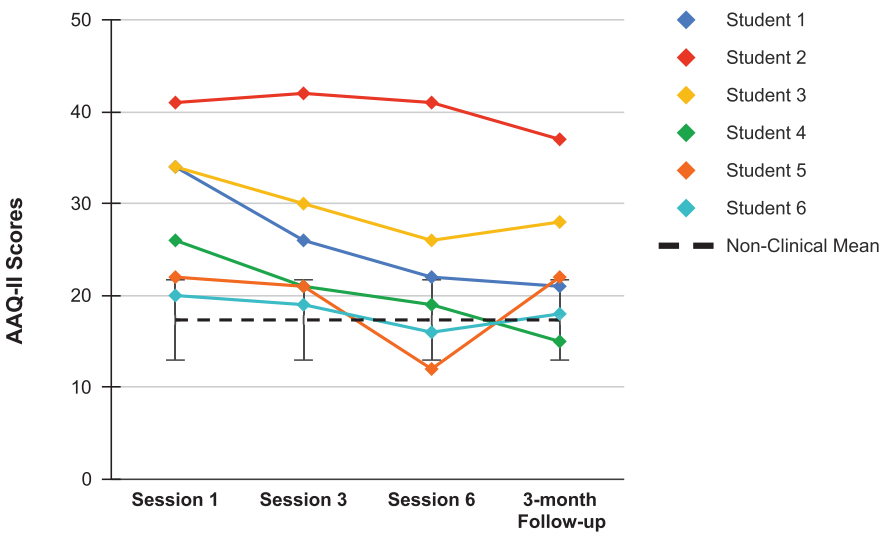


FIGURE 4 | AAQ-II scores for the current students, from pre-coaching (Session 1), midway (Session 3), post-coaching (Session 6), and the 3-month follow-up, with the non-clinical mean (17.34) and bars spanning one standard deviation up/down (*SD* = 4.37; Bond et al., 2011).

shows the seven vocal students' KMPAI scores from Juncos et al. (2017). **Figure 8** shows all of the current students' KMPAI scores at both baseline points fell above the recommended clinical cutoff score (105), whereas 2 students' KMPAI scores were below the cutoff at Session 6 and half (3 of 6) were below it at the follow-up. Similarly, **Figure 9** shows all of the vocal students' KMPAI scores were above the cutoff (105) at baseline or at the beginning of ACT psychotherapy (Juncos et al., 2017), whereas 2 students were at or below the cutoff at Session 12 and the majority (4 of 6) were below it at the 3-month follow-up. KMPAI scores falling about the cutoff indicate clinically elevated levels of MPA. Lastly, **Figures 10**, **11** show the current students' ESS scores and the

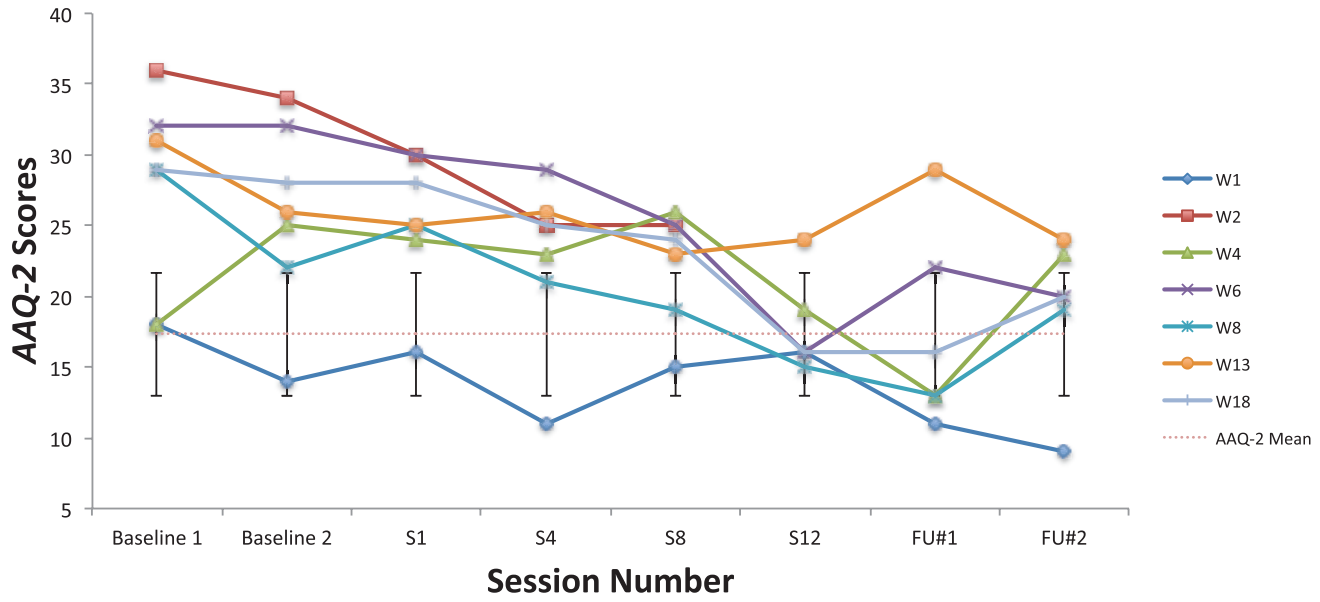


FIGURE 5 | AAQ-II scores for seven vocal students (Juncos et al., 2017) showing scores from the baseline period to post-treatment, 1- and 3-month follow-up points, also with the non-clinical mean (17.34) and bars spanning one standard deviation up/down (*SD* = 4.37; Bond et al., 2011).

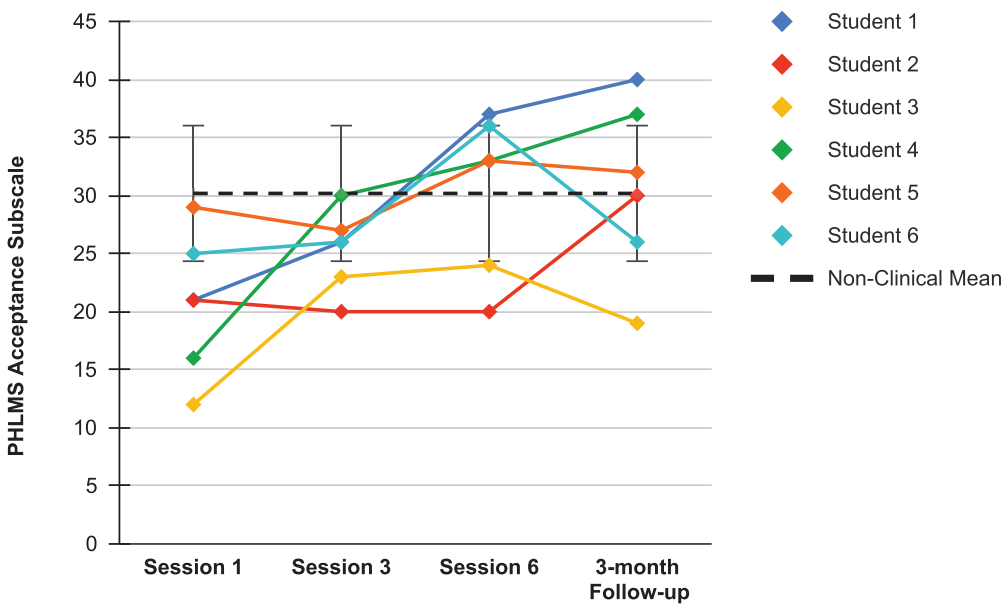


FIGURE 6 | PHLMS Acceptance subscale scores for the current students, from pre-coaching (Session 1), midway (Session 3), post-coaching (Session 6), and the 3-month follow-up, with the non-clinical mean (30.19) and bars spanning one standard deviation up/down (*SD* = 5.84; Cardaciotto et al., 2008).

7 vocal students' ESS scores from when performing in front of their peers in Juncos et al. (2017), respectively. Please note, the ESS scores collected during the vocal students' peer performances in 2017 (as shown here in **Figure 11**) are different from the ESS scores taken before/after ACT treatment in Juncos et al. (2017) – the former were included here to compare this study's clinically significant results to those from Juncos et al. (2017). **Figure 10** shows half (3 of 6) the current Students' ESS scores fell above the normative range prior to the ACC intervention (songs 1 and 2 were recorded pre-coaching, whereas songs 3 and 4 were recorded post-coaching), whereas all ESS scores fell within the normative range (or better) at post-coaching. Similarly, **Figure 11** shows two of the vocal Students' ESS scores from Juncos et al. (2017) fell above the normative range at either their first or second peer performance, yet scores from each student's final performance fell within the normative range (or better). ESS

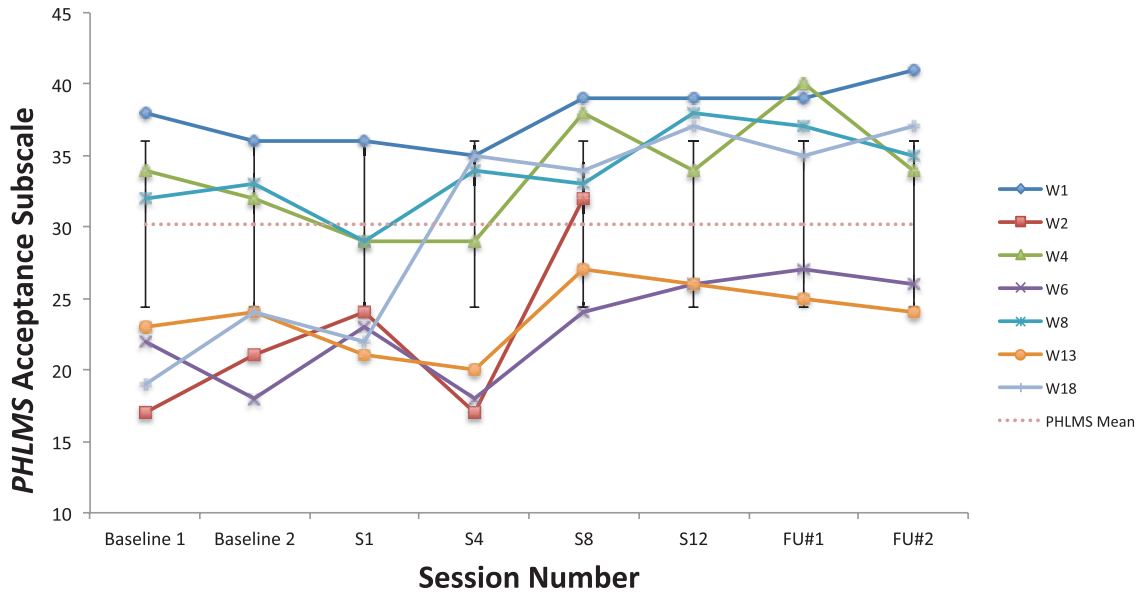


FIGURE 7 | PHLMS *Acceptance* subscale scores for seven vocal students (Juncos et al., 2017) showing scores from the baseline period to post-treatment, 1- and 3-month follow-up points, also with the non-clinical mean (30.19) and bars spanning one standard deviation up/down (*SD* = 5.84; Cardaciotto et al., 2008).

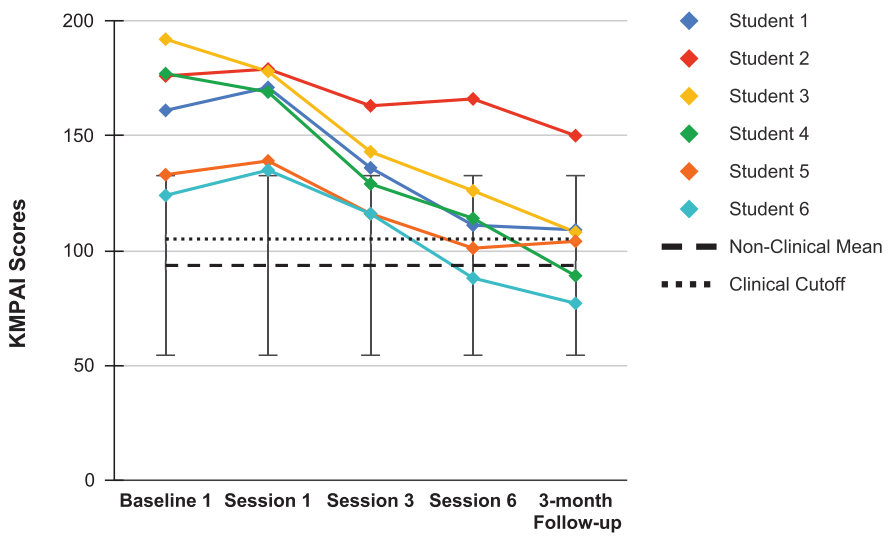


FIGURE 8 | Kenny Music Performance Anxiety Inventory scores for the current students, from the screening assessment (Baseline 1) pre-coaching (Session 1), midway (Session 3), post-coaching (Session 6), and the 3-month follow-up, with the mean for musicians under age 30 (93.5), standard deviation bars (*SD* = 39.1; Kenny et al., 2012), and the recommended clinical cutoff score (105; Ackermann et al., 2014).

scores falling above the normative range indicate elevated levels of state shame during music performances.

Students' Impressions of the Acceptance and Commitment Coaching Course and Coded Qualitative Data

Throughout the ACC course, SM recorded and transcribed the sessions and then highlighted key statements made by the students detailing their struggles with MPA and their responses to ACC processes and to the overall course. What follows below is a summary of their impressions of the ACC course, as noted by SM during it and at the post-coaching interview. Due to time constraints, the transcripts did not go through the process of member checking, with it being unlikely that the many hours worth of transcribed data would have been returned on time. However, the stringent cross-checking of students' accounts from multiple sources of qualitative data ensured an accurate representation of how they felt about the process.

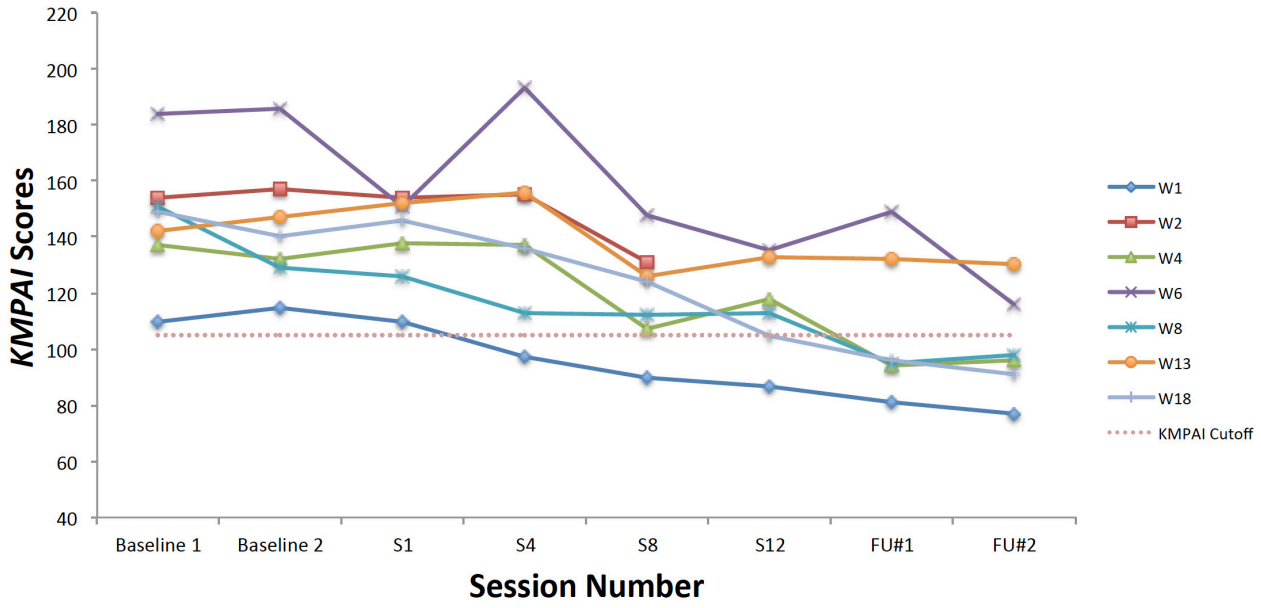


FIGURE 9 | Kenny Music Performance Anxiety Inventory scores for seven vocal students (Juncos et al., 2017) showing scores from the baseline period to post-treatment, 1- and 3-month follow-up points, also with the mean for musicians under age 30 (93.5), standard deviation bars (*SD* = 39.1; Kenny et al., 2012), and the recommended clinical cutoff score (105; Ackermann et al., 2014).

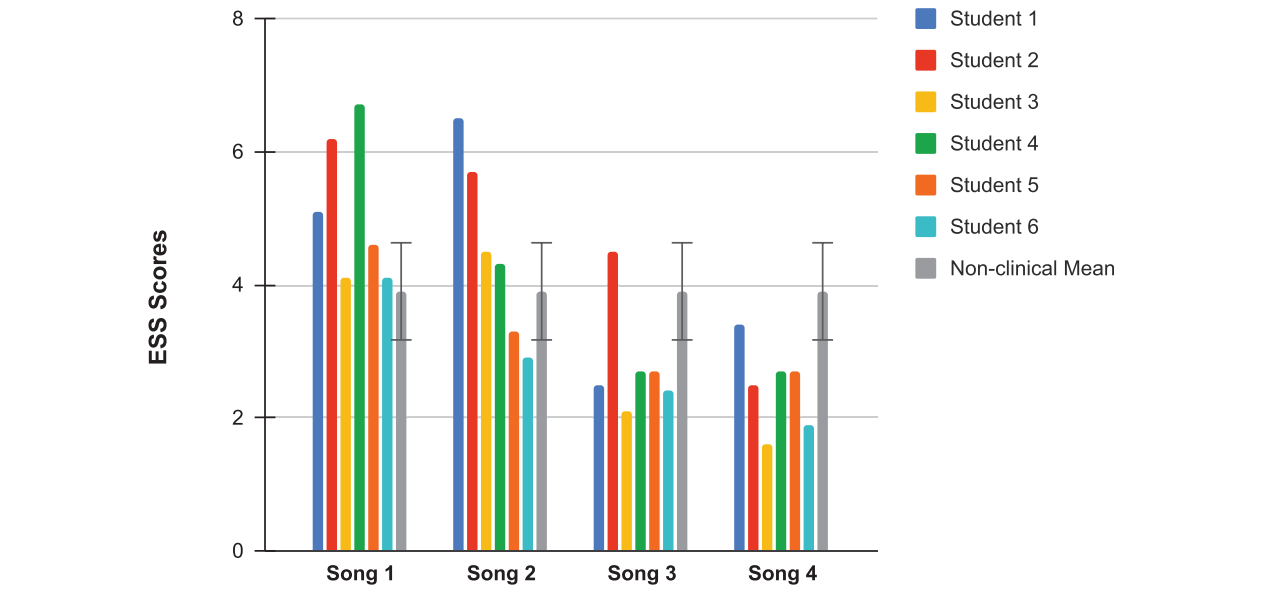


FIGURE 10 | Experiential Shame Scale scores for the current students, from pre-coaching with accompaniment (Song 1), pre-coaching a cappella (Song 2), to post-coaching with accompaniment (Song 3), to post-coaching a cappella (Song 4), with the non-clinical mean (3.9) and bars spanning one standard deviation up/down (*SD* = 0.73; Turner, 2014).

They found it useful to have a different topic to focus on each session, "*I liked having something to work on each week. And then...it gradually built up.*" The small group size was related to an increased sense of social inclusion and support, "*Everyone got comfortable with each other because it was a small group. . .you don't feel intimidated.*" This sense of belonging was related to reduced shame over having MPA, "*It was useful to relate to others. . .hear them saying things I felt. . .realizing you're not alone. Sometimes I used to think I was the only one.*" The first session included information and discussion about why some performers experience MPA. Students reported the "*learning about the biological background of these symptoms made it easier*

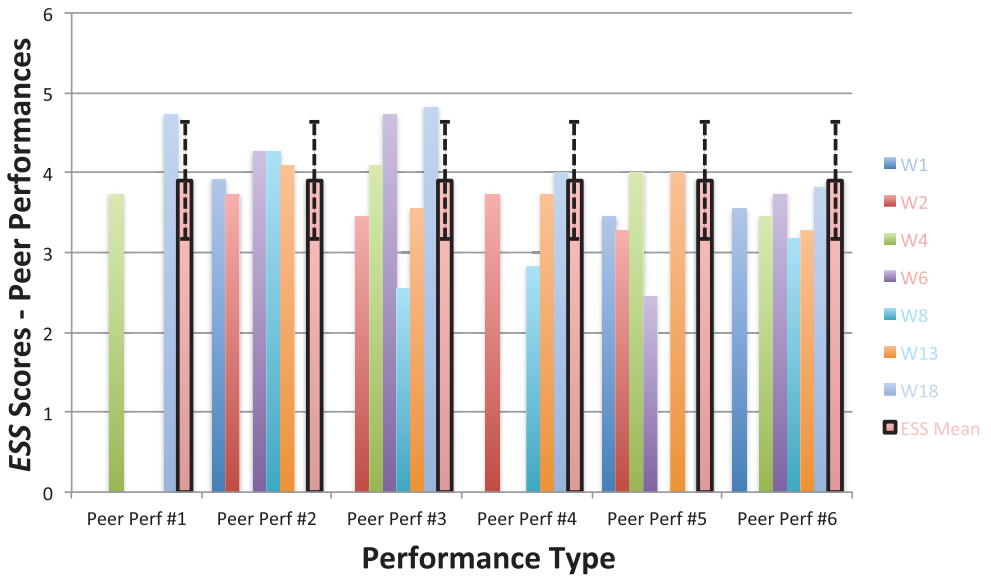


FIGURE 11 | Experiential Shame Scale scores for seven vocal students from six peer performances with piano accompaniment (Juncos et al., 2017), also including the non-clinical mean (3.9) and standard deviation bars (*SD* = 0.73; Turner, 2014).

for me [them] to accept them and not judge myself [themselves] for any feelings," and the group dialogue helped normalize MPA, leading students to realize that "*MPA is not talked about enough.*"

Prior to ACC, students engaged in overt and covert avoidant behaviors to manage their MPA, "*I often give up on songs and discard them as the negative thoughts dominate,*" "*I used to, like, avoid singing as much as possible and like, be ill, so that I wouldn't have to sing.*" They found themselves fused with perfectionistic and self-critical thoughts, "*If I made one tiny mistake, I would beat myself up,*" and they were frustrated with MPA symptoms serving as barriers to progress with their singing, "*I work a lot on my songs but feel people can never tell. It makes me really frustrated, because I know that I can do it. But then when I get to do it in front of someone, I can't.*"

They were able to implement tools and techniques from ACC into their lessons and performances almost immediately, "*I used mindful breathing before singing practice and my singing lesson and I was less tense.*" One student remarked that present moment awareness had a positive effect on their vocal technique, "*When I got stressed about singing the high notes. . .I was able to focus on something (in the room) to bring me back to the present, and I found that I could sing them!*" They reported the defusion techniques were particularly helpful too, giving them instant, practical tools, e.g., saying their thoughts aloud in a silly voice or character. They found these exercises imaginative and fun, which resonated with their values as performers, "*I got anxious before singing in front of the class. . .I put on a silly voice and sung my thoughts, which made me laugh. Then I felt more relaxed, more grounded.*" Defining their performance-related values gave students a sense of meaning and direction, enabling them to accept MPA symptoms while continuing to perform, "*This week was the first time I had sung in front of the class. . .it had been building up. But I decided I would take valued action despite the nerves – it went better than I thought!*"

The work on self-compassion appeared to be a major turning point in the students' progress. For most, this was an alien concept, as they felt they could only be highly critical of themselves. They defined barriers to self-compassion, such as not being deserving, "*I tell myself I can't be kind to myself as I don't deserve it,*" fear of being perceived as arrogant, and the need to be perfect. However, the work on self-compassion led to realizations such as, "*You would never speak that way to a friend. Maybe I could talk to myself before a solo like I would talk to my best friend,*" and "*If you had self-compassion after a performance, you'd be accepting of it. . .you might even be proud.*" This work appeared to improve their overall wellbeing as well, "*I bought a gratitude journal as part of self-compassion element. . .I want to be more positive and make lifestyle changes.*"

They were motivated by supportive feedback from their individual singing teachers, who had noticed improvements in their singing, "*My singing lesson actually was really good. . .and I got compliments saying he [the teacher] could see real progress,*" and "*Even after the second week, within my singing lessons my teacher would say* 'Your mindset's completely different already.'" Following the coaching, students were more accepting of their MPA symptoms, and more willing to perform in their presence, "*I don't need to force them [the symptoms] to stop, I can still perform.*" They also demonstrated improved psychological flexibility by using their ACC skills in combination with each other, "*I noticed comparison thoughts in class, remembered my values, and moved toward them. Less went wrong, and when it did, I moved on.*" They made connections between ACC for singing and other disciplines, such as dance, "*Before my ballet assessment I used [ACC exercises] and it works just the same as doing it before singing.*" Their written feedback at the follow-up interview

suggested they experienced lasting change, and that the overall ACC course was very helpful for them. Some remarks were, "*It's changed my approach to singing lessons,*" "*Being more accepting of my journey lifted a lot of pressure off my shoulders,*" and "*It's not just helped me from a singing perspective, I feel like taking the things I've learned from this about singing and performance, and then add it to life.*"

In ACT/ACC, the use of language and cognition is contextual, and as the mindset of the students changed during the coaching intervention so too did their use of language. This change correlated with them moving away from psychologically inflexible behavior and toward more psychologically flexible behavior. Using emotion coding to look at students' verbatim qualitative data at Session 1 (**Figure 12**) and Session 6 (**Figure 13**), a visual snapshot emerged of their changing emotional states from pre- to post-coaching.



FIGURE 12 | Students' use of psychologically inflexible language at Session 1, as revealed through emotion coding of their verbatim qualitative data.



FIGURE 13 | Students' use of more psychologically flexible language at Session 6, as revealed through emotion coding of their verbatim qualitative data.

DISCUSSION

Consistent with Shaw et al. (2020) findings, the results obtained here provide further preliminary support for an alternative, non-clinical treatment model for MPA – that is, it appears possible a singing teacher without training or education in psychotherapy may achieve significant results, and seemingly replicate the results obtained by a clinical psychologist (Juncos et al., 2017), when trained to use ACC to help manage MPA for a small group of performing arts students with anxiety related to their vocal performances. Such an intervention could be feasible in fulfilling the growing need for music teacher training in support of students who suffer with problematic MPA, as identified by a number of researchers (Fehm and Schmidt, 2006; Patston, 2014; Patston and Waters, 2015; Sarikaya and Kurtaslan, 2018; Jeong and Ryan, 2021). If the results observed here were valid, the six students showed a very similar pattern of improvement as both the musical theatre student did in Shaw et al. (2020) study, and the seven vocal students did in Juncos et al. (2017) study. After six group ACC sessions, they appeared to make significant improvements in their ability to mindfully accept physiological MPA symptoms, defuse from MPA-related cognitive symptoms, and perform in a more psychologically flexible manner, even while experiencing distressing MPA symptoms. The observed improvements in these ACC processes were also maintained at the 3-month follow-up assessment. The processes of acceptance of distressing experiences and defusion from them are two proposed mechanisms by which ACT treatments enhance psychological flexibility (Ciarrochi et al., 2010), and these changes have been observed with other musicians who received ACT psychotherapy for MPA (Juncos et al., 2014; Juncos and Markman, 2015; Clarke et al., 2020). The singing teacher in this study received training in ACC from the second author that was of a similar duration and format (8 h via Zoom) as the training administered in Shaw et al. (2020) study (7 h via Skype), which suggests a brief training in ACC of less than 10 h may be sufficient to produce significant results for singing teachers, and perhaps music teachers at large, who are looking to address students' problematic levels of MPA.

In studies with stronger internal validity than the current one, other applications of ACT have led to significant improvements in psychological flexibility when delivered by non-expert practitioners of varying professions, which lends further credibility for a non-clinical treatment model for MPA. For example, 40 early childhood teachers with low singing confidence were randomized to receive either four group sessions of ACT or four sessions of group singing (Swain and Bodkin-Allen, 2017). A trained singer was selected to facilitate all the sessions, because her knowledge of vocal technique was relevant for the group singing intervention, and she was able to be trained to deliver the ACT sessions effectively. Both the ACT and group singing interventions significantly improved the teachers' singing confidence, as measured by their answers to six questions about overall singing confidence (Swain and Bodkin-Allen, 2017). Another important example from an unrelated profession is how American correctional officers with a Bachelor's degree, and little to no clinical background, were trained to deliver an

ACT-based, group intervention for men with domestic violence offenses (Zarling et al., 2017, 2020). The results showed men in the ACT group (N = 843) committed significantly fewer domestic assault charges, or violent charges, than participants receiving a group Cognitive Behavioral Therapy intervention (N = 2,361) at both a 1-year and 5-year follow-up point. The officers' training included 4 days of ACT training plus ongoing supervision throughout the intervention with non-clinical peers already trained in ACT (Zarling et al., 2017, 2020). Furthermore, a recent, well-controlled study investigated ACT's effectiveness as an adjunct to physical therapy for treating chronic lower back pain (Godfrey et al., 2020). Two hundred and forty eight adults with chronic lower back pain were randomly assigned to receive either ACT-informed physical therapy or physical therapy alone, and the results showed the ACT-informed group reported significantly better outcomes than the physical therapy group for pain-related disability, physical health, and patient functioning at a 3-month follow-up (Godfrey et al., 2020). The ACT interventions were administered by physical therapists who were trained to achieve a high fidelity to the ACT model. In fact, when it comes to chronic pain treatment, England's National Health Service (NHS) now recommends using psychologically informed practices to treat chronic pain, when other treatments are proven ineffective or when a condition is at risk for becoming chronic (de Campos, 2017; National Health Service of England, 2017). Considering the preliminary results observed in the current study, those from Shaw et al. (2020), and the results of these other non-psychotherapist delivered applications of ACT, there is a growing consensus that adequately trained practitioners other than psychotherapists may be capable of effectively delivering psychological interventions, despite their feeling unqualified to do so (Hall et al., 2018). However, future research with larger samples of teachers and stronger internal validity is needed first to determine whether the observed results across some of the studies are indeed due to the ACT/ACC interventions. If teachers can demonstrate efficacy in applying these interventions, recommendations for psychologically informed practices should be incorporated into curriculum guidelines for performing arts and music colleges as well, because MPA, like chronic pain, is a potentially chronic and debilitating condition if untreated, and psychotherapy may be an unrealistic treatment for it considering the aforementioned hurdles preventing music students from seeking psychotherapeutic help. Training music teachers to deliver ACC-based interventions individually and/or in group settings appears ecologically valid and is possibly more acceptable for students than referring them to a psychotherapist.

The students here reported experiencing significantly less states of shame during their performances at post-coaching, and significantly less MPA at post-coaching and at a 3-month follow-up, as the seven vocal students also did in Juncos et al. (2017) study. Additionally, a novel finding here was the students significantly improved their socially comparative thinking at post-coaching and follow-up. These findings are potentially noteworthy, considering the students in Juncos et al. (2017) study received 12 ACT psychotherapy sessions whereas the students here received six group ACC sessions. It appears possible, then, to achieve significant reductions in MPA and in one's emotional distress related to vocal performance in less time than previously thought. One possible explanation for a shorter ACC intervention leading to significant reductions in MPA and less maladaptive use of social comparisons was through improvements in defusion skills occurring *prior* to the reductions in those symptoms. As shown in **Figure 4**, all students' scores on the BAFT clearly fell within a healthy range by Session 3, which was the point in the ACC course when SM taught them defusion techniques. By that time, students appeared to learn how to notice the occurrences of their unwanted, cognitive MPA symptoms and their unhelpful comparisons to others, without taking them as literally or personally, and possibly enabling themselves to perform more flexibly in their presence. **Table 2** also shows a very large effect size with respect to students' improvements on BAFT scores was found at post-coaching (g = 3.07), yet it remained the same at the follow-up point (g = 3.07). On the other hand, the effect sizes for students' improved scores on the KMPAI and SCS were both notably larger at follow-up than at post-coaching: g = 1.87 at post-coaching and 2.48 at the follow-up for changes in KMPAI scores; g = 1.44 at post-coaching and 1.86 at the follow-up for changes in SCS scores. These different trends suggest the ACC intervention was exerting a greater effect on students' MPA symptoms and maladaptive social comparisons *after* the coaching had ended, compared to its effect on their defusion skills during that same timeframe. Such an outcome was also observed in Juncos et al. (2017) study with the vocal students' KMPAI scores: g = 1.55 at post-treatment and g = 2.19 at a 3-month follow-up. Thus, it is possible students in both studies were continuing to defuse from their unwanted symptoms post-intervention, which led them to suffer less with their symptoms by a 3-month follow-up point. Of course, there could be other reasons for the continued reductions in MPA symptoms and improved social comparisons after the coaching finished, i.e., regression to the mean, students feeling more relaxed as their fall semester had recently ended. However, such temporal differences in outcomes have been observed in numerous ACT treatments, and consequently, there is a growing body of support for the hypothesis that changes in psychological flexibility, via improvements in defusion (as well via improvements in acceptance and increased valued actions) will precede reductions of symptoms in both clinical samples (Dalrymple and Herbert, 2007; Twohig et al., 2010; Kocovski et al., 2013; Juncos and Markman, 2015; Gloster et al., 2017; Juncos et al., 2017) and non-clinical samples (Zettle and Hayes, 1986; Gifford et al., 2004; Hesser et al., 2009). Therefore, the length of the ACC intervention may not predict reductions in symptoms as much as the prerequisite that improvements in psychological flexibility occur first, regardless of the duration of the intervention.

In reference to the second hypothesis, there was not a significant improvement in the quality of students' accompanied or a cappella vocal performances at post-coaching, according to the three judges' ratings. This could be due to the small sample of students and small number of judges, and also to the judges' inexperience in using the ABRSM scoring criteria, though to a lesser extent. A future ACC for MPA study should investigate this same hypothesis with a larger sample of students,

as many as four or five judges, and with judges more experienced in adjudicating vocal performances with the ABRSM criteria. It is possible the observed improvements in scores for one non-technical subscale, i.e., Character and Story Telling, may become significant with a larger sample of students and/or more judges. Such a potential outcome would make sense, considering ACC does not aim to improve the technical elements of vocal performance, but it would be expected to help students lessen their struggle with MPA symptoms and maladaptive social comparisons, which could potentially free up more energy to be put into their valued-actions like communicating their connection to the character and text through their performances. In fact, ACT treatments have led patients with various anxiety conditions to earn better ratings from independent observers regarding the quality of their performances on various behavioral tasks evoking fear, e.g., a public speaking task for patients with public speaking anxiety (Glassman et al., 2016), an academic test for students with test anxiety (Brown et al., 2011), a distress tolerance task for patients with spider phobia (Wagener and Zettle, 2011), a social interaction task for patients with Social Anxiety Disorder (Herbert et al., 2018), a music performance for an undergraduate violinist with MPA (Juncos and Markman, 2015), and accompanied/a cappella performances for seven vocal students with MPA (Juncos et al., 2017). Furthermore, ACT-related interventions have also led to improved self and observer ratings of performances when applied non-clinically in athletic, academic, and occupational settings (Bond and Bunce, 2003; Lutkenhouse et al., 2007; Bernier et al., 2009; Thompson et al., 2011; Ruiz and Luciano, 2012; Castro et al., 2016; Paliliunas et al., 2018; Josefsson et al., 2019). All of these aforementioned studies included objective measurements of participants' performances, and most included samples with more than six participants, with the exceptions of Ruiz and Luciano (2012), Juncos and Markman (2015), and Castro et al. (2016). As mentioned earlier, the judges' inexperience with using the ABRSM criteria could have led to the observed non-significant improvements in students' performance quality as well. However, the judges' inter-rater agreement ranged from moderate to excellent (**Table 3**), and they had extensive experience assessing vocal performances using similar criteria in musical theatre colleges, thus, their use of the ABRSM scoring tool was deemed to be reliable. Lastly, it was unclear why the students' a cappella performances might have earned them better ratings on the Character and Story Telling subscale at post-coaching than their accompanied performances did on the same subscale. One possibility is that their accompaniment was not typical for them – given the UK's restrictions on social gatherings in late 2020 due to the COVID-19 pandemic, students were neither able to perform in-person nor with a live pianist, so they provided an instrumental back-up track instead. It is likely they lacked experience with this type of accompaniment, and the judges had less experience adjudicating such performances, and perhaps these factors led to a difference in how a cappella vs. accompanied performances were rated.

One final consideration when interpreting the results is that the group delivery of ACC could be responsible for some of the improvements observed. While Juncos et al. (2017) also included group performances in the second half of their ACT psychotherapy study – those students performed a minimum of four times in front of their peers who were also participants in the study, with some students performing six times – there were no group discussions of MPA and ACT-based processes in that study. Rather, those discussions occurred privately in students' psychotherapy sessions (Juncos et al., 2017). Communication about MPA may prove more beneficial in a group setting, because several known processes that facilitate individual psychological and behavioral change occur more readily in groups, i.e., social comparisons, social support, the provision of challenging yet supportive feedback (Borek and Abraham, 2018). It is possible, then, that learning about MPA in a group setting, and hearing others' experiences with it, provided students here with the social support needed to create a sense of common suffering with MPA that mitigates against the distressing effects of MPA and unhelpful social comparisons. Providing a sense of common humanity like this helps to buffer against the harmful effects of self-criticism and isolating oneself when attempting to manage mental health problems like anxiety and depression (Gilbert and Procter, 2006; Neff, 2012; Neff and Germer, 2013). It is reasonable that such emotional support would be fostered more easily in a group setting than an individual one. In support of this, the effect sizes obtained here for students' changes on the KMPAI at post-coaching and the 3-month follow-up were larger compared to those obtained in the 2017 study: post-coaching (g = 1.87) and follow-up here (g = 2.48), compared to post-treatment (g = 1.55) and follow-up (g = 2.19) in Juncos et al. (2017) study. The same was true for the effect sizes for students' changing ESS scores on their accompanied vocal performances: post-coaching here (g = 2.35), compared to post-treatment (g = 2.03) in Juncos et al. (2017) study. The combination of group discussions about MPA and group performances may have contributed to the slightly larger effect sizes obtained here on students' ESS scores compared to those from Juncos et al. (2017) study. Moreover, it is also possible the group delivery of ACC led students to make significant improvements in their ability to accept physiological MPA symptoms, a finding that was not observed as robustly with the students in Juncos et al. (2017) study. See **Table 1** here for changes in students' PHLMS *Acceptance* data, and see Table 1 in Juncos et al. (2017) study for similar data. Thus, providing supportive, yet challenging, feedback about the futility of attempting to control one's MPA symptoms may prove more beneficial when communicated in a group setting than when communicated individually.

Limitations and Future Directions

Given this study had a small sample and lacked a control/comparison group, direct conclusions about ACC's efficacy as an intervention for problematic MPA cannot be made. Without stronger checks on internal validity, potential confounds such as history, regression to the mean, and maturation could not be ruled out as alternative explanations of the results. It is possible, for example, the students became less anxious toward the end of the ACC course because their winter break was starting at that time, and also that their scores on the self-report questionnaires were regressing to each measure's mean by post-coaching. Both of these confounds could explain why their

scores had improved after the ACC intervention. However, the apparent similarities between the results observed here and those from previous ACC/ACT for MPA studies (and from other ACT for anxiety studies) strengthen the likelihood the observed improvements in self-report data were due to the ACC intervention. Furthermore, it is possible the non-significant improvements on the Character and Story Telling subscale on the ABRSM criteria were due to students' ongoing engagement with their broader educational curriculum, rather than to the ACC intervention. Students are expected to make improvements in their performance skills over time, which theoretically would include both technical and non-technical improvements. However, considering that none of the judges' ratings on the four technical subscales from the ABRSM criteria were approaching significant at post-coaching (**Table 3**), and that ACC/ACT would be expected to improve the more non-technical, or behavioral, elements of music performance with its emphasis on increasing valued actions in spite of MPA, it is possible the non-significant improvement on the Character and Story Telling subscale may be due to the ACC course. Future studies with larger samples and more judges are needed to establish whether ACC/ACT treats MPA via some of the mediating processes observed here, i.e., defusion, acceptance, and whether it differentially affects the technical vs. non-technical elements of students' performances.

One potential difficulty in replicating this work in music and performing arts colleges will be in overcoming some practical challenges in applying it. It may be difficult for singing teachers (and students) to carve out an additional 6 h a semester to administer a group ACC course to students with MPA, on top of their already-busy schedules. Some students also may feel uncomfortable with the group nature of the work, yet they may still struggle with problematic MPA and shame so they may avoid participating, unfortunately. It remains to be seen whether other, more realistic ACC interventions may also help music teachers effectively manage students' MPA, e.g., delivering a didactic-only ACC intervention in a classroom setting to potentially impact more students but without a coaching element, or incorporating ACC interventions more "on the fly" within private lessons, rather than dedicating an hour each week for 6 weeks, as was done here and in Shaw et al. (2020) study. Future studies should examine the effectiveness of such interventions that may be easier to deliver for a larger number of music teachers. However, given the consistency between the results obtained here and those obtained by a clinical psychologist in Juncos et al. (2017), it is possible a group ACC course would continue to benefit students struggling with MPA and shame-related distress. For those schools who can afford to implement it, the same group ACC course should be replicated to see if it makes a similar impact.

At times, SM needed to consult with the second author, a clinical psychologist with expertise in treating MPA with ACT, about how best to proceed when certain students responded more slowly to the ACC intervention or in other ways that were difficult to understand. A music teacher administering ACC to a similar cohort will inevitably face similar challenges in working with students of varying levels of psychological inflexibility and flexibility. However, not every teacher has access to a psychologist with adequate experience in ACC, or in treating MPA, for consultation about such students, so this aspect of the study may not translate easily into real-world settings. In these instances, we strongly recommend the teacher seek supervision or peer consultation from an ACT-trained practitioner(s), many of whom can be found through the Association for Contextual Behavioral Science's webpage www.contextualscience.org, which is an online learning and research community for those seeking information about ACT. It is actually common for participants undergoing ACT treatments for anxiety to resist some of its central ideas, i.e., acceptance of anxiety rather than attempting to control it, especially given that avoidant behaviors are negatively reinforced in the short term (Gloster et al., 2017). Unfortunately, there is a predictable pattern between the degree to which one struggles against their anxiety and their emotional suffering related to it, in that patients whose symptoms of anxiety remain high during treatment are likely still engaged in a struggle to control them (Gloster et al., 2017). This may have happened with some students here (see **Figures 6**, **8**, **10**).

During their post-coaching interviews, students had asked that more time be dedicated to learning about and improving self-compassion in future group ACC courses, as they appeared to benefit greatly from this work. SM was able to incorporate self-compassion into just one session, as it wasn't part of the ACC curriculum adopted from Hill and Oliver's (2019) six-session guide. ACT is highly compatible with other therapies aiming to enhance self-compassion, e.g., Compassion Focused Therapy (Gilbert, 2010) and Mindful Self-Compassion (Neff and Germer, 2013), thus, we recommend future researchers include more opportunities to train in self-compassion within group ACC interventions for music and performing arts students with problematic MPA.

Lastly, the ACC course was conducted entirely online via Zoom due to the UK's restrictions on social gatherings during the COVID-19 pandemic. Future group ACC courses should be conducted in person to compare the results to those obtained here. It is possible the online environment, and the lack of live accompaniment, created less anxiety for students when performing in front of one another as one might expect from live performances, even though their KMPAI and ESS scores did not appear different than those of the vocal students in Juncos et al. (2017) study. Neither of those two questionnaires measured state anxiety during performances, so future ACC for MPA research should include measures like *The State-Trait Anxiety Inventory* (STAI; Spielberger, 1983) to ensure there are no significant differences between students' MPA levels when performing live vs. online.

CONCLUSION

This mixed-methods pilot study marked the first application of a group ACC course administered by a singing teacher to help manage MPA for a small sample of performing arts students (N = 6) with anxiety about their vocal performances. After receiving a brief ACC training of less than 10 h she appeared to replicate the results of a previous ACT for MPA treatment

administered by a clinical psychologist (Juncos et al., 2017), and the results of an ACC for MPA single-subject design also administered by a singing teacher (Shaw et al., 2020). However, given the small sample size and lack of a control group, it was unclear if the observed results were due to the ACC intervention. If valid, these results and those from Shaw et al. (2020) study add to a small, but growing body of research supporting the potential effectiveness and feasibility of non-clinical interventions for MPA (Sisterhen, 2005; Hoberg, 2008) and of non-clinical applications of ACT in a broader context (Swain and Bodkin-Allen, 2017; Zarling et al., 2017, 2020; Godfrey et al., 2020; Shaw et al., 2020). Such an alternative model for treating MPA is promising and should be studied further in other forms, as it could be more helpful than psychotherapy for students in music and performing arts colleges with problematic MPA, given the common hurdles preventing them from working with a psychotherapist, i.e., stigma, lack of time/access to services (Shaw et al., 2020). In particular, the combination of group performances and group discussions about MPA appeared to lower students' levels of shame while performing in front of another slightly better than the combination of individual psychotherapy and group performances did in a previous ACT for MPA study (Juncos et al., 2017), thus, future group ACC interventions should include supportive discussions to help normalize students' experiences with MPA. The same appeared true for ACC-based group discussions that challenged students' attempts to control MPA symptoms - students here reported a better ability to accept MPA symptoms than students receiving individual ACT psychotherapy did (Juncos et al., 2017). For an outline of the ACC course used here, please visit: https://www.researchgate.net/publication/358271152_Acceptance_and_Commitment_Coaching_for_MPA_Course_Design_Sarah_Mahony.pdf, and for more information about ACC/ACT, please visit www.contextualscience.org.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Wales Trinity Saint David. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this manuscript.

AUTHOR CONTRIBUTIONS

SM and DJ designed the study. SM and DW obtained IRB approval. SM created and administered the group ACC course for the six students. DJ provided the ACC training and ongoing supervision for SM about the sample's response to the ACC course, and about SM's quantitative data and issues related to statistical significance. DJ and SM co-wrote and edited the manuscript. DW provided supervision to SM on the study's ethical matters and on understanding the qualitative data. All authors contributed to the article and approved the submitted version.

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REVIEW
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Current State and Future Directions of Technologies for Music Instrument Pedagogy

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Technological advances over the past 50 years or so have resulted in the development of a succession of hardware and software systems intended to improve the quality and effectiveness of Western music instrument pedagogy during classroom instruction or individual study. These systems have aimed to provide evaluation or visualization of single or combined technical aspects by analyzing performance data collected in real time or offline. The number of such educational technologies shows an ever-increasing trend over time, aided by the wide diffusion and availability of mobile devices. However, we believe there are unrealized opportunities for modern technologies to help music students in their technical development and assist them during their practice sessions in between visits to their teachers. The ubiquity of PCs and mobile devices with built-in microphones, speakers, and cameras has inspired the development of media technologies in support of music pedagogy. They offer an attractive potential for implementing audio signal processing algorithms addressing different technical skills of the performer, providing real-time feedback, collecting data over time, and applying statistical models. Despite this potential, most available software for music instrument pedagogy remains very limited in functionality. This study provides a survey of music edTech software available, together with the methods of use, addressed technical skills, commonalities, and limitations. Results show that most current software is based on the metronome and tuner, with only a few systems that have limited abilities to follow a performance in real-time and compare it to a given score to monitor correctness of notes, intonation, and rhythm. The survey also highlights a high and under-exploited potential regarding the monitoring of other more specific technical skills, which are more instrument-dependent, but no less important, such as the control of dynamic range and clarity of the attack. This article ends with a discussion of possible directions for future development of technologies to support the practice of music students at different levels, with some consideration for the corresponding signal processing methods that can be utilized or that need advancement. By helping students to more efficiently achieve a high level of proficiency of their instruments with assistive technologies, we hope to minimize stress and afford better enjoyment of the music performance experience for all.

Keywords: technology, learning, musicians, performance, edTech

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1. INTRODUCTION

Musical pedagogy for learning traditional Western musical instruments is currently most often delivered in one-on-one or group contexts through a master-apprentice model, typically one time per week for 30–60 min per session (Hanken, 2017). Between those meetings, students practice on their own the assigned exercises and, attempting to apply the suggestions received in class, try to reach the learning goals set out by the instructor. It is a common problem that students either misunderstand or do not correctly remember the details of a performance technique (Welch, 1985), which can lead to frustration, slower development, and potentially termination of music studies.

Evidence from a wide variety of motor control tasks shows that real-time visual feedback can accelerate the learning progress (Shea and Wulf, 1999) and can help learners to identify, become aware of, or modify specific bodily actions (Welch et al., 2005). These findings suggest the development of technological tools based on audiovisual feedback to help music students address the aforementioned problems. Indeed, improvements in the effectiveness of learning classical music through aural and visual feedback has been demonstrated in different study applications (Ferguson, 2006; Leong and Cheng, 2014; Malandrino et al., 2019; Pardue and McPherson, 2019).

Among the oldest assistive technologies available for musical practice is the tuning fork, invented in 1711 by John Shore in London (Feldmann, 1997). Presenting a resonance frequency almost constant under any weather condition, this tool was used as a reference for tuning musical instruments. About a century later, the metronome was devised, providing a periodic "tick" sound at a desired tempo, typically in beats per minute, that can be set by the user. Patented for musical purposes in 1815 by Johann Maelzel, the metronome was proposed as a tool for composers, to indicate in a simple and objective way the speed of execution of their scores, and for music students, to develop a proper observance of time (Parker, 1825). More recently, based on the tuning fork principle, electronic tuners have become widely available and inexpensive, providing feedback on a player's intonation with respect to a particular tuning system, though they are often only used at the beginning of a practice session to make sure an instrument is correctly tuned.

The rapid spread of digital technologies with ever greater computational capabilities has made possible the continuous development of increasingly refined musical educational software. The metronome and tuner have been transformed from dedicated hardware devices to software that use the integrated components of PCs and mobile technologies. Furthermore, new functionalities and methods of interaction have been added that create greater engagement between the musician and the system.

A comprehensive survey on software for musicians and music teachers was provided by Axford (2015), although this field is constantly evolving and characterized by a high launch and dropout rate, making the list partially outdated after a few years. Despite there being a large number of software developed for music pedagogy in recent years, these systems appear to be underused due to interface inefficiency, technological complexity, and lack of institutional support (Kenny and McDaniel, 2011; Fautley, 2013; Gall, 2013). One might expect this situation to stem from a reluctant and conservative philosophy of thinking toward technology in music education (Creech and Gaunt, 2012; Gaunt, 2017). However, Waddell and Williamon (2019) found evidence of a generally positive attitude toward current and future technology use among teachers, amateur, students, and professional musicians. This also points to a general problem in perceived or actual effectivity of current software technologies for music pedagogy.

Musicians appear to be interested in integrating new technological tools into their practice routines and the ubiquity of mobile devices offers a convenient platform through which such tools can be made available. In this context, the present study provides a survey of existing technologies in the field of music education. By analyzing how they are structured, classifying them and discussing their pedagogical potential, we attempt to show their strengths and weaknesses, with the objective of providing an explanation regarding the gap between the wide availability of edTech music software and its relative under use in music education. We then discuss promising directions for future technologies in this field.

Section 2 outlines how educational technologies have been researched to assist music students. Section 3 presents a collection of the most common and innovative technologies in support of music education, proposing different classifications. Finally, in section 4 we discuss their pedagogical potential in music classrooms, highlighting strengths and weaknesses, in order to illustrate future directions in the development of educational technologies in this field.

2. REVIEW OF MUSICAL INSTRUMENT EDUCATIONAL TECHNOLOGIES

The present study is focused on technologies that support music students in their development in learning to play a musical instrument. Such technologies are more applicable to the learning of standard technical skills (e.g., control of dynamics, articulation, intonation) rather than musical expression, which can be more subjective. Thus, it is expected that these tools will be more beneficial for beginning, rather than advanced, students as they work to develop basic functional skills on a given instrument. From a technological standpoint, we believe that tools designed to evaluate music learning from sound signals, rather than video or special purpose sensors, hold the most promise for widespread acceptance.

There have been several past academic research projects aimed at developing tools to assist with music instrument learning. A project to support piano instruction for beginner students was pursued during the 1980s and early 1990s, with reported achievements in polyphonic score following, page turning, analysis, feedback, and the application of Instructional Design theory (Dannenberg et al., 1993). Another study examined the effect on improving harmonic intonation skills, specifically the ability to play justly tuned major thirds on a reference tone, using

Coda Music Technology's Intonation Trainer software program (Swift, 2003). This technology is based on the concept that musical instruments with variable pitch (e.g., strings, woodwinds, brass) can adjust their pitch as they are played. Players of these instruments are therefore released from the equal tempered intonation system and it becomes important for them to develop the ability to play chords with improved harmonic ratios (compared to equal-tempered tuning), and thus reduce beating effects. However, the idea did not find widespread adoption at a time when accessibility to a computer workstation and recording equipment was still limited to music students.

The Interactive Music Tuition System (IMUTUS) was a European project that ran from 2002 to 2005 with the goal of developing an open platform for training beginner students on the recorder (Tambouratzis et al., 2002; Raptis et al., 2005; Schoonderwaldt et al., 2005). It focused on score matching pitch and note onsets, with a user interface that "graded" students on their overall performance, indicated locations in the score where mistakes were made and provided some basic description on each error.

Another project was focused on the evaluation of saxophone performance using a system to track the fundamental playing frequency and perceived loudness level for specifically prescribed exercises consisting of long tones of both fixed and varying dynamic level (Robine and Lagrange, 2006; Percival et al., 2007; Robine et al., 2007; Percival, 2008). The use of such exercises helped avoid problems in distinguishing between technical errors and deliberate expressive decisions by performers, whereby they may intentionally nuance their playing to achieve expressive effects. The results of the analysis were reported to users *via* a simple computer interface, with additional features to allow comparison of results between other students in a class.

In the field of music information retrieval, a research project investigated the possibility of using machine learning algorithms to differentiate between good and poor quality trumpet notes (Knight et al., 2011). Each of the notes were analyzed and rated individually in a monophonic and unaccompanied context. Although the results of this study were not conclusive, the widespread application of artificial intelligence methods in nearly all computing contexts offers opportunities for the development of tools to provide useful feedback to students learning to play music instruments.

A more recent European Commission project, Technology Enhanced Learning of Music Instruments (TELMI, 2016–2019) included the design and implementation of new interaction paradigms for music learning and training based on state-of-the-art technologies (Kholykhalova et al., 2017; Ortega et al., 2017; Giraldo et al., 2019; Perez-Carrillo, 2019). The project focused primarily on violin performance, with the development of a prototype tool called SkyNote that can provide real-time feedback on pitch and intonation, dynamics, tone quality, and rhythm. When combined with a motion-tracking system, SkyNote can also monitor specific aspects of bowing technique including bow tilt, speed, weight, contact point, inclination, and direction. A recent project reported the use of an interactive robot for recorder tutoring (Bagga et al., 2019).

A limited number of technologies have been commercially developed to assist with general music learning, such as software systems for music theory, ear and rhythm training, music notation, and music instrument practice. In section 3, we provide an overarching overview of these software, analyzing classifications between them and examining their functions. In section 4, the potential limitations of such software and the possible future directions from the perspective of optimal technology enhanced music learning are discussed.

3. REVIEW OF CURRENT EDUCATIONAL TECHNOLOGIES

In this section, a list of computer software and mobile apps, chosen among the most popular for number of downloads and the most innovative systems created for music pedagogy, is analyzed and described. The software selected in alphabetical order are (refer to **Table A1** for URL references): Anytune Pro+, Amazing Slow Downer, EarMaster, Estill Voiceprint Plus, forScore, GNU Solfege, Guitar Pro, GuitarToolkit, GuitarTuna, KORG cortosia, Knock Box Metronome, Modacity: Pro Music Practice, liveBPM—Beat Detector, Piascore, QuantiForce, Rec'n'Share, Rhythm Teacher, Rhythm Trainer, Riyaz, RTFactory Rudiments, SkyNote, SmartMusic, Tempo, The Metronome by Soundbrenner, TonalEnergy, tonestro, Visual Note, Yousician. These edTech systems offer functionality normally applicable to all categories of musical instruments, with some exceptions for technologies dedicated to plucked strings (i.e., Guitar Pro, GuitarToolkit, GuitarTuna, Visual Note, Yousician), to percussion (i.e., liveBPM, Knock Box Metronome, RTFactory Rudiments) or winds and bowed strings (i.e., KORG cortosia, QuantiForce, tonestro). Some of the systems provide flexibility in terms of expected proficiency level, allowing the learning goals and exercise levels to be modified as the student progresses.

As mentioned in section 1, an inclusive list of software in support of music education is provided by Axford (2015) in a 250+ page book published in 2015 that is now partially outdated, given the high birth and death rate of these technologies. For this reason, we prefer to avoid the replication of a similar updated work, but to focus on the classification of the pedagogical aspects addressed. Thus, we have chosen to present a comprehensive list of software across the range of provided functionality and adopted hardware components. Within each category, we select the most popular—in terms of number of downloads—or innovative systems reported in publications.

3.1. Classification Based on Functionalities

Table 1 provides a list of the computer software and mobile apps considered in this study. The categories adopted for the classification are described below.

3.1.1. Digital Score Rendering

All software applications in this category provide a score in Western diastematic notation. The musician can add annotations as on a paper score (i.e., forScore, Piascore), play by turning the page through a specific functionality (e.g., foot switchers, touch pad, wink detection on camera), write in musical notation

TABLE 1 | List of software in support of music instrument learning classified according to the provided macro-functionalities.

Software	Digital score	Metronome	Tuner	Rhythmic refinement	Sound	Fingering display	Performance feedback	Statistics	External hardware
Piascore	✓	✓	✓						
forScore	✓	✓	✓						
Modacity		✓	✓					✓	
GuitarToolkit		✓	✓			✓			
Guitar Pro	✓	✓				✓	✓		
GuitarTuna		✓	✓			✓			
Visual Note		✓	✓			✓	✓		✓
SmartMusic	✓	✓	✓			✓	✓	✓	
tonestro	✓	✓	✓			✓	✓	✓	
Yousician	✓	✓	✓			✓	✓	✓	
TonalEnergy		✓	✓		✓				
KORG cortosia		✓	✓		✓				
QuantiForce					✓				✓
Riyaz – Learn to Sing		✓	✓		✓		✓	✓	
Vocal Pitch Monitor		✓	✓		✓				
Estill Voiceprint Plus			✓		✓				
SkyNote	✓	✓	✓		✓		✓		✓
GNU Solfege		✓		✓					
EarMaster	✓	✓	✓	✓			✓	✓	
liveBPM				✓			✓	✓	
Tempo		✓	✓	✓					
Anytune Pro+				✓					
Amazing Slow Downer				✓					
Rec'n'Share				✓					
Rhythm Trainer				✓					
Knock Box Metronome		✓		✓					
RTFactory Rudiments	✓			✓				✓	
Soundbrenner		✓		✓			✓		✓

directly by playing the instrument (i.e., Guitar Pro), or following the score on a rolling window. Such software can also keep track of how much time the user spends on each exercise, allowing statistical calculations on the distribution of study time. While applications in this category do not directly assist with pedagogy, they provide a useful and popular functionality in music performance, especially as digital versions of music scores become prevalent. This type of software contains pedagogical potential especially when embedded in larger-scale systems that include algorithms to analyze the performer's sound in parallel and provide visualization or feedback on musical skills. A popular program in this category includes forScore, which offers the possibility to read PDF scores, organize music through metadata, build set lists, annotate, rewrite lyrics, add music notation, share, download and edit the scores, as well as providing metronome, tuner, and MIDI keyboard functionalities.

3.1.2. Metronome and Basic Rhythm Functionalities

This category includes software systems that provide metronome functionality. This can be implemented according to its standard application by marking every beat, playing rhythmic structures of more complex subdivisions (i.e., Soundbrenner, TonalEnergy), detecting the metronomic tempo through tapping (i.e., KORG cortosia, Soundbrenner, TonalEnergy), illuminating the correct fingering in time (i.e., Visual Note), or verifying in real time the rhythmic accuracy of a musical performance on a given score (i.e., EarMaster, Riyaz, SkyNote, SmartMusic, tonestro, Yousician).

3.1.3. Tuner Functionalities

Technologies included in this category provide tuner functionality. It can be implemented to facilitate the intonation of strings (i.e., GuitarToolkit, GuitarTuna, TonalEnergy, Visual Note, Yousician), as a chromatic tuner (i.e., EarMaster, forScore, GuitarToolkit, Modacity, Piascore, SmartMusic, TonalEnergy, Visual Note, Vocal Pitch Monitor), to tune on tuning systems other than equal temperament (i.e., Riyaz, TonalEnergy), to tune drums (i.e., Tempo), or to check the accuracy of the pitch of a musical performance on a given score (i.e., EarMaster, Riyaz, SkyNote, SmartMusic, tonestro, Yousician). For example, tonestro "listens" to a student playing along with a given (or

purchased) score and provides feedback when pitches or rhythms are incorrectly executed.

3.1.4. Systems That Assist With Advanced Rhythmic Refinement Skills

Software in this category offer exercises to improve rhythmic skills, such as rhythmic solfeggio tapping with the finger or clapping (i.e., EarMaster, GNU Solfege, Rhythm Trainer), identifying the metronomic value through sound analysis in real time (i.e., liveBPM) and offline (i.e., Rec'n'Share), setting tempo changes and rhythm patterns with increasing speed at any given number of beats (i.e., RTFactory Rudiments, Tempo), changing the tempo of an audio track (i.e., Amazing Slow Downer, Anytune Pro+, Rec'n'Share), setting cycles in which the metronome plays intermittently to check if the tempo is maintained during the absence of the beats (i.e., Knock Box Metronome), or providing rhythmic pulses on wearable hardware (i.e., Soundbrenner).

3.1.5. Systems That Assist in the Technique and Control of Sound Production

This category includes features that provide an analysis or visualization of sound characteristics and technical aspects other than pitch, such as vibrato (i.e., Riyaz, Vocal Pitch Monitor), sound spectrum (i.e., Estill Voiceprint Plus, TonalEnergy), articulation and timbral characteristics (i.e., KORG cortosia, SkyNote), bow and brass mouthpiece pressure (i.e., QuantiForce), or posture and bow control (i.e., SkyNote). An interesting application in this category, KORG cortosia, was developed through a collaboration between KORG Inc. and Pompeu Fabra University (Bandiera et al., 2016). It provides an evaluation of what is defined as sound "goodness" by rating in real time five elements: pitch stability, dynamic stability, timbre stability, timbre richness, and attack clarity.

3.1.6. Fingering Display

All software applications in this category provide correct fingering to play a specific note or chord. It can be displayed in the form of a chord library (i.e., GuitarToolkit, GuitarTuna), on a rolling score window in real time (i.e., Guitar Pro, Yousician), offline (i.e., SmartMusic, tonestro), or by illuminating the keys *via* a purchased external hardware component (i.e., Visual Note). A popular software in this category includes Yousician, which illustrates the appropriate fingering on a scrolling window in real time with the performance of a song. For plucked string instruments, it shows which string should be plucked, the corresponding fret number to press, and different colors recommend which finger to use for playing the note. In case there are different alternative fingerings for playing the same note or the same chord, Yousician suggests the most convenient solution to perform the specific song more easily.

3.1.7. Systems Providing Feedback on Music Performances

This category includes functionalities that display, monitor and/or assess the correctness of a music performance. The implementation of these functionalities is coupled with algorithms that check the accuracy of rhythm and pitch (i.e., Guitar Pro, Riyaz, SmartMusic, Tonestro, Yousician), timbre and articulation (i.e., SkyNote) for a given score to provide an overall grade of the performance. This type of software is generally applied to the overall evaluation of pieces from the repertoire of performance and musical expression. However, alternative applications can be found dedicated to individual technical aspects, such as monitoring tempo (e.g., LiveBPM, Soundbrenner) and indicating fingering (e.g., Visual Note) in real time.

3.1.8. Systems Applying Statistical Models to Keep Track of the User's Proficiency

Software in this category collect data on performances, displaying or analyzing them according to specific parameters, and store and process the results over time by applying statistical models to illustrate the progress of the musician (i.e., EarMaster, Riyaz, RTFactory Rudiments, SmartMusic, tonestro, Yousician). For example, EarMaster provides a window interface where users can visualize their achieved results and the time spent on each exercise, to help them monitor their progress and analyze strengths and weaknesses. The statistics functionality is also used to provide a visualization of a specific parameter over a short period of time for a single performance (i.e., liveBPM).

3.1.9. Systems Requiring External Hardware

This category highlights technologies that rely on dedicated hardware components, instead of using the built-in sensors of PCs and smartphones. They can include cameras to provide indications about posture and bow tilting angles through motion capture techniques (i.e., SkyNote), wearable devices (i.e., the Soundbrenner metronome smartwatches), force transducers (i.e., QuantiForce), or LED lighting systems (i.e., the LED keyboard adapter for guitar proposed by Visual Note).

3.2. Classification Based on Hardware Components

In **Table 1**, a set of macro-functionalities for technology enhanced music learning is represented. An alternative classification consists in subdividing the aforementioned software according to the hardware components used:

- **Graphic display**: Many software systems use a graphic display to illustrate sheet music, show fingerings, provide light pulses as metronome indication, and generally explain the software functionalities. Some systems also use touch displays, for example, to add annotations or determine rhythmic information by finger tapping.
- **Microphone**: Systems that record audio signals for further processing and display make use of microphones in order to extract specific sound information, such as the fundamental frequency, onset detection, spectral descriptors for timbral information retrieval, articulation, vibrato, and loudness metering.
- **Speaker**: Some systems output audio signals through speakers, such as metronome ticks, edited audio tracks or melodic and harmonic accompaniment.

- **Camera**: Visual information can be collected using a camera in order to provide indications about posture and bow tilting angles through motion capture techniques or detect specific cues, such as winks, to turn page.
- **Other hardware components**: The software systems previously mentioned in the external hardware category all make use of non-standard hardware components not provided on PCs or mobile devices.

This further classification clearly indicates how the development of this type of software has tried to exploit the use of built-in sensors normally installed in PCs or mobile phones. Although software programming and calibration difficulties may be introduced, this choice is largely justified by the difference in marketing costs. Indeed, the cost of the software highlighted in the rightmost column of **Table 1** exceeds by more than one order of magnitude the cost of software that rely on already installed built-in components.

Music pedagogy software systems that support audio and video recording of performances for subsequent analysis by students or teachers (e.g., Modacity) are not considered in **Table 1**. These systems allow students to externally identify weaknesses that need improvement and develop their own critical sense. Although this technology is still under-used, it offers very promising pedagogical potential for students of music (Fautley, 2013). However, this study intends to consider systems whose support and feedback are provided by the technology itself through the implementation of dedicated algorithms (and not as subjective judgments provided by the user).

Other categories of functionalities useful for music learning not included in **Table 1** are the inclusion of videos on educational courses and masterclasses [e.g., Pickup Music[1], Riyaz, tonestro, TrueFire (see text footnote 1), Youtube (see text footnote 1)] or the availability of a platform to receive individual private lessons *via* video with professional teachers [e.g., Play with a Pro (see text footnote 1), Riyaz, tonestro]. However, in this case the technology is used just as a communication platform to carry out live or recorded music lessons with a human teacher. This category is beyond the scope of this study, which intends to analyze an exclusive relationship with technology that the student can turn to and rely on during practice sessions in between visits to their instructors. Since music lessons for beginners typically take place once a week, we believe that the individual practice sessions between lessons contain a high learning potential which, when exploited effectively, can improve and speed up the overall learning experience.

Although the list of software examined is far from exhaustive, the described classifications give an idea of the state of the art on how software supporting music pedagogy are structured and what types of algorithms and technologies they implement. Section 4 discusses the classifications provided, identifies their possible limitations and proposes future directions of technologies for music instrument pedagogy.

[1]Refer to **Table A1** for URL references.

4. DISCUSSION

The software survey and classification demonstrates the extent to which the metronome and tuner have been widely adopted by nearly all current music pedagogy technologies. They are implemented in most of the systems considered in **Table 1**, indicating a high level of perceived usefulness. Initially implemented on dedicated hardware devices, the metronome and tuner functions were integrated into PC software or mobile apps, using their built-in components. Despite the huge technological advancement of the Digital Revolution, the functionalities of the metronome and tuner are clearly considered essential in music learning contexts.

We believe that the widespread use of metronome and tuner stems mainly from the fact that they are focused on teaching or assisting with an abstract technical concept. The metronome provides an audible indication of the tempo the player has to maintain during the performance, while the tuner provides a visualization of the fundamental frequency played, comparing it to a previously selected reference frequency. Such tools help the musician to understand musical concepts that are often difficult for performers to consistently internalize or perceive. By clearly understanding the technical concept and then the musical goal to be pursued through an audiovisual learning approach, students can therefore considerably improve the quality of their practice sessions and internalize more quickly a correct way of playing. Thus, music students develop and improve procedural memory, which allows them to learn movements, habits and skills almost independently of their conscious thought (Squire, 1992). These skills, learned automatically and internalized correctly, guarantee musicians a solid and effective technical background on which to rely during the performance and allow them to improve response and recovery to mistakes during performance (Lam, 2020). In fact, being based on abstract concepts, the metronome and tuner can be effectively applied in flexible ways and without particular limitations in most performance contexts, demonstrating their universality of application.

4.1. Current Limitations

The widespread use and perceived usefulness of the metronome and tuner in music pedagogy has inspired numerous other musical software, as previously surveyed, which have focused on developing their application on predetermined musical scores drawn from the repertoire of performance and musical expression. Indeed, current developments in many software systems have focused on expanding the metronome and tuner functionalities to provide real-time feedback on pitch and rhythm correctness during the performance of a given musical score (i.e., Guitar Pro, Riyaz, SkyNote, SmartMusic, Tonestro, Yousician). By applying an objective judgment on the accuracy of rhythm and pitch, these software offer an evaluation of the overall musical performance. However, the adoption of this technological method in the field of music education for beginners may present significant limitations to the effectiveness of their pedagogical experience:

- This type of music software, which evaluate the correct pitch and rhythm, can give the false impression that to play well and be a good musician it is sufficient to play the right notes and in time. However, this is obviously not true. A good musician is a performer capable of communicating emotions through sound, drawing on their wealth of technical skills developed and refined over time. While the musician needs to execute the notes and rhythms correctly, artistic expression fundamentally involves often subtle deviations from exact rhythmic or pitch accuracy. The attention of the performance should be mainly linked to the expressiveness and communication of emotions with the audience (which normally varies according to the type of audience, their response, the acoustics of the environment, the type of concert, etc.); the overall quality of the performance is therefore less suitable to be judged by the software, but rather by human sensitivity. In fact, musicians are granted a flexibility of expression within the technical rules to be less rigid and more communicative. This is one of the main differences between a mere MIDI performance and an artistic interpretation.

  Informal experiments with tonestro, for example, have shown that a very inexpressive performance, in which the notated dynamic and articulation marks were ignored, can achieve very high scores. On the other hand, more expressive musical performances with proper attention to notated articulations and dynamics generally earn poorer scores.
- If the software provides an evaluation of the performance by rigidly judging rhythmic and pitch correctness on a note-by-note basis, according to a subtractive method of judgement (i.e., each error lowers the overall judgement score), the musician's attention will be focused on playing correctly each note in order to achieve the highest final score. This can inhibit the expressiveness of the performer, who concentrates on playing note by note in a pedantic manner, breaking up the melody, instead of artistically playing longer and more expressive musical phrases.

  Moreover, all this can cause an incorrect approach to performance, especially for beginners, who have not yet developed a solid personal style of expression. Musicians become more focused on receiving positive feedback from the software, trying to avoid the appearance of red error marks in the display, rather than trying to express their musical ideas by seeking empathetic contact with the audience. This approach to performance, based on trying to avoid mistakes instead of proposing musical ideas and communicating emotions, can even generate tensions in musicians that ultimately affect their wellbeing.
- Some of the reviewed software follows student progress through statistical analysis of their score. Implementing statistical models applied to collected data to generate a learning curve over time is an effective way to identify strengths and weaknesses for targeted practice. However, this indication is not pedagogically relevant if the software expects the musician to sound like a robot.

Despite these potential limitations in the pedagogical experience for beginners, such software offers powerful playful and entertaining aspects for music players, which greatly encourages user motivation. In particular, the aspect of playing along with backing tracks leads the musician to imagine playing together with others, bringing a deeper involvement in the experience, although the feedback component still continues to present the aforementioned drawbacks.

Another barrier to the adoption of technology within music courses might be represented by ineffective and overly-complicated interfaces. For example, KORG cortosia is one of the few software systems that intends to address different technical aspects beyond rhythm and pitch: pitch stability, dynamic stability, timbre stability, timbre richness, and attack clarity. Although the idea of tackling different technical skills within a single app is compelling, it is severely limited in terms of the interface. The KORG cortosia software shows a five-axis view, each associated with the five different skills considered, and provides an overall numerical score averaged over those five parameters. It is therefore complicated to isolate one parameter at a time, and it is difficult for a student to focus on and manage five at once. For example, a student may need to study pitch stability while playing a crescendo or diminuendo, without the overall numerical score being affected due to changes in dynamics.

Furthermore, even if the functionality of isolating one parameter at a time were easily accessible, a numerical score may not be the most pedagogically effective way to provide feedback. For example, wind instrumentalists need to develop different types of attack or articulation, using different pronunciations, to fulfill equally varied musical needs. It is therefore difficult to implement an algorithm that gives a consistent judgment of attack clarity for all types of attacks. A generic numerical score on this technical skill may not give the students a clear understanding of what they are doing wrong and how to fix the problem. This type of feedback easily risks confusing the students further. A visualization of sound initiation, on the other hand, is much more effective from a teaching point of view, because it allows musicians to associate an image with the execution of a technical skill, and once they understand how the interaction between their body and the musical instrument affects the image, the student has the opportunity to understand how to self-correct and improve. Moreover, a visualization provides flexible feedback that can be adapted to give useful information about different types of a technical skill. For example, a wind musician may associate different images with different types of attack and, by seeking out those images during practice sessions, gain greater clarity on how to manage and master the various articulations.

Other examples of software with possible interface problems are the timbral indications of Estill Voiceprint Plus and TonalEnergy. These systems illustrate the evolution of the audio spectrum over time or the height of harmonic peaks in real time in order to provide indications of the timbral quality of the sound. The sound spectrum and its relative harmonic distribution contain important information about the correctness of the sound produced. An unnatural or strained sound may indicate the presence of muscular rigidity in a wind performer and inefficiency in playing (Thompson, 2003; Jacobs and Nelson, 2006). However, being able to extract this information by

referring only to the spectrogram and its harmonic distribution is a difficult or almost impossible task for a music student.

These difficulties in analyzing particular technical abilities—such as timbre quality or technical skills considered by Estill Voiceprint Plus, TonalEnergy, and KORG cortosia—are further accentuated by the fact that these software systems analyze audio data collected by microphones embedded in PCs or mobile devices. The recorded audio signal therefore depends on the particular model of microphone sensor installed (usually not suitable for recording musical instruments with sufficient quality), on the distance and position of the microphone with respect to the sound source, and on the acoustics of the room. For example, if a trombone player changes orientation or places the smartphone behind the bell in order to better see the display, the feedback provided by the software will be altered compared to when holding the smartphone in front of a stationary bell, making the system unrepeatable and unreliable. In fact, sound dynamics is a determining factor in identifying the timbral properties of an instrument (Fabiani and Friberg, 2011).

Another limit to the creation and production of technologies for music instrument learning involves the cost and complexity of necessary external hardware components. SkyNote, for example, presents excellent goals regarding what we believe can support music pedagogy. However, the project never left the research phase to find a real application in music classrooms, as it requires hardware equipment that is too expensive and sophisticated to be easily obtained and installed by a music student.

In the next subsection, we propose possible directions for technologies in support of music pedagogy that address the limitations mentioned above.

4.2. Future Directions

Given the issues discussed in the previous section, a sensible direction for the development of new pedagogic software systems is to focus on teaching a specific technical concept in an "exercise-like" context (in comparison to a context in which the player may be inclined to be musically expressive). In this way, the musician learns the technical skill in a universal context and, once internalized, can apply it confidently to any performance without incurring the aforementioned risks and limitations. Considering feedback and visualization on a technical aspect, rather than a performance, allows the system to provide higher accuracy and reliability, given fewer variables involved in software development. By focusing on a specific technical skill, players are expected to play like a robot, in order to train their muscle memory through deliberate practice. Systems designed in this way would have a type of functionality that is similar to the metronome and tuner.

There are other technical aspects besides pitch and rhythm that can be addressed with newer technologies and a development in this direction could open new ways to improve musical pedagogy. These technical abilities are generally more dependent on the particular musical instrument played, requiring greater specificity of the parameters analyzed and provided by the system. Here lies significant potential that is still under-explored in the field of technology-enhanced music learning.

Skills which are fundamental for the optimal technical control of a musical instrument include for example dynamics, vibrato, articulation, staccato/tonguing, sound resonance, body setting (e.g., efficient embouchure, bow, and sticks handling), or legato quality. Some of the software listed in the **Table 1** pursue this direction, although in some cases their pedagogical potential may face the mentioned limitations. In the following, a selection of addressed technical aspects, are analyzed and discussed.

4.2.1. Vibrato

Some systems provide a visualization of the evolution of the fundamental frequency or sound spectrum over time (e.g., Vocal Pitch Monitor, Estill Voiceprint Plus). This provides visual indications of the amplitude, frequency and extent of the vibrato.

Possible applicable extensions to these features could include interactive exercises that assess control of these parameters. For example, a system could specify a sequence of long notes, embedded in a rhythmic context, that the performer has to play at predetermined vibrato patterns (e.g., duines, triplets, quatrains at each beat) within specific frequency and amplitude threshold values. Training on these exercises would allow the musician to learn vibrato control under different conditions and master this skill from a technical standpoint. In this way, when performers later want to expressively interpret a piece of music (e.g., aria, sonata, cantata), they will have the flexibility to produce the type of vibrato they feel is most appropriate for that performance, without being constrained by technical limitations.

4.2.2. Attack Clarity

Attack clarity refers to the purity or accuracy of the onset of a sound, especially with respect to achieving the desired fundamental frequency that is not contaminated by noise or undesired frequency components. Attack clarity may involve different characteristics depending on the musical instrument considered. Optimal articulation usually requires a very short time duration between the silence before the attack and the achievement of a fully developed sound, regardless of the particular type of articulation, dynamics, or accent required.

Among the software systems listed, some of them (i.e., TonalEnergy, Vocal Pitch Monitor, Estill Voiceprint Plus) include useful features to provide a visualization of this skill. They in fact provide a display of the evolution of the fundamental frequency or spectrum over time. By looking at the graphs, musicians can partially verify the accuracy of their articulation. However, this functionality could be greatly improved by providing detailed visualization of the attack of the notes produced, using short time windows to analyze the audio signal. Also, it could be very useful to provide feedback (e.g., in milliseconds) on the time duration used to achieve a relatively stationary sound from a timbral point of view.

Advanced sound processing algorithms implemented in SkyNote, within the TELMI project[2], have been developed to identify different types of violin pronunciation (e.g., staccato, martelé, détaché) (Ramirez et al., 2018; Giraldo et al., 2019).

[2]http://telmi.upf.edu/

However, the project has not yet found use in music pedagogy, as it has remained in the research phase.

4.2.3. Dynamics and Timbre Characteristics

Some software provide a real-time display of the sound spectrum or of the harmonic energy content, through which the musician can search for specific timbral characteristics and dynamics (e.g., TonalEnergy, Estill Voiceprint Plus). However, as discussed in section 4.1, their application in music pedagogy is limited due to feedback interpretation difficulties and because the audio recording conditions of a mobile device microphone in a practice room is not guaranteed to provide sufficient levels of repeatability and accuracy. An attempt at interpretation is provided by SkyNote, but only still in an exploratory research setting.

To provide feedback based on timbral characteristics, we might suggest to use a dedicated external microphone that has a configuration to be installed at the same distance and position from the sound source (e.g., clip-on microphones). In this way, the variable of dynamics, which is crucial for the identification of the timbral properties of a sound (Fabiani and Friberg, 2011), is normalized. With this solution, more robust software algorithms can be developed that rely on the recording characteristics of a single microphone sensor, suitable for recording musical instruments, instead of relying on recordings taken from several microphones, usually optimized for voice calls, embedded in different devices. In this case, the additional cost of having to use an external hardware component is justified by the improved reliability of the overall system. The adoption of such a microphone would open the opportunity to provide feedback and visualizations on the sound dynamics produced and on timbral aspects for which a higher quality recording is required.

4.2.4. Relative Tuning

Standard tuners represent useful tools to develop a consistent intonation through intervals, scales, dynamics, and articulation. However, players of variable-intonation pitched instruments (e.g., violin, trombone) must adjust their pitch relative to that of others when performing in ensemble music contexts. It is therefore important that students of these musical instruments develop the ability to listen to the sound of others as they play, understand how much it differs from their own pitch, and correct any discrepancies.

We believe that modern technology has the potential to help musicians of these instruments develop this skill, using graphic displays, microphones, and headphones. It would help future students better integrate into ensemble music groups, more easily find a common pitch, and generally better control the dynamic balance of their sound.

In summary, this study intends to highlight the scarcity of low-cost technologies that provide visualization and feedback on the technical concepts necessary for a complete learning of a musical instrument, as the metronome and the tuner do. Their development, coupled with data collection and statistical analysis capabilities to monitor the level of the musician in their respective technical skills, would provide significant support to visualize progress over time, identify effective practice routines, and method of study, as well as represent important tools for stress management and improving performance wellbeing.

5. CONCLUSIONS

This study presents a review of the main features provided by the technological tools that have been developed to support music instrument learning and investigates their potential benefits and utility. The widespread success of the metronome and tuner have prompted the subsequent development of numerous software and mobile applications that attempt to go beyond basic rhythm and pitch accuracy. However, their use in applied performance repertoire contexts, where the system makes an evaluation that discourages artistic expression, can present important drawbacks in pedagogical experience especially for beginners, who generally have less technical control and sense of self-evaluation.

There are numerous other facets of learning to master an instrument that are still poorly addressed by current music technologies, such as control of dynamics, attack and release precision and refinement, flexibility with timbre, vibrato, embouchure configuration and variation, finger position and movement, posture, and breathing, to name a few. We believe that the development of new technologies that provide visualization or perception of technical concepts related to the learning of a specific musical instrument may find broad use in music practice rooms, if they are relatively cheap and have user-friendly interfaces. Clearly understanding a musical concept to be researched and pursued in individual study sessions through audiovisual systems can consistently help instrumentalists in becoming more efficient with their practice. In addition, such systems would represent objective yardsticks for teachers to verify proposed recommendations and improve lesson effectiveness.

By suggesting these new directions for future assistive technology supporting music pedagogy, we hope to better connect the field of technology development with the music school community so that students can enjoy a more fulfilling artistic experience.

AUTHOR CONTRIBUTIONS

AA: conceptualization, survey, discussion, visualization, writing—original draft, and review and editing. GS: supervision, discussion, visualization, and review and editing. Both authors contributed to the article and approved the submitted version.

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APPENDIX

Table A1 | List of considered software with corresponding URL (accessed December 11, 2021).

Software	Reference link
Anytune Pro+	https://anytune.us/
Amazing Slow Downer	http://www.ronimusic.com/asdiphone.htm
EarMaster	https://www.earmaster.com/
Estill Voiceprint Plus	https://store.estillvoice.com/collections/clinical-software/products/voiceprint-plus-cd-mac-edition
forScore	https://forscore.co/
GNU Solfege	https://www.gnu.org/software/solfege/solfege.html
Guitar Pro	https://www.guitar-pro.com/c/15-guitar-pro-ios-android
GuitarToolkit	https://apps.apple.com/ca/app/guitartoolkit-tuner-metronome-chords-scales/id284962368
GuitarTuna	https://yousician.com/guitartuna
KORG cortosia	https://www.korg.com/us/products/software/cortosia/
Knock Box Metronome	https://www.pfeiferdrumco.com/knock-box-metronome.html
Modacity	https://www.modacity.co/
liveBPM - Beat Detector	https://play.google.com/store/apps/details?id=com.DanielBach.liveBPM
Piascore	http://piascore.com/
Pickup Music	https://www.pickupmusic.com/
Play with a Pro	https://www.playwithapro.com/
QuantiForce	https://www.bonsai-systems.com/music-tech/
Rec–n–Share	https://ca.yamaha.com/en/products/musicalinstruments/drums/eldrums/apps/recnshare/index.html
Rhythm Teacher	https://play.google.com/store/apps/details?id=net.gamya.rhythm
Rhythm Trainer	https://play.google.com/store/apps/details?id=ru.demax.rhythmerr
Riyaz	https://riyazapp.com/
RTFactory Rudiments	https://rhythmtoolsfactory.de/appsios/rudimentsios/
SkyNote	http://telmi.upf.edu/
SmartMusic	https://www.smartmusic.com/
Tempo	http://www.frozenape.com/tempo-metronome.html
Soundbrenner	https://www.soundbrenner.com/
TonalEnergy	https://www.tonalenergy.com/
tonestro	https://www.tonestro.com/
TrueFire	https://truefire.com/
Visual Note	https://www.visual-note.com/
Yousician	https://yousician.com/
Youtube	https://www.youtube.com/

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Musicdrops@work: Impact of Shared Listening to Short Live Music Interventions on Sense of Belonging and Subjective Wellbeing at Work

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Assuming live music can foster belonging in the workplace, this study linked companies in the secondary and tertiary sectors with the world of music performance. Specifically, students from a Swiss music university offered live mini-concerts (10 min of classical music) on the premises of three companies over a period of 3 months. To analyze the impact of these brief musical interventions on the sense of belonging of staff in these companies, a mixed methods approach was adopted using a standardized questionnaire (Barcelona Music Reward Questionnaire, a short online questionnaire on the appreciation of the music and the emotional state induced, and focus groups interviews at the end of the experiment). The short concerts were much appreciated. On the individual level, they led to a greater sense of pleasure and were perceived as a break, a possibility to connect to one's emotions and above all, as a "moment for oneself." On the group level, the short concerts allowed the members of teams to meet, prompted conversations and new ways of sharing, created links, and offered opportunities to get to know work colleagues differently and to discover them on a more personal level.

Keywords: live music, belonging, wellbeing, workplace, musicking, intervention research, shared listening

INTRODUCTION

Positive relationships are one of the five pillars of authentic wellbeing identified by Seligman (2011). For Reis and Gable (2003), relationships may be the most important source of life satisfaction and wellbeing. These important relationships include not only family and personal friends but also the wider groups and communities to which we belong. Thus, forming connections and a sense of community with co-workers around a shared mission or identity is a major contributing factor in individuals' wellbeing and achievement at work.

In 2020, belonging at work became an increasingly popular topic of conversation for HR and business leaders. In fact, it ranked as a top topic in the Deloitte (2020) Global Human Capital Trends survey, with 79% of organizations considering it important for their success. A growing body of work explores the experience of belonging in the workplace, including the conditions and factors favoring its emergence and their respective contribution to strengthening it. The question this paper addresses and which, to our knowledge, is unexplored so far,

concerns the potential contribution of music—more specifically of short live music interventions—to the sense of belonging in the context of work.

Belonging, a Fundamental Human Need

There is general agreement in the literature that belonging—the subjective feeling of deep connection with social groups, physical places, and individual and collective experiences—is a fundamental human need that almost all people seek to satisfy (Maslow, 1954, 1968; Baumeister and Leary, 1995; Deci and Ryan, 2000; Leary and Kelly, 2009; Allen et al., 2021). According to Maslow's (1968), of the five levels, the need for love and belonging ranks third, after the physiological and safety needs (i.e., basic needs) and is a vital step on the journey to self-actualization. Baumeister and Leary (1995), among the top-cited authors for the concept of belonging, assemble a large body of empirical findings and conclude that "human beings are fundamentally and pervasively motivated by a need to belong, that is, by a strong desire to form and maintain enduring interpersonal attachments. People seek frequent, affectively positive interactions within the context of long-term, caring relationships" (p. 522). More recently, Walton and Brady (2017) define belonging as "a feeling of being accepted, included, respected in, and contributing to a setting, or anticipating the likelihood of developing this feeling" (p. 272). This understanding of the concept brings to light an interesting nuance: a sense of belonging may be felt even in settings where strong relationships do not yet exist, whereas even in settings where close relationships do exist, the feeling may be one of a lack of belonging.

So, why is belonging important? Well, it increases positive emotions like elation, contentment, and calm (Baumeister and Leary, 1995). A sense of belonging also predicts the extent to which individuals find their life meaningful (Lambert et al., 2013). Positive emotions, relationships, and meaning allow thriving (Frederickson, 2009) and are pillars of flourishing and wellbeing (Seligman, 2011). In psychologist Christopher Peterson's words, *other people matter* (Park et al., 2013). In fact, they matter so much, that they become a source of our self-esteem (Tobin et al., 2014). Self-concept is based on not only one's unique traits and characteristics (the individual self), but also the attachments formed with significant others (the relational self) and the social groups with which one identifies (the collective self), forming a continuous back and forth between "I" and "we" (Brewer and Gardner, 1996).

Importance of Belonging at Workplace

Positive interactions in the workplace have been shown to improve job satisfaction and positively influence staff turnover, as employees who experience support from colleagues are more likely to remain in an organization in the long term (Hodson, 2004; Moynihan and Pandey, 2008). Social interactions in the workplace have been found to increase self-reported positive feelings at the end of the workday (Nolan and Küpers, 2009). Furthermore, they have a positive impact on employee engagement, which in turn results in improved productivity or performance outcomes, lower staff turnover and absenteeism, and fewer safety incidents (Gallup, 2015).

Following the experience of remote working during the COVID-19 pandemic, fostering employee belonging appears to be one of the most important human resource issues for 2022. "There is simply no question that the establishment of a culture of belonging must be a strategic point of focus for every business and HR leader seeking an engaged, satisfied, and resilient workforce" [Achievers Workforce Institute (AWI), 2021, p. 3]. In the 2020 Deloitte Human Capital Trends report with its 8,949 global participants, more than 90% of respondents agreed that belonging impacts performance, 79% said that fostering a sense of belonging in the workforce would be important to their organization's success in the next 12–18 months, and 93% agreed that a sense of belonging drives organizational performance. The findings of the 2020 BetterUp "Belonging at Work study" tend toward the same direction. According to the 1,789 people it surveyed, the benefits of a strong sense of belonging are a 50% reduction in turnover rates, a 56% increase in overall job performance, and a 75% reduction in employee sick days.

Music as Means of Fostering Belonging

Music is a powerful social magnet, even if one may play or listen to it alone, in the privacy of one's four walls or with headphones. In almost all cultures globally, and throughout history, music is a social activity (Nettl, 2000) that involves movement to rhythmic sound and plays a significant role in both creating social bonds (Freeman et al., 2000; Dunbar, 2004; Trevarthen, 2012) and permitting meaningful cooperative relationships between groups (Hagen and Bryant, 2003). This effect of musical activity on "social bonding" (the psychological experience of increased social closeness, reflected in prosocial behaviors) may be responsible for the widespread occurrence of musical activities and may have played an important role in the evolution of human sociality (Dunbar, 2012).

In phase with this idea of music creating social bonds, Small (1999) argues for introducing a new word to the English dictionary, that is, "musicking" (from the verb "to music"): any activity involving or related to music performance. According to his own definition, "the essence of music lies not in musical works but in taking part in performance, in social action. Music is thus not so much a noun as a verb, "to music." To music is to take part in any capacity in a musical performance, and the meaning of musicking lies in the relationships that are established between the participants by the performance" (p. 9). A musical performance is therefore an encounter among human beings wherein meaning is generated beyond the simple meanings assumed to be borne by a musical work. Furthermore, a musical performance is situated; it takes place within a physical and social space "which makes its own meanings" (Small, 1999, p. 13) and which must therefore be taken into account when observing, analyzing, or trying to understand it.

In a similar vein, Moran (2014) examines the social implications identified in embodied music cognition research. This line of thinking comes hand-in-hand with a social interpretation of music, focusing on the real-world basis of

its performance, and fostering an empirical approach to musician movement regarding the communicative function and potential of those movements. This paradigm is in contrast to the "individualist" approach, which treats performers and listeners as separable from each other and from the musical stimulus, potentially understating the extent of the interaction among these three components. An essential feature of musical activities is the importance of shared rhythms and the frequent externalization of predictable rhythms (e.g., shuffling feet or swaying heads) that allow synchronization to occur between two or more people (e.g., Bispham, 2006; Merker et al., 2009; Launay et al., 2013). This mechanism of interpersonal synchrony is known as *self-other merging* and may account for the social bonding effect of music. There is evidence that synchronization among people can influence their subsequent positive social feelings toward one another. This has been demonstrated in a number of experimental studies, involving participants tapping synchronously with an experimenter (Hove and Risen, 2009; Valdesolo and DeSteno, 2011), walking in time with other people (Wiltermuth and Heath, 2009) and dancing together (Reddish et al., 2013).

Given the reliance of the self-other merging account of social bonding on simultaneous, similar movements, it is likely that this mechanism does not provide a complete account for the bonding that arises in large group situations. Hence, there is a need to examine the roles played by other factors, for example, endorphins that play a central role in the maintenance of non-sexual, non-kinship social bonds (Machin and Dunbar, 2011) and that arguably mediate the pleasure experienced when listening to music (e.g., Koelsch, 2010).

Aims and Research Questions

The impact of music listening in work settings has been studied since the 1920s and is well documented (Gatewood, 1921; Antrim, 1943; Kaplan and Nettel, 1948; Uhrbrock, 1961; Fox, 1971; Thorsén, 1989; Lanza, 1994; Oldham et al., 1995; Sloboda et al., 2001; Korczynski, 2003; Lesiuk, 2005; Prichard et al., 2007; Haake, 2010, 2011; Raglio et al., 2020). Nevertheless, these studies and publications focus mainly on job performance, productivity, stress reduction or mood regulation, and concern listening to recorded music.

What about the subjective experience of employees engaging in music at work, what about the impact of different ways of musicking on both a workplace community and individuals? Little research has been done on the subject so far. One exploratory study examined how choral singing at work was experienced and how it changed organizations (Jansson and Balsnes, 2015). Four axes of impact were identified: enjoyment, comfort zone, communality, and identity and roles. According to the authors, singing interventions at work can change the way how colleagues view each other and transform the workplace as a practice community. The present research is a continuation of this exploratory study, while proposing another form of musical engagement at work, namely collective listening of live music. The objective was to provide answers to the following main research question: How is a series of short live music interventions offered during work time experienced individually and collectively, and in what way does this experience foster a sense of belonging among the staff who attended? A secondary research question sought to identify factors—for example, the composition of teams, the structure or culture of the company, or the infrastructure available—facilitating or hindering the impact of the short live music interventions on social bonding and hence on the feeling of "togetherness."

MATERIALS AND METHODS

Participants

Three companies in the canton of Vaud (Switzerland) took part in the project: a car garage, an engineering office, and a kitchen sales space. A series of short concerts was offered to them free of charge. In exchange, the companies agreed to free up some or all of their staff for 10 min a week outside their usual breaks to attend these musical moments, to allow data to be collected through questionnaires, interviews, and participant observation, and to host a piano for the duration of the project (and to cover the costs associated).

Table 1 gives some indication of the teams from each of the three companies part in the project (number of staff, socio-demographics, and music listening habits). The kitchen sales team appears to strike the best gender balance, followed by the engineering office team, whereas the composition of the garage team was strictly male (only 25 of the 64 car garage employees filled out the preliminary questionnaire, mainly due to communication and coordination problems between the HR department—responsible for distributing and collecting the forms—and the team, but this had no impact on the gender distribution). On average, the teams of the engineering office and of the car garage were younger than the kitchen sales team. In terms of educational background, the engineering office had the highest, but also the most diverse level of education.

There were no significant differences in terms of hours of weekly music listening. In terms of musical practice—present and past—the kitchen sales team came out on top, followed by the engineers, then the garage employees. Finally, with regard to the styles and genres of music listened to by the employees of the three companies, the repertoire evoked by the kitchen sales team is more varied than that of the engineers, who in turn evoked a wider range than the technicians and mechanics of the garage.

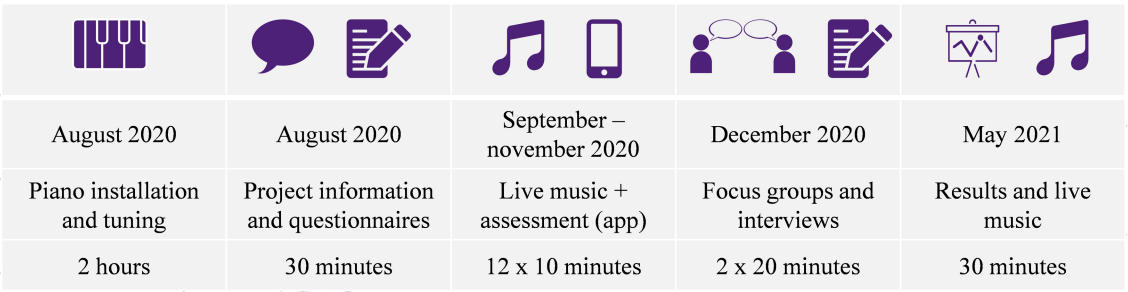
Method

Separate agreements specifying the terms and conditions and above all the general timetable for the project (**Figure 1**) were established with each company. However, the timetables agreed at that stage were later modified due to the COVID-19 pandemic. The start of the weekly musical interventions, planned for March 2020, was postponed until mid-August. In addition, instead of the 12–16 mini-concerts initially planned, only 11 consecutive concerts could be performed before the arrival of the second wave of coronavirus infections in Switzerland and the increasingly severe restrictions introduced as of the end of November 2020.

TABLE 1 | Socio-demographic data of the staff who participated in the project.

	Car repair		Kitchen sales		Engineering office	
	Workshop staff, *N* = 64		Office team, *N* = 30		Whole staff, N = 33	
	N	Valid %	*N*	Valid %	*N*	Valid %
Gender						
Men	25	100.00	17	58.6	22	68.8
Women			12	41.4	10	31.2
Education						
CompulsorY	7	29.2	1	3.4	3	9.4
Apprenticeship	16	66.7	16	55.2	12	37.5
Baccalaureate	1	4.2	6	20.7	2	6.3
Bachelor			2	6.9	2	6.3
Master			4	13.8	10	31.3
PhD					3	9.4
Music listening						
<1 h/week	1	4.0	1	3.3	1	3.2
1 h/week	3	12.0	4	13.3	6	19.4
3–6 h/week	7	28.0	10	33.3	9	29.0
> 6 h/week	14	56.0	15	50.0	15	48.4
Musical practice						
Past	9	36.0	17	56.7	14	45.2
Current	1	4.0	7	23.3	6	19.4
Styles of music listened to						

The category of staff and the total number of persons concerned by the project are, for each of the three companies, followed by the answers of those who filled in the French version of the Barcelona Music Reward Questionnaire (BMRQ; Saliba et al., 2016). Each time, the N and % of valid answers are indicated.



August 2020	August 2020	September – november 2020	December 2020	May 2021
Piano installation and tuning	Project information and questionnaires	Live music + assessment (app)	Focus groups and interviews	Results and live music
2 hours	30 minutes	12 x 10 minutes	2 x 20 minutes	30 minutes

FIGURE 1 | Calender of the project.

Once the agreements were signed, professional music students[1] ready to play a short program (6–8 min of music) in each of the three companies were recruited. Based on their proposals, a varied repertoire (always in a small formations, duo, or trio), mainly classical, was put together (see **Supplementary Table**).

To gather information on how these interventions were received and experienced, a mixed methodology was used combining questionnaires, observations, and interviews. Before the first concert, all collaborators involved in the project were invited to complete the French version of the Barcelona Music Reward Questionnaire (BMRQ; Saliba et al., 2016) with a view to obtaining select socio-demographic information and to understanding the place of music in their lives. The BMRQ

[1]HEMU – Haute École de Musique.

examines five main facets that characterize musical reward experience in individuals: musical seeking, emotion evocation, mood regulation, social reward, and sensory motor. Musical seeking refers to the way individuals pursue music-related activities (e.g., attending concerts, playing an instrument) or seek additional information about music they listen to (performers, composers). The emotion evocation aspect is related to the emotional impact of music on individuals. In contrast, the ability of listeners to use music to modulate their emotions (i.e., to relieve stress, to release emotions, to comfort) is referred to as mood regulation. The social reward facet examines the social bonding effect of music on individuals. Lastly, the sensory motor facet addresses the capacity of music to induce body movements in certain individuals (i.e., head nodding, dancing). The questionnaire contains 20 statements, four per facet. Participants indicate the level of agreement with each statement by using a five-point scale ranging from "fully disagree" (1) to "fully agree" (5).

During the musical moments, participant observation (logbook and observation grid) allowed the course of the interventions to be recorded. In addition, after each concert, listeners used an application downloaded to their mobile phones to rate the following aspects on a five-point scale ranging from "fully disagree" (1) to "fully agree" (5): their appreciation of the music performed (I enjoyed the music that was played), their emotional experience (I was in a constant mood during the musical intervention), their physical reactions (My body was reacting during the musical intervention), their feeling of living a common experience (I felt close to the other people present), their desire to share about this experience (I wanted to share with the other people present), and their ability to leave or forget the reality (I forgot the realities of my immediate environment). Finally, and after the series of musical interventions, four focus group interviews were held with 17 volunteer staff members from each of the three companies in order to explore with them further specific issues relating to the experience. Taking part in the first interview were four long-standing employees of the car garage (11.9 years on average in the company); in the second were two women and three men of the kitchen sales team (5.3 years on average); in the third, one woman and three young men working in the engineering office (3.5 years on average); and in the fourth, four more-experienced men from the engineering office (5.3 years on average). Each focus group interview lasted 30–45 min.

Data Analysis

The responses to the preliminary questionnaire (BMRQ; Saliba et al., 2016) and the data from the smartphone application (i.e., feedback on participants' subjective experience of interventions) were imported into SPSS (version 24) for simple statistical processing (descriptive statistics, e.g., frequencies and means; Spearman correlations, *t*-tests). The interviews were recorded, transcribed in full, and then coded using NVIVO software, in order to carry out a thematic analysis. Three successive deductive coding steps were carried out in NVIVO, first identifying "parent nodes" reflecting the main categories of analysis, and then subdividing them into child themes and sub-nodes, some of which were further sub-divided into grandchild sub-nodes.

Ethical Concerns

To respect confidentiality, both of staff and management, the names of the three companies that participated in the project do not appear in this publication, and the names of the focus group participants have been changed. To allow employees to express themselves freely, it was agreed with HR managers and management that only aggregated data would be communicated to them. Finally, in accordance with our data management plan, the raw data made available on the SWISSUbase platform[2] have been anonymized.

RESULTS

Relying on the focus group interviews, we will first examine how the series of short live music interventions was experienced at the time of listening. We will then look at its impact on the lives of the teams and therefore on its possible contribution to the feeling of belonging of the employees. Finally, following a question posed by Small (1999), that is, "[w]hat does it mean when this performance takes place at this time, in this place, with these people taking part?" (p. 13), we will try to identify factors likely to favor the impact of the musical interventions.

Experience at the Time of Listening

At the individual level, the mini-concerts seem to have been experienced as moments of pause and relaxation.

> You feel better afterwards! In any case, speaking for myself, I did, it was… Yeah, I felt, I felt good, almost as rested as after a long break, when actually it was only 10 min [Lisa].

This pause provided a breath of fresh air (an idea mentioned several times) and contributed to wellbeing, in the moment, sometimes also for the rest of the day:

> I think it went with me a little for the rest of the day… We were a bit tense, we came to listen to the music, we got some fresh air, and then back off to work again and, I do not know, there was a bit, a bit of a calming side to it, well … It was… I liked it, well precisely when there were music days, then I knew that at 10 o'clock I was going to enjoy it and that the rest of the day was

[2]SWISSUbase is a national cross-disciplinary solution for Swiss universities and other research organizations in need of local institutional data repositories for their researchers. The platform relies on international archiving standards and processes to ensure that data are preserved and accessible in the long-term. To access the musicdrops@work project: https://www.swissubase.ch/en/catalogue/studies/14067/17102/overview.

> going to go well: there's a bit of an effect that sets us up to be calm, well, in a state of well-being for the whole day [Leonie].

The concerts made it possible to leave, to escape, to travel in thought:

> It also lets you quickly imagine yourself somewhere far away, or to think about something else, to escape, for at least 10 min of the eight and half hours you spend at work. Even if it's not the music I usually listen to, it already allows me to escape a bit [Andrew].

"Getting away" at the concerts allowed the employees not only to distance themselves from their tasks and immediate environment—"Some kind of calm moment when you could imagine some other place while the music played but that you could also see" [Noah]—but also to be aware of their emotions and the associated bodily sensations, as illustrated by the following interview extract:

> Nelly. Yeah, it was very strong … I was moved the first time.
> Leonie. Yeah, it makes you shiver.
> Nelly. I was shivering and almost had tears in my eyes.

Listening to the music, observing the musicians and their movements, and feeling their emotions were contagious and also invited movement:

> I mean the emotions of the musicians I mean it was moving and it almost made us want to move too so you really feel … the music makes you travel. It's a good way to let off steam and then … [Leonie].

The difference between the impact and the experience of a "canned" and live music was noted: "I think that … there's more feeling when it's real instruments and even more when you see the people in front of you, there's more connection, it's true that you can notice it" [Josiane].

Finally, listening to the music was a moment that some employees wanted to keep and live for themselves.

> Often I close my eyes because I do not want the reaction of someone next to me to have an impact on what I am thinking. So eyes closed and I live for myself, I do not care about what's going on around me (laughs) … I do not want the outside world to interfere with what I'm thinking [Pauline].

They talk about it with some embarrassment, as this attitude might be perceived as selfish: "I'm very selfish, uh, I do not share with anyone, these moments I lived only for me and with me" [Olivia].

Although the listening is primarily personal and participants have strategies to place themselves in their own bubble, the concerts take place in the workplace. It is not, therefore, possible for them to ignore the reactions of colleagues completely:

> Exactly, and then you see a colleague tapping with his leg or doing this, and you think, 'oh, he's getting into it', I would not have thought of that, and then, yeah … But on a more personal level, it was very rare that I actually looked at my, my colleagues to see what reaction they had [Lisa].

And it is precisely this awareness of a commonly felt experience that brings us to the second section of the results section, the one that focuses on the impact of the musicdrops@work intervention on the lives of the teams.

Impact on the Lives of the Teams

Several participants noted that attending the musical interventions together created a moment of convergence and assembly during the working day, whereas in everyday life not everyone necessarily interacts with everyone else, especially in times of pandemic:

> It allowed us all to see each other for a little while during the day, when normally, well, we do not meet, well, sure, there are breaks etc., but we do not always all take our breaks at the same time … And nowadays, with the restrictions, there cannot be more than a few people in the canteen and so on … So it's true that it meant that there were little moments when we could all see each other a little bit during the day, when on some days we do not even cross paths [Lisa].

Listening to the same music, sharing the same feelings was experienced as unifying for the team or group:

> Lisa. It brings us all together at some point, all in the same … in the same place to listen to the same thing, to have the same feeling really … Yeah, I think it's somewhat …
> Alan. It creates a feeling of togetherness.
> Lisa. Yeah, it brings the team together.

Attending a concert with one's colleagues arouses curiosity: How will they react in this new, somewhat incongruous situation? What will happen?

> We watch or listen to music in specific places, in theatres, festivals, etc. In headphones too. But not at work, not in an office. So there was also this little bit of a different side to it, which nudged up the level of curiosity about seeing what a group performance would be like in an office [Andrew].

The conversations that the moments of musical listening kindled were different from ordinary professional exchanges and created a more personal contact:

> Afterwards in the office, I think it leads to chat, the staff coming together where we all meet up and listen to music, create connections or … or share uh, emotions and so on. Even if it's a short moment, a short period of time. It was enough to let you feel something and then either share or not share, keep it to yourself, that is … After all, everyone reacts differently [Andrew].

Discussions and sharing covered a range of topics, for example, whether the music played on that day had been liked or not, the sensations or emotions evoked, the personal experiences with music or with playing an instrument, recommendations for other concerts.

> Well, I think obviously, because there's this concert, we talk about it afterwards, and that allows us to share, to … to share feelings, if we liked it, if we had already heard, listened to, talked about music: ah there's a concert, ah yes, great [Theo].

Generally, these moments of discussion were not long:

> William. Yeah, straight after the concert, the mini-concert we said ah yeah, that was good, I liked it and then, then it was back to work again.
>
> Noah. I agree, 5, 10 min of chat no more and then we went back to the usual routine.

… and they seem to have taken place mainly between those who already knew each other well or who worked side by side. The common experience therefore seems to have strengthened pre-existing links rather than created new ones:

> After the concert there was a little opening up between … between the closest colleagues etc. So the break, let us call it an interruption, also went on a bit longer with discussions, chatting, uh. The break went on a little longer. The smokers go to the balcony and there they are talking about it, they chat a little … Anyone left around the islands [groups of work tables] as we are split into groups of four, among the four we also spoke a little bit about – about the concert so I think yeah [Alan].

Arising often was that the exchanges around the music increased the acquaintanceship of certain colleagues, on a more personal level, and sometimes uncovered totally unexpected facets of their personality, of their lives, as the following brief exchange illustrates.

> Olivia. We found out that our colleague played the oboe and we were stunned (laughs) Guillaume! He used to play when he was young, but then it was a bit of a shock to find out.
>
> Arthur. Yeah, then we talk …
>
> Olivia. Because it's not at all the guy's image, I cannot even imagine him playing music! Guillaume driving a tractor or a forklift, no problem, driving heavy machinery. But playing an oboe? I'm sorry, but it was a shock …
>
> Gregory. Oh yeah there was a very strong contrast (laughs)
>
> Arthur. I think these contrasts are really cool and it's really interesting to get to know a bit more about someone you work with.

The presence of the pianos at the companies for three months, clearly visible and present, also led to discoveries …

> Yeah, then perhaps it also means we find out something unexpected about someone, or at least something that we did not know about them! We have little … It's true that … it's not easy to get under someone's skin I mean, yeah, I would not go so far as to say to get under their skin, but to get to know them a little better on a personal level, and then I think that it was also quite positive because it's true that then suddenly one of our colleagues started playing the piano. She played a little bit of Amélie Poulain and it was really cool. And we did not necessarily expect that from her! [Alan].

…. so much so that the kitchen sales team even suggested that a piano instead of the planned table football would be a plus for office life:

> Lisa. So it's true that it … we think if we had a piano in the long term instead of table football and whatever, maybe it's something that … that would bring in well …
>
> Mia. Warmth.

Factors Influencing the Impact of Music Interventions

A first factor which appears to be related to both the experience of the musical interventions and the exchanges that followed is the composition of the teams of the three companies that took part in the project. We have already seen above that they differed in respect of gender distribution, the level of training of employees, their personal musical practice, and their tastes and preferences in terms of the styles and genres to which they listened. Looking at associations between socio-demographics and the five BMRQ facets, respectively the data from the smartphone application

TABLE 2 | Descriptive statistics, reliabilities, of the BMRQ facets and the application scales, and associations with socio-demographic variables.

	Descriptive statistics						Socio-demographics							
							T-Tests					Correlations[a]		
	M	*SD*	*S*	*K*	Min	Max	Sex		Training		Edu	Listen	Age	
							t	*p*	*t*	*p*				
BMRQ facets														
Musik seeking	3.75	0.84	−0.42	0.59	1.33	5.00	−0.42	0.679	1.89	0.067	0.16	0.21	−0.21	
Emotion evocation	3.81	0.77	−0.29	−0.84	2.25	5.00	1.03	0.310	2.95	0.006	0.30	0.02	0.28	
Mood regulation	3.85	0.82	−0.54	−0.54	2.00	5.00	0.21	0.834	2.75	0.010	0.19	0.36*	−0.30	
Sensory motor	3.60	0.85	−0.18	−0.64	1.75	5.00	3.52	0.001	0.922	0.363	0.36*	0.08	−0.24	
Social reward	3.16	0.86	0.09	−0.20	1.25	5.00	1.06	0.295	4.68	0.000	0.38*	0.24	−0.04	
Smartphone application														
Consistent mood	4.18	0.51	−0.11	0.45	3.00	5.00	−0.90	0.377	−0.82	0.419	−0.16	0.15	0.17	
Bodily response	4.06	0.53	0.00	0.17	3.00	5.00	1.07	0.292	2.45	0.020	0.36*	0.16	0.01	
Feeling close	3.74	0.64	0.53	−0.78	3.00	5.00	−0.87	0.931	0.62	0.543	0.21	0.23	0.04	
Forgetting reality	4.01	0.54	0.17	0.07	3.00	5.00	1.33	0.193	0.77	0.443	0.32	−0.10	0.09	
Desire to share	3.78	0.69	0.48	−1.01	3.00	5.00	0.22	0.831	1.60	0.118	0.24	0.17	0.23	
Enjoyment of music	4.50	0.49	−0.83	0.64	3.00	5.00	1.12	0.271	3.45	0.002	0.24	0.28	0.06	

*N = 36 (male = 24, female = 12), S = skewness, K = kurtosis. Sex (1 = male; 2 = female), Training = musical training (1 = no; 2 = yes), Edu = educational level (1 = compulsory education; 2 = apprenticeship; 3 = baccalaureate; 4 = bachelor; 5 = Master; 6 = PhD), Listen = weekly music listening (1 = less 1 h/week, 2 = 1–3 h/week; 3 = 3–6 h/week; 4 = > 6 h/week). [a] Spearman correlation. *p < 0.05.*

(**Table 2**) shows that men scored significantly higher than women on the BMRQ sensory motor facet [$t(34) = 3.52$, $p = 0.000$]. Those who received musical and/or instrumental training during their childhood or adolescence scored significantly higher on the BMRQ emotion evocation [$t(34) = 2.95$, $p = 0.006$], mood regulation [$t(34) = 2.75$, $p = 0.010$], and social reward facets [$t(34) = 4.68$, $p = 0.000$]. Furthermore, they reported on more bodily reactions [$t(33) = 2.45$, $p = 0.020$], and on greater appreciation of the short concerts [$t(33) = 3.45$, $p = 0.002$] than those who never received musical training. Higher education, in turn, was correlated significantly with the BMRQ sensory motor [$r(33) = 0.36$, $p = 0.035$] and social reward facets [$r(33) = 0.38$, $p = 0.032$] on the one hand, with experiencing bodily reactions [$r(32) = 0.36$, $p = 0.038$] on the other. Finally, using music for mood regulation was correlated positively with the number of weekly hours of music listening [$r(34) = 0.36$, $p = 0.031$].

The fact of having had musical training (or not) thus seems to have played an important role in the experience of musical interventions. The impact of the project was not the same in teams with musically active people as in those without. An excerpt from one of the interviews conducted in the engineering office points in this direction: the employees interviewed mention the fact that there are several amateur musicians in their team who seized the opportunity to discuss this "personal side" and took great pleasure in it:

> It seems to me there's as many as 5–6 musicians here in the office, even 6–7, well whatever their levels, yeah, musicians tho'. And it's pretty cool to, to talk about that, then to get to know a bit about the personal side of a colleague and then yeah … It's cool to connect in these … moments [Andrew].

A second factor that seems to have played a role is the hierarchical structure of the companies—ranging from rather horizontal in the engineering office to very vertical in the garage—that is, the trust of the employees toward their management and especially their perception of the reasons that may have led them to take part in the project. While the employees in the engineering office knew well their boss and his affinity for music, especially classical music, which was a sufficient explanation for participation, the workers in the car repair shop expressed distrust:

> *Interviewer. And why do you think your company decided to participate in this project?*
>
> William. No idea … (laughs)
>
> Chris. We see evil everywhere, there's surely a … (laughs)
>
> William. Because it was organised with HR
>
> Chris. There! You should know HR is not part of our world
>
> *Interviewer. It's two separate worlds?*

Chris. Yes, it's two separate companies, in fact

Interviewer. Oh, really …

Chris. Yes. No, HR used to be part of the company, now it's an independent external firm that belongs still to the same group, but we hardly know them anymore, to be honest.

William. They are not allowed to be buddies with the employees.

A third factor that often came up in the interviews is the degree of autonomy that employees enjoy in organizing their work, and the nature of their task. For the engineers, it seems to have been easy to organize themselves:

Gregory. In September–October I was working on something due in October and I said to myself well I'll take 10 min – a quarter of an hour for that and too bad I'll stay on in the evening when I do stay longer, but I absolutely wanted to have that … that interruption. I wanted to come absolutely.

Theo. In our industry we can manage our … our work quite easily and when we cannot, well, we just do not come.

Leonie. It's not the time, 10 min, it's not what influences our rate of professional activity, well … it's not the 10 min … that necessarily bothers us, I'd say.

The forced break was experienced as more complicated and stressful for the mechanics and technicians in the garage:

William. Well it all depends on what work we are doing. There are times when you cannot stop. So in painting, if we were spraying, well, doing a spray job, we would not come. Or we'd finish a coat, we'd come and listen to a bit and then we'd have to go back and continue …

Antonio. Yeah, it was cut short then but … then, what's for sure is that when we have a schedule, the cars have to be ready! Especially in mechanics, the cars come in for a service, the customer can come and pick it up at 3 pm, sometimes 4 pm, sometimes 5 pm. So uh it's true that when we are really busy in terms of our schedule, sometimes a quarter of an hour, well that's all it takes, we can really need it.

Integrating a new practice into the professional context—in this case, offering employees the opportunity to interrupt their work to listen to live music or concerts—required ritualizing these moments, defining times and a dedicated space for the interventions, and it is a fourth factor which seems to have played a role. In all the companies, the space around the piano was set up in order to create a concert setting, a kind of "stage." A certain distance between artists and audience was naturally created. However, there was not necessarily any seating for the audience, who therefore remained standing during the first concerts. After a few weeks, the car garage employees organized themselves, appropriated elements of their work environment to settle down more comfortably, as they would do on seats during a concert in a more traditional setting (see **Figures 2A,B**).

In the engineering office, the piano was first placed in a corridor, which did not allow the whole team to meet. It meant that most collaborators remained seated at their workstations (**Figure 2C**). The expansion of the premises allowed the piano to be moved after a few weeks to a space adjacent to the offices proper, which allowed the whole team to meet in a more neutral concert space (**Figure 2D**). According to the staff, moving was crucial, as it reinforced the "exceptional" aspect of the concerts, considered as events with their own space, disconnected from the usual tasks.

Arthur. Yeah, I think at the beginning, we did not think well about the positioning of the, of the performance, a tiny corridor, I think that did not help for the first few shows, so yeah sorry about the first few uh … it was really a small spot and everyone was a bit more scattered. And then when we moved here to the restaurant, uh …. it was much better – it feels to me that there was more movement involved, people really had to get up to come and listen.

Gregory. Location matters

Kevin. Exactly, exactly yeah!

Gregory. It boosts the atmosphere, I do not know, it creates.

A fifth factor is related to the classical repertoire played by the students. It was clearly more familiar and hence more accessible to the teams in kitchen sales and engineering than to the employees in the garage. The idea that the short musical interventions would allow listeners to discover and appreciate a repertoire and style of music unknown to them, was only partially confirmed. Although the post-concert questionnaire showed that the music offered was generally appreciated, several participants, especially in the garage, mentioned the fact that they would have preferred listening to another repertoire, jazz, pop, rock or world music. Accordingly, the audience's familiarity with the repertoire clearly seems to be a facilitating factor. Also in connection with the choice of repertoire, another point emerged: the fact that the teams would have liked to have been involved, to make proposals and for them to be taken into account.

It's always nice to have a little break like that in the middle of the workday. Then what's even better was the day when … I think it was you who played a song that we had asked for, I think that was it. It was great and

there was even more of a connection because we related it to … something that many of us know [Kevin].

A sixth and final factor is the perspective gained from talking to customers, family and friends. The fact that they were surprised, did not believe their eyes or ears, and were interested and even enthusiastic allowed the employees a certain pride. This, in turn, had an impact on their experience:

Josiane. I received some comments, yes! People wanted to know how it works etc., I told them roughly what it was, once a week and yes, they found it interesting too, yes.

Cedric. That's right, it's true that when we talked about it, people around us were like "oh yeah, you do that at work? Huh! well, that's not so bad! (laughs)."

DISCUSSION

Summary of the Main Results

The main objective of the musicdrops@work project was to offer a series of short weekly musical interventions in three companies in Lausanne and to study the impact of this measure on the subjective experience of staff, on the lives of the teams, and thus on the sense of belonging. A second objective was to improve our understanding of the conditions that facilitated or hindered the insertion and reception of these mini-concerts within the three companies.

The level of appreciation of the interventions and of the music played was globally high across the three companies. The teams' greater or lesser familiarity with classical music does not seem to have played a role in this dimension of subjective experience. In all the companies, the staff considered the concerts to be a moment of "relaxation" that allowed them to create distance from the tasks at hand and their immediate environment, co-workers included. These moments were rather savored by each for themselves, in a somewhat "selfish" way as some put it, so as not to be influenced by the reactions of others. The musical interventions therefore allowed a form of self-empowerment as defined by Hatzfeld (2002), an opportunity to "reacquire a form of autonomy within the constrained framework of work," notably through imagination. Thus, the concept of musical affordance (DeNora, 2001), according to which the listener appropriates the music according to his or her needs at the time of individual listening, also seems to apply in the context of group listening during a work break. The mini-concerts were an invitation that employees could seize and a resource that they could mobilize in order to regulate their affects and act on their wellbeing.

At the group level, the avenues explored in the introduction concerning the possible impacts of collective listening on the group were confirmed. The notion of "connection [*lit*. sharing]" was often mentioned by participants during the focus groups. They emphasized that the moment of group listening was

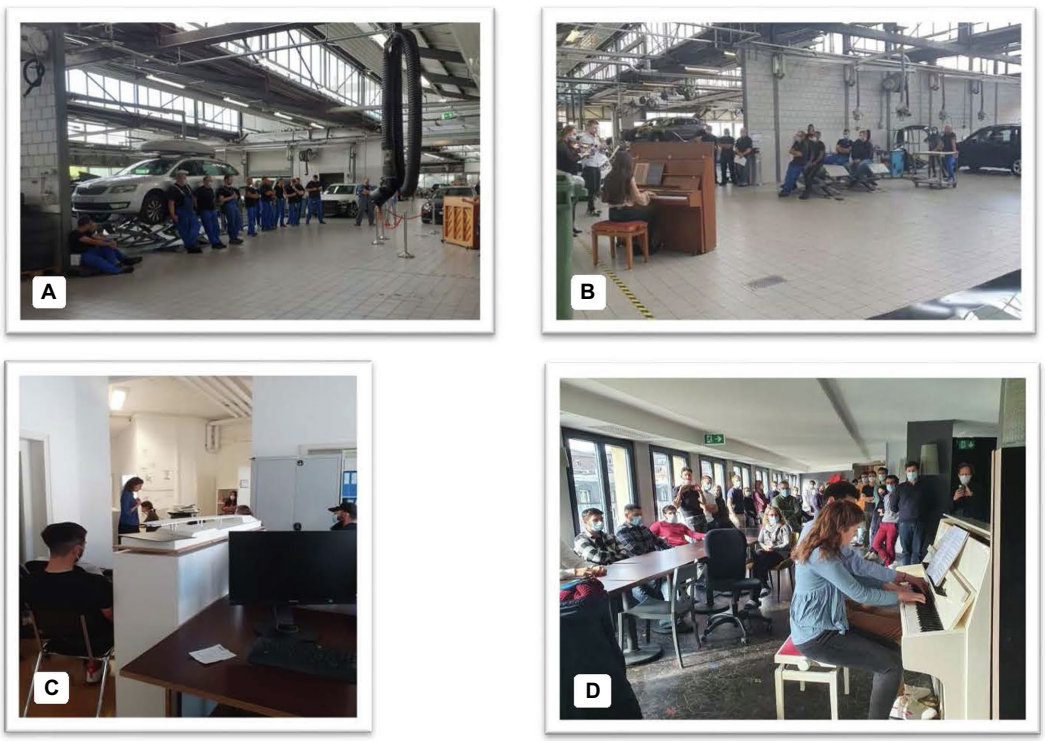


FIGURE 2 | Ritualization. Car garage, first **(A)** and last **(B)** concert; Engineering office, fourth **(C)** and ninth **(D)** concert.

perceived as moment of convergence and assembly, as a shared experience (even if lived individually) outside of their professional tasks. It not only lead to new exchanges—concerning the appreciation of music, feelings, and emotions evoked, personal experiences with music or with playing an instrument—but also allowed them to get to know some co-workers better and to discover previously unknown facets of their lives or personalities. It appeared that these exchanges and discussions mainly took place between those who already knew each other, reinforcing pre-existing relationships. This finding is consistent with what we know from the literature, namely that the impact of collective listening depends primarily on the quality of the relationships between listeners, but that it can also modify pre-existing relationships or enable new ones (Hargreaves and North, 1999; Groarke and Hogan, 2015). In summary, both the literature and our results indicate that group listening fosters positive intra-team dynamics and can therefore contribute to community wellbeing.

Even if the exchanges and interactions generated by the music interventions were occasional, as several participants in the focus groups pointed out, they seem to have had an effect on team dynamics. The concept of "high-quality connections" (Dutton and Heaphy, 2003), short, subjectively positive experiences between two people that generate beneficial outcomes, could explain the impact of these rather time-limited interactions. High-quality connections are marked by three subjective experiences: feeling alive, positive regard, and mutuality; all of which have benefits for wellbeing. High-quality connections can happen between two total strangers (e.g., exchanging a sincere smile with someone you see also buying diapers in the check-out line) or within established relationships (e.g., having a genuine "good morning" conversation with a co-worker). The mechanisms that influence high-quality connections are cognitive (e.g., other awareness, perspective taking), emotional (e.g., positive emotions, empathy), and behavioral (e.g., respectful engagement; Stephens et al., 2011).

Several conditions and factors favorable to the adoption of musical interventions in companies were identified, for example, the composition of the teams, the company's management style, the fact that the staff had tasks that allow them a certain flexibility and autonomy in the organization of their work and time, but also the fact that the concerts took place in a dedicated space, which contributed to creating a ritual away from their workstations. This is in line with Small's idea of a musical performance as a situated experience taking place within a physical and a social space "which makes its own meanings" (Small, 1999, p. 13) and which must therefore be taken into account when observing or analyzing or trying to understand it.

In all three companies, the decision to host the musicdrops@work project was "top-down." Even in the engineering office, whose management was less traditional and vertical than in the other two companies, the teams were not involved in the organization and implementation of the series of short concerts (choice of location for the piano and the "stage," choice of timetable, choice of repertoire, etc.). This observation raises the question of whether the musical interventions—beyond promoting subjective wellbeing and belonging at work through the appropriation of music as a tool for regulating subjective affects and through the encouragement of interpersonal dynamics—truly constituted a "social innovation" as defined by Cloutier (2003):

> […] a "new response" to a social situation deemed unsatisfactory, a situation that may occur in all sectors of society. Social innovation fits this title because it aims at the well-being of individuals and/or communities. It is defined in action and sustainable change. It aims to develop the individual, the place of life (territory) or the enterprise […] Some researchers also define social innovation by its process. Social innovation is then that which results from the cooperation between a diversity of actors (p. 12).

Although a new practice aimed at "the wellbeing of individuals and/or communities" and "defined in action" has been introduced into companies, it is likely that their one-off nature has not led to "sustainable change." Furthermore, and centrally, the implementation of the musicdrops@work system was not the result of a "cooperation among a variety of actors," but of a proposal from outside (the research team) and of a unilateral decision taken internally (management and/or HR manager). It is not clear whether the objective of the latter was indeed to respond to a demand or a need, and hence to improve a "social situation deemed unsatisfactory" (and if so, which one), or whether musicdrops@work was above all a great opportunity to be seized.

Limitations

As with much intervention research planned for, 2020, musicdrops@work was heavily impacted by the COVID-19 pandemic. As already mentioned, the series of weekly musical interventions in the three companies, initially planned for 12–16 consecutive weeks, began with a five-month delay and had to be stopped after 11 weeks, due to the arrival of the second wave of infections and the new severe restrictions. Furthermore, the program had to be revised several times to take into account the changing health measures and withdrawals of quarantined or ill musicians. Apart from this obvious impact on timing and organizational aspects, the health crisis had a more indirect influence on the project and the results: in Autumn, 2020, very few "normal" live concerts could take place in Switzerland. For the student musicians, the musicdrops@work project was one of the very few opportunities to perform in public. When asked about their experiences, they repeatedly referred to the intensity of the emotion they felt, to the importance of these few minutes for them, to the responsibility they bore, given the exceptional nature of their performance. On the employees' side, a great intensity in listening was visible and noticeable. Given that the pandemic did not allow for the deployment of the methodological system as initially planned, and that furthermore it reinforced the intensity of the experience of both musicians and listeners, the results of our study must be interpreted with great caution, pending confirmation by a second series of concerts or by a second study that would take place under normal circumstances.

Boumaza and Campana (2007) write that the company is a "difficult" terrain that is not easily "approached" or "tamed," which requires "a certain pragmatism" and the establishment of "risk avoidance strategies" (p. 5). This is what we experienced: the methodology had to be adapted several times to the reality of the companies. The length of the questionnaires, the time needed to fill them in, and even the language level and/or the content of the envisaged standardized tools (employee experience questions were not welcome in all companies) were all subject to negotiation, and it was necessary to scale down to obtain the cooperation of HR managers or directors. We therefore decided not to include a questionnaire assessing employees' sense of belonging and opted for a more qualitative approach, which would capture the experience of the teams and the changes in interactions among colleagues. Nevertheless, the use of such a questionnaire should be considered should the experiment be repeated, ideally with a longer series of concerts.

A third limitation of the research concerns the sampling. Although all employees were able (in some cases obliged) to take advantage of the musical interventions, there was no onus or checks on the completion of the questionnaires nor on participating in the interviews: participation and in some cases recruitment were done solely on a voluntary basis. It is therefore possible that only people who were relatively enthusiastic about the music interventions and willing to talk about them came forward, and that this led to a bias by reducing the diversity of views.

Conclusion

The musicdrops@work project is intervention research aimed at implementing and studying the impact of short live music interventions on belonging at work, and therefore on the wellbeing of individuals and teams. A positive impact of the intervention was highlighted by the observation of the dynamics that developed over the weeks around the mini-concerts, by the data that were collected after each moment of collective listening, and by the analysis of the group interviews conducted at the end of the experience with 17 volunteer employees. This was true both at the individual and group levels. On the former, the mini-concerts were experienced as a moment for oneself, as an opportunity to distance oneself, as an invitation to self-empowerment, and as a resource for acting on one's wellbeing. On the latter level, the mini-concerts generated exchanges and interactions, and provoked moments of "high-quality connections," thus contributing to employees' sense of belonging.

These results lead us to reflect on the place of music and the musician in society, and on their potential in the world of work. A recently published article refers to the musician as a "maker in society" (Gaunt et al., 2021, p.1). According to the authors, "questions […] cannot be ignored about the ways in which musical practises are […] of value in societies and the degrees to which these are realised, the roles musical practises may play within rapidly changing situations, and how they may be part of nurturing flourishing and inclusive societies for the long term. In many ways a contemporary zeitgeist is crying out for the creativity and humanity of music and the arts: their unique potential to uplift, heal, and engage people in expressing themselves, to help make sense of experience and challenge perspectives, and to contribute to building and sustaining communities" (p. 3).

Too little is known about the potential for social innovation to be found in inclusive musical practices that avoid revolving around excellence, elitism, or "star" culture, but instead conceive of music as a social practice and invite participation. It is up to educational and research institutions to seize this opportunity by proposing training programs that place the concept of artistic citizenship at the center of their curricula, by attaching value to the social engagement of their students and graduates, and by promoting research activities that aim simultaneously to change reality (i.e., action or intervention research) and to increase our understanding of the mechanisms that underlie the change.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://www.swissubase.ch/en/catalogue/studies/14067/17102/overview.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at https://www.frontiersin.org/articles/10.3389/fpsyg.2022.865938/full#supplementary-material

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The Magnetic Urtext: Restoration as Music Interpretation

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This paper discusses *historical-critical thought* to address the problems of restoration and preservation of tape music, proposing viable solutions to the matter of digitizing the historically valuable data that exists on and is represented by magnetic tapes. A detailed program of research and restoration and some software for helping in creation of critical editions of the musical works are proposed. We also present some of the issues and controversies that must be considered and approaches we have applied in the preservation of tape music, highlighting how these *interpretations* can impact later performances (playback) of these tape documents. Fundamentally, we argue that the act of tape music restoration has a parallel with the interpretation of the "Urtext score" in the performance of music from the Common Practice Era.

Keywords: audio document preservation, re-interpretation, electronic tape music, archiving, reel to reel recording, restoration, urtext, heritage

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INTRODUCTION

The enormous industrial scale production of sound recordings (e.g., wax cylinders, phonographic discs, audio cassettes), in addition to an incalculable quantity of audio documents produced outside the industrial process of recording, has progressively become an integral part of the documentary heritage of the twentieth century (Bressan and Canazza, 2013). Frozen in a mass of recordings made in the last century by analog devices, these events, performances, electronic tape music compositions (hence "tape music"), and soundtracks can now survive the degradation of their carriers (the material on which the audio coded documents are stored, see Bressan et al., 2016) and can be duplicated by digitizing the audio signals, which gives them a representation that can be losslessly conveyed in the new media environment (Canazza et al., 2015).

We introduce a *historical-critical* approach to address the problems of preservation, edition, and access of documents according to a plurality of *interpretative* choices. This is guided by the knowledge of the internal history of the document and the study of both the material and the technological conditions that produced it and the contexts in which the document was produced. Such considerations must be carried out on the basis of a genuinely interdisciplinary approach, considering the restoration as a philological operation of *constitutio textus* (i.e., in the textual criticism: to produce a text as close as possible to the original; Maas, 1958). This paper will examine: (1) Tape Music (section "Tape Music")—setting up the significance of restoring audio reel to reel compositions from a historical perspective, to demonstrate that there exists precious source material that is at risk of being a lost heritage; (2) Tape Music preservation (section "Tape Music Preservation")—detailing the technical problem of deterioration of analog magnetic tape; (3) Restoration as reinterpretation (section "Restoration as *Reinterpretation*")—(a) introducing the (somewhat counterintuitive) need to alter the source signal to allow faithful reproduction; and (b) discussing their implications for the digitization processes, to which we then turn our attention, and

(4) (section "Conclusion") proposing viable solutions to the matter of digitizing the historically valuable data that exist on and are represented by these magnetic tapes.

TAPE MUSIC

The quest for authentic reproduction of the *great compositions* (Taruskin, 2010) ushered in the concept of the urtext (*original* and coming to mean *originally intended*) score. Despite the limitations of the urtext idea in printed scores (Feder, 2011) analogy with the current question is striking. By considering additional technical and sociological factors, the historically significant audio tape is importantly different to the music score in that the music documentation *is* the sound world source that the creator inhabited. If enough is known about the reproduction of the source (e.g., the reproductive equipment, the ambience of the typical playback venue) then the goal of obtaining access to the *authenticity* of the creative act and output, directly from the document, becomes feasible, in contrast to music notation of the past. From this point of view the magnetic tape is undoubtedly an urtext (see, Somfai, 1981), and realizing this, the urtext concept is practicable and, we shall argue, feasible.

Our project is concerned with pieces of music that come into existence as a result of placement of audio on the sound recording medium. Unlike recordings of live instrumental musicians (which have their own set of problems, e.g., Fabian, 2003), the music that concerns us here is not recorded on a podium to be later stored and reproduced, but it is born with the help of electronic valves, transistors, and the like; it "exists" only on magnetic tapes (in the case we are considering) and can be listened to with loudspeakers. Such techniques of composition became viable with the invention of magnetic tape sound recording technologies where direct human manipulation and (acoustic-)electromagnetic treatment of the recording medium was possible. And so, it attracted the interest of the most important experimental and avant-garde creative minds of the mid-twentieth century in Europe, including Edgard Varése (1883–1965), Olivier Messiaen (1908–1992), Iannis Xenakis (1922–2001), Luigi Nono (1924–1990), Luciano Berio (1925–2003), Pierre Boulez (1925–2016), and Karlheinz Stockhausen (1928–2007).

In the United States we can see an extreme example of how the physical interaction with the recording medium was also part of the artistic process, in John Cage's (1912–1992) four and a half minute (at 15 ips tape playback speed) work *Williams Mix* (1952). The creative process involved preparing "minutely and obliquely cut pieces of magnetic audiotape, chosen and spliced together through chance operations from a stack of 500 to 600 recorded sounds in six categories—city sounds, country sounds, electronic sounds, manually produced sounds (including the literature of music) and wind produced sounds (including songs) and small sounds requiring application to be heard with others" (Kahn, 1999, p. 112). From a philological perspective this process, and the state of the magnetic tape after the process, must also be considered part of the artwork, making it important to consider the visuo-spatial-tactile-olfactory world in restoration (re-interpretation), not just the sound world encoded on the tape (Benjamin, 1955).

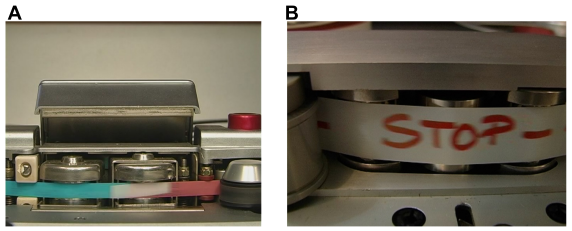


FIGURE 1 | (A) Spliced tape; **(B)** signs by the composer on the tape.

TAPE MUSIC PRESERVATION

The preservation and restoration of historically significant tape music recordings is an urgent aspect of musicology research. Moreover, as this issue is linked to philological, musicological, and information engineering areas, it is a central concern for performance science, yet is often overlooked.

As composers manipulate tapes with cutting and splicing techniques (see **Figure 1A**) as well as marks on the tape (**Figure 1B**), for which the analog magnetic tapes are the only available documentation, we propose that the tape itself is an artwork. Analog tapes deteriorate under normal storage conditions, and playback of the tape further hastens deterioration. Conversely, indefinite storage in hermetically sealed, temperature-controlled environments renders the material inaccessible.

Analog-to-digital conversion is an indispensable mode of preserving audio documents, as archived tape music recordings are often the only reference material, and without careful preservation and restorative intervention these musical works would be permanently lost. The use of specific playback technology is further tied to the compositional process, as reproduction on modern equipment may diverge considerably from the sound world intended by the composer. Thus, the tape is an integral part of the music performance that provides artistic value as well as significance as a historical document. To save valuable historical recordings, the audio signal and other relevant information (such as metadata and contextual information) can be extracted from the source audio document and transferred onto another medium such as a digital storage system (a remediation process).

An example of the complexity of restorative choices in the field of electronic music on tape is given by the work *Y entonces comprendió* (1970) by Luigi Nono. In this work the composer re-records an existing tape source (containing Fidel Castro's voice, reciting the words of Che Guevara) onto disc; this leads to a noticeably different timbre between the sources. In these hybrid works the relationship between tape and live interpretation favors the permanence of spontaneity, which increases the weight of the source material, full of unpredictability and originality, with respect to the preserved product. Here, therefore, there is the



FIGURE 2 | The main graphic user interface of the REMIND app. A video of the original tape is shown outside the body of the tape recorder (top right inset) to improve its readability.

choice of whether or not the restoration should leave a trace of the source: voice and sounds recorded on a disc are linked to the noise of the disc, which is different from that of the tape. Different noises produced by a continuous transfer on different media leave a trace of the system that produced the document.

RESTORATION AS *REINTERPRETATION*

A tape music document is related to the playback system and therefore a musicologist (and a live electronics performer) must use technical (analog and then digital) devices for both music playback and sound texture analysis. Two factors are combined: human attention (that can introduce errors, i.e., *noise*) and the imperfection of the machine (that introduces noise, i.e., *errors*). The interpretation of the tape requires systemic reconstruction in the world of experimental electronic music praxis (e.g., of the interactions between the composer, sound engineer, and audio technology used). Several factors impact the reconstruction, showing parallels with traditional music scores, including: (1) knowledge of the recording system, (2) exact identification of the recording format, (3) metadata transmitted by the whole documentary unit, (4) track labels and numbers, (5) editing operations by the technician and the composer, (6) writings on the tape (e.g., markings by the composer for synchronization of the performance, as in **Figure 1B**), and (7) the composer's performance prescriptions. The remediation process is not neutral and opens the philological issue of document authenticity. Removal, enhancement, or compensation actions can lead to different interpretations.

Several *interpretive* choices need to be made (Brandi, 1977), which can be particularly complex in the field of tape music. A philology of sound documents is urgently needed because of the apparent simplicity with which the transfer from the analog to the digital domain can be carried out, coupled with the potential for inaccuracy here. The audio document includes information related to its realization process, which is significant for the audio content transferring (Bressan and Canazza, 2013). Specifically, (a) the physical-chemical structure of the carrier; the technology, the production system (acoustic, electroacoustic, magnetic), the recording format (total number of tracks, playback speed, etc.); (b) the primary (useful) information relating to the message contained in the recording; (c) the secondary (ancillary) information: signals characterizing the recording system; (d) the playback and listening system; (e) metadata (labels, notes on the case, etc.); (f) the history of its transmission (types of archiving, duplications, digitization, playback dates/locations, etc.).

The Centro di Sonologia Computazionale (CSC) of University of Padova has defined a rigorous scientific protocol for different interpretative approaches, during several restoration projects involving the most important European music archives (Canazza and De Poli, 2020): in the following we describe two of them, used in restoration projects related to tape music.

(1) The ***archivist's*** interpretative choice needs to consider the information stored in the audio document as an artifact. It focuses on the document physiognomy and aims to preserve the documentary unit. Its bibliographic equivalent is the diplomatic copy or *facsimile*. The format detection and the choice of the playback system are essential. Restoration processing is considerably aided by good documentation, and amenable to restoring the functionality of the carrier (splicing at the breaking points, hydration of the substrate to counteract hydrolysis, etc.; Bressan et al., 2016). Intentional endogenous alterations of the signal (equalization, noise reduction systems, and *compander*, e.g., DBX Type I) made in the recording process are compensated. This interpretative choice aims to preserve material characteristics of the document, and optimize similarity of the new digital medium with the original document.

The output of this interpretative choice is the *preservation master*, that includes high resolution uncompressed audio (96 kHz/24 bit) and contextual information, stored using a combination of textual, photographic and video documentation

(Orio et al., 2009; Fantozzi et al., 2017; Pretto et al., 2019). Video of the tape flows along the head of the tape player during digitization. In addition to the contextual information of tape discontinuities (e.g., **Figure 1A**) and facilitating one's potential to discriminate intentional from unintentional alterations, the video recording also offers the possibility to verify other irregularities in the playback speed of the tape which cause changes in frequency (i.e., wow or flutter). Photos report accurate information about labels, edition boxes and other attachments, as well as clearly visible magnetic tape (or—also—phonographic disc) corruptions. Finally, information that cannot be directly represented in digital format has to be thoroughly documented in the descriptive sheet (e.g., smell of a magnetic tape, which can indicate the presence of syndromes and olfactory characteristics like mold, vinegar odor, etc.).

The preservation master could be re-experienced by means of the software application REMIND (acronym for "Restoring the Experience: Mobile INterfaces for accessing Digitized recordings") developed by a selection of the authors (Canazza et al., 2015), aimed at re-creating the experience of a phonograph or a reel-to-reel audio tape recorder (the focus of the present paper), including a complete set of metadata and contextual information (**Figure 2** and **Supplementary Figure 1** show the two graphic user interfaces of the app).

(2) The ***philological*** interpretative choice pays attention to (a) the fact that multiple versions of the same work can exist (referred to in philology as multiple *witnesses*), and the relationships between these versions (which can be created by collation of these witnesses *via* various means of audio digital process techniques; it is possible to examine these versions by comparison, or analysis by synthesis); (b) the audio equipment and techniques used in the recording phase; and (c) the compositional practice. The revived product is based on a single document, with a process that restores the audio to the technological state as close as possible to when it was first reproduced, along with the limitations of its contemporary technologies, rather than artificial enhancements or inauthentic degradation. If unintentional alterations exist (e.g., misalignment of the recording equipment), it is possible to subsequently compensate for the A/D conversion of the original signal. This interpretative choice aims to create historically informed *critical editions* including reports on *variant copies*, necessary for the reconstruction of the sound texture of each recording.

The 30-year experience that the authors have gained in the field of audio philology has resulted in the development of software CAP (Computer Aided audio Philology) that supports researchers in the processes of *recensio*, *collatio*, *eliminatio, codicum descriptorum*, and *stemma codicum* (West, 1973; Verde et al., 2018) (see main interface in **Supplementary Figure 2**). An operator inserts all the data, metadata, and contextual information in CAP, which creates the final critical edition of the musical work.

CONCLUSION

Tape music from the 1940s to the 1980s is in urgent need of archiving because we are starting to lose the direct human, hardware and information links to those heritage sound worlds, which are critical for authentic and comprehensive archiving. Our philosophy of tape music archiving is that it is not solely a technical restorative act, but an artistically interpretive one, with some analogies to the historically informed performance of conventional music, where interpretation of the score is needed even if knowledge about performance practice is no longer fully available. In tape music restoration we do not have to retrace the *true* sound, but through an *interpretative* process of the materials we aim to safeguard the compositional and recording techniques of the time, such as in the two examples described in section "Restoration as *Reinterpretation*."

The evolution from analog tape editing to computer programming poses a new and challenging task for the preservation of electronic music works, including the electronic music *born digital* production. Specifically, the rapid obsolescence of computer equipment and the loss of information on performance-compositional practice endanger the survival of this recent musical heritage. Therefore, progress in this area will need to focus on saving the original technological environment, developing a philology-informed hardware/software virtual emulator to replicate functions of obsolete audio technology, interpreting computer music composed using different programming languages, and systematically documenting primary witnesses (work versions) and composer experiences. Audio philology, specifically in the field of tape music, needs specially designed and developed software. Frameworks such as CAP, combined with algorithms capable of interpreting multichannel acoustic information (Salvati and Canazza, 2014) and phylogenetic techniques (Verde et al., 2018) will enable a process of preservation of the work and its reactivations, taking into account of the interpretative possibilities in its technological and physical-acoustic aspects.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

SC, ES, and AR: conceptualization. SC and ES: writing—original draft preparation. AC and NP: writing—review and editing. NP: REMIND software. All authors have read and agreed to the published version of the manuscript.

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Case Report: Psychoacoustic Analysis of a Clarinet Performance With a Custom-Made Soft Lip Shield Worn to Prevent Mucosal Erosion of Lower Lip

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Tanabe G, Hattori M, Obata S, Takahashi Y, Churei H, Nishiyama A, Ueno T and Sumita YI (2022) Case Report: Psychoacoustic Analysis of a Clarinet Performance With a Custom-Made Soft Lip Shield Worn to Prevent Mucosal Erosion of Lower Lip. Front. Psychol. 13:852866. doi: 10.3389/fpsyg.2022.852866

Introduction: Wind instrument players sometimes suffer from erosion of the mucous membrane of the lip. This is caused by the action and pressure of the mouthpiece of the wind instrument against teeth. To address this problem, a lip shield is fitted over the dental arch to prevent direct contact between the lips and teeth. However, there are a few studies on the influence of the lip shield on the acoustics of wind instruments. The purpose of this study was to analyze the psychoacoustics of a clarinet performance with the player wearing a custom-made soft lip shield to prevent mucosal erosion of the lower lip.

Case Description: A lip shield was custom-made with a soft thermoplastic material for a female clarinetist who complained of mucosal erosion and pain of the lower lip. The psychoacoustics of her musical performance played in different dynamics, fortissimo, mezzo forte and pianissimo were analyzed, including loudness and sharpness. A self-evaluation questionnaire with items rated on a 10-point scale was administered. After wearing the lip shield, the patient reported that the mucosal erosion and pain of her lower lip when playing clarinet resolved. The lip shield had little effect on the loudness. There was a slight decrease in sharpness when the lip shield was worn compared to when it was not, describing the reduction of high frequencies. Furthermore, fewer variations in sharpness between the tones were observed.

Conclusion: The results suggest that lip shields made of soft materials can eliminate mucosal erosion and pain of the lower lip while having little effect on performance, although, a slight change in timbre is possible.

Keywords: lip shield, wind instrument, clarinet, mucosal erosion, performing arts

INTRODUCTION

The maxillofacial region is important for sound production, especially when playing wind instruments. In the 1960s, Porter first described the dental aspects of embouchure and conservative tooth treatment for a wind instrument player (Porter, 1967). Porter said that for single-reed instruments, such as clarinets and saxophones, the sharp, chisel-like edges of the incisal enamel tend to cut into the lips in players of these instruments. Often, there is a linear impression on the mucous membrane caused by the teeth, which can be painful and may hinder playing. Thus, wind instrument players sometimes suffer from mucosal erosion of the lip caused by the action and pressure of the wind instrument mouthpiece against teeth. In some instances, it becomes impossible to execute certain specific blowing exercises (Phillips, 1972).

The cause of mucosal erosion and pain of the lower lip in single-reed instrumentalists is thought to be due to the incisal edge morphology of the mandibular anterior teeth and the alignment of the dentition. A recent systematic review stated that tooth position affects the performance and embouchure comfort of wind instrument players, and that extreme malocclusion can interfere with a wind instrumentalist's performance (van der Weijden et al., 2018). Discomfort while playing can also be caused by a combination of other factors, such as the reserve force of the lower lip against mechanical load, that is, the thickness and elasticity of the lower lip, the relationship between the blowing method and playing style, the reed characteristics, time factors, and psychological factors. These factors have not been examined in the literature.

Some wind instrument players have placed folded cigarette-rolling paper or oil-absorbent paper over their lower central incisors while playing to avoid discomfort or pain in the lower lip from playing. In some cases, these solutions may cause musicians to generate greater and unnecessary force in the embouchure, causing discomfort to the teeth and temporomandibular joints after playing (Pais Clemente et al., 2019). Some players have also used commercially available polyolefin resin protectors. These protectors can be easily made by themselves. However, their thickness and design are difficult to control, and they are thought to be less effective, especially when the fit is not good.

A lip shield fitted over the dental arch of the lower jaw to prevent direct contact between the lips and teeth may solve these problems. Lip shields are applied to the mandibular anterior teeth. Materials, such as dental rubber-like materials, silicone rubber, plastic, and metal, have historically been used. Lip shields should be made as thin as possible, covering the incisor, canines, and possibly part of the first premolars (Porter, 1967; Wilson, 1989; Katada et al., 2005). The devices used to protect the lower lip when playing clarinet and/or saxophone have been given different names by different authors, clinicians, or musicians. These devices have been referred to as lip shields, embouchure aids (Krivin and Conforth, 1975), and music splints (Katada et al., 2005; Nii et al., 2021), among others. To date, there is still no consensus regarding the name for lip shields used by instrumentalists. In the present study, with consideration to the historical background, the authors have referred to the device as a lip shield.

In recent years, sports mouthguard materials and fabrication techniques have been applied to lip shields. Sports mouthguard materials are mainly composed of ethylene-vinyl acetate (EVA) and polyolefin, with a Shore A hardness of ∼80. Pais Clemente et al. reported the first lip shields made of 1-mm EVA sheets that were stable during a performance and did not interfere with playing (Pais Clemente et al., 2019). Nii et al. (2021) also discussed the optimal stiffness and thickness of EVA sheets and other hard materials based on subjective feedback from instrumentalists and pain resolution. The authors reported that softer and thinner types of lip shields were particularly effective in addressing the pain (Nii et al., 2021). However, few studies have investigated the influence of lip shields made using sports mouthguard materials on the acoustics of wind instrumental performance.

This study aimed to analyze the psychoacoustics of a clarinet performance with the player wearing a custom-made soft lip shield for the prevention of mucosal erosion and pain of the lower lip.

CASE DESCRIPTION

The patient was a 70-year-old amateur clarinetist. She presented with mucosal erosion and reported pain on the lower lip when playing the clarinet when the duration of practice exceeded 2 h. The duration of daily practice was about 1–2 h. She practices every day and has been playing for about 50 years. At the time of visit, no obvious erosions were seen and there was no color change of mucosa. However, on palpation, a friable lump was felt. The facial and intraoral photographs are shown in **Figure 1**. The mandibular anterior teeth were plexiform and had chiseled edges. Mesio-distal classification was grade 4, and the bucco-lingual classification was grade 4 according to Chu's classification of dental crowding. The occlusal status of patient was normal occlusion (overbite 0.3 mm, overjet 0.3 mm), and the occlusal supporting area was classified as Eichner's A-1, and there was no tooth movement or defective restoration in this area. We confirmed that the pain in the lower lip occurred where it was caught between the reed and the mandibular anterior teeth when playing the clarinet and inferred that this symptom was due to clarinet playing. The authors think that the prolonged pressure on the lower lip and the resulting blood flow disturbance might be triggering the erosions. Therefore, a lip shield was applied to the mandibular anterior teeth to protect the lower lip from the pressure while playing the clarinet. In this case, the technique and materials of a sports mouthguard were applied to create a lip shield. Soft polyolefin sheets (MG21; CGK, Hiroshima, Japan), 2.0 mm in thickness, were used to fabricate the lip shield.

The lip shield was fabricated as follows. An impression of the mandibular arch was made with an irreversible hydrocolloid (Aroma Fine Plus; GC Corp, Tokyo, Japan). The impression was filled with a dental plaster (New Plastone II; GC Corp.,



FIGURE 1 | Patient's facial and intraoral photographs and the lip shield.

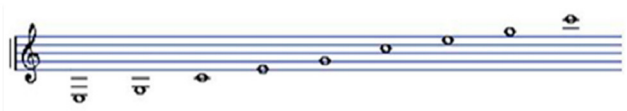


FIGURE 2 | The musical scale task used for psychoacoustic analysis.

Tokyo, Japan) to make a working cast. The lip shield was fabricated by thermoforming a polyolefin sheet over the working cast using a vacuum forming machine in a vacuum tank (Erkoform 3d motion; Erkodent, Pfalzgrafenweiler, Germany) at 105°C, in the same manner as for the fabrication of sports mouthguards (Tanabe et al., 2020). An image of the design and fabrication of the lip shield is shown in **Figure 1**. The lip shield covered all six mandibular anterior teeth for enhanced retention. The margins were polished to ensure comfort during clarinet playing. We checked the fit, retention, and occlusion of the lip shield with and without a reed at the dental chair side. The thickness of the buccal lip surface of the lip shield was 1.1 mm. One week after using the lip shield, the patient visited our clinic for follow-up and evaluation.

Her performance was analyzed using psychoacoustic analyses based on loudness and sharpness (Acoustic Workstation SQ6600; Ono Sokki Co, Ltd., Kanagawa, Japan). Psychoacoustic analysis is a sound analysis method based on the characteristics of human audition. In psychoacoustic analysis, loudness and sharpness were the primary outcomes. Loudness is defined as a physical value that represents the sound intensity in human perception (Zwicker et al., 1957). Sharpness is defined as the physical value that represents the balance between low and high frequencies, where high values correspond to higher frequencies of sound (Bismarck, 1974).

Each subject was seated in the chair position and a high-quality dynamic microphone (LA5120; Ono Sokki Co, Ltd, Kanagawa, Japan) was positioned 15 cm away from the instrument. A sound processor (Sound Blaster Extigy; Creative Technology Ltd, Tokyo, Japan) was used, and the recording conditions were 16 bit/96 kHz. Subjects were given an interval of at least 1 s for breath between each test tone. The analysis of each test tone was from the beginning of the tone to the end of the tone. Subjects performed the test only one trial per tone task after one practice session. In task, the following three dynamics were used: pianissimo (very soft), mezzo forte (moderately strong), and fortissimo (very strong). Analyses were performed with and without the lip shield. **Figure 2** shows the music-scale task used for psychoacoustic analyses.

And a self-evaluation questionnaire with items on a 10-point scale was administered at 1 week, 3 months, and 8 months to evaluate the usability of the product. The questionnaire rated the following using a 10-point scale: lip shield stability, lip shield discomfort, holding fit, blowing comfort, sound quality, and overall satisfaction, based on Hattori's reports (Hattori et al., 2015).

After wearing the lip shield, the patient reported that the mucosal erosion resolved and the pain of the lower lip she experienced when playing the clarinet also disappeared. The patient wore the lip shield for 1–2 h per day, almost every day. There was no staining or deformation after 8 months of regular use.

Figure 3 shows the loudness and sharpness results of the psychoacoustic analyses. The player was able to project the difference of the three dynamics regardless of the use of the lip shield. There was no decrease in loudness when the lip shield was worn, and it was thought that the effect on blowing was small. There was no drastic change in sharpness either with or without lip shields. There was a slight decrease in sharpness when the lip shield was worn compared to when it was not, describing the reduction of high frequencies. Furthermore, there were fewer variations in sharpness between the tones. **Figure 4** shows the results of the self-evaluation questionnaire after 1 week, 3 months, and 8 months. All usability outcomes remained favorable over the 8-month follow-up.

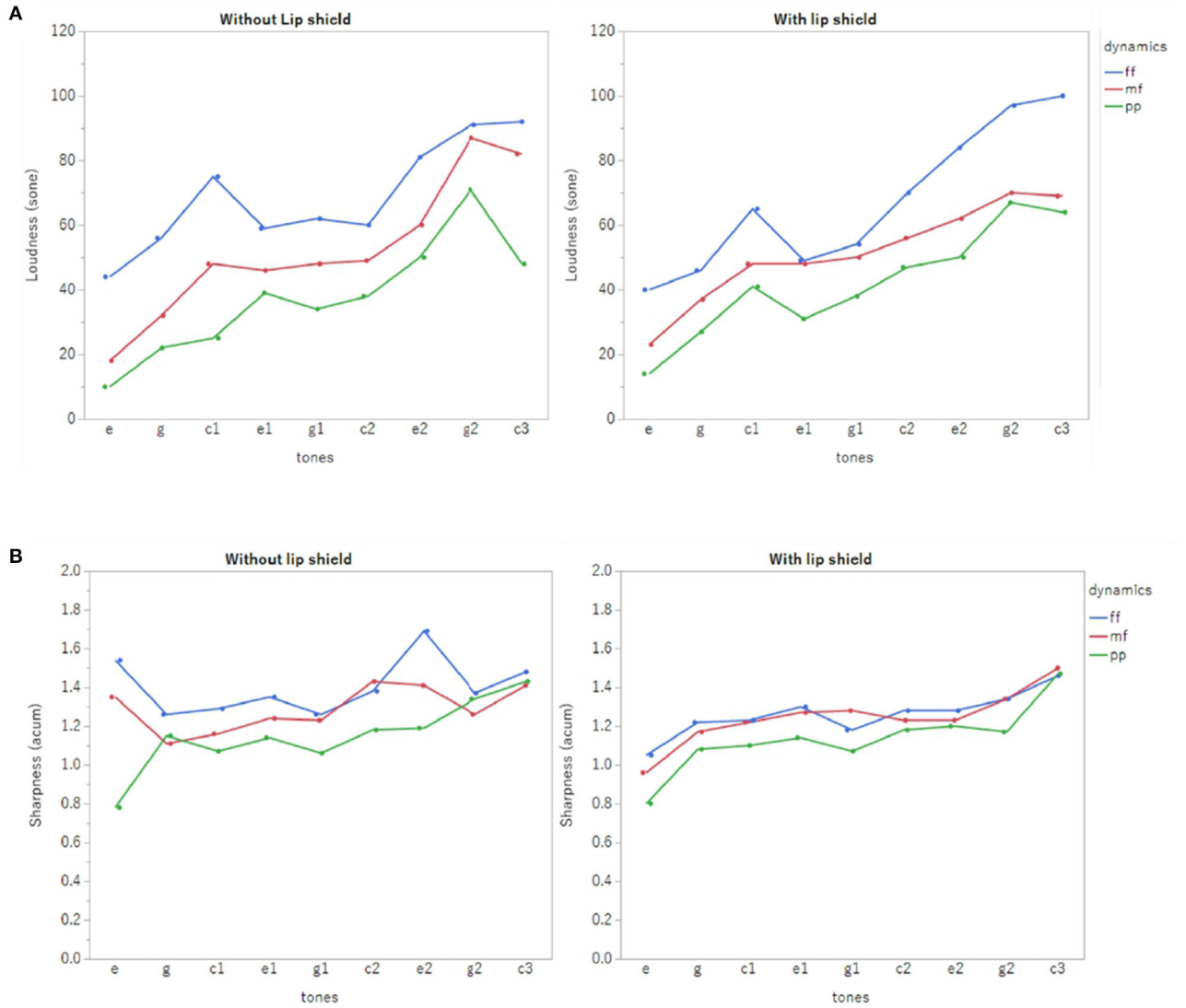


FIGURE 3 | The loudness **(A)** and sharpness **(B)** results of the psychoacoustic analyses.

DISCUSSION

In this study, the lip shield prevented pain in the lower lip when playing the clarinet. It is thought that the lip shield buffered the pressure on the lower lip caused by being sandwiched between the incisal edge of the mandibular anterior teeth and the clarinet reed. The effectiveness of the lip shield in preventing pain in the lower lip was similar to that reported in previous studies (Krivin and Conforth, 1975; Nii et al., 2021). A follow-up questionnaire survey of the lip shield's usability over 8 months showed that the product maintained good usability, with no damage or staining observed. These suggested that custom-made soft lip shield was practical as the prevention of mucosal erosion and pain of the lower lip.

Wearing a lip shield over the mandibular anterior teeth is expected to modify the oral volume, exhalation volume, and flow rate of breathing, as well as tongue movements and sensations, thereby changing the overall performance. Because wind instrument players change the dynamics and timbre of their sound by changing the oral capacity, flow rate, and speed of their breathing. Hattori et al. (2014) experimentally altered oral morphology with a palate-covering device and evaluated its performance. Changes in psychoacoustic features and the frequency and intensity ranges were observed. In this study, psychoacoustic analysis and a questionnaire survey were conducted to examine the effects of the lip shield on performance.

Regarding loudness, it was possible to distinguish three different dynamics with or without the lip shield. There was also no decrease in loudness when the lip shield was worn. Since loudness is controlled by the exhalation volume and velocity, the results suggest that lip shields are unlikely to interfere with

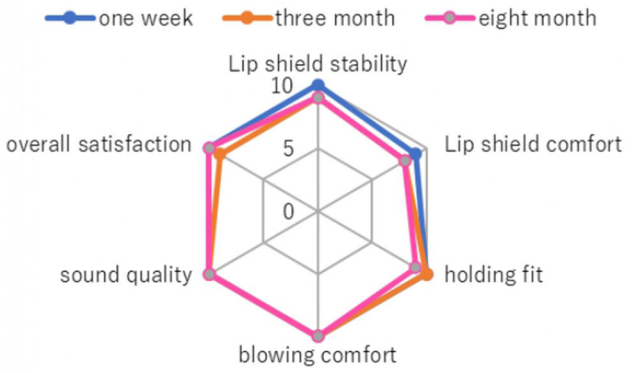


FIGURE 4 | The results of the self-evaluation questionnaire, with items rated using a 10-point scale, at 1 week, 3 months, and 8 months. A score of 10 indicates good and 0 indicates bad.

the exhalation volume and velocity to the extent that they affect performance.

There was a slight decrease in sharpness when the lip shield was worn, and high frequencies were reduced. This change suggests that the metallic component of tone may have changed. The metallic component of the tone is related to the hardness and softness of the sound. The patient in this study reported a change in tone quality, especially a softer sound. It is thought that the lip shield may have changed the vibration applied to the reed during blowing. In particular, the high frequencies were reduced, and the high-frequency components may have been suppressed. This change in vibration is dependent on the way the player holds the reed in the mouth and the material of the reed. There may also be changes depending on the thickness of the lip shield and its fabrication material. It is conceivable that players may adapt to the changes in sound quality caused by this device by changing their technique, such as their embouchure. In such a case, it will be necessary to consider training suggestions for improvement and device design so that these changes do not affect the blowability.

The present study and previous studies provide limited evidence for the validation of the effectiveness of lip shields. In the future, large-scale prospective epidemiological studies and randomized controlled trials, such as those conducted in studies examining the trauma-preventive effects of sports mouthguards, should be conducted to further clarify the effects of lip shields. And the durability of the lip shield and the recommended timing of its replacement needs to be considered in the future. Further clarification of the mechanisms underlying lower lip erosion and pain while playing wind instruments will lead to physically beneficial and improved blowing methods, correct use of lip shields, and better lip shield designs that meet the necessary and desired conditions.

CONCLUSION

A lip shield was custom-made with a soft thermoplastic material for a female clarinetist who complained of mucosal erosion and pain of the lower lip. After wearing the lip shield, the patient reported that the mucosal erosion and pain of her lower lip when playing clarinet resolved. The lip shield had little effect on the loudness. There was a slight decrease in sharpness when the lip shield was worn compared to when it was not, describing the reduction of high frequencies. The results suggest that a lip shield made with a soft material can eliminate mucosal erosion and pain in the lower lip, with little effect on performance. Only a slight change in timbre was observed.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee of Tokyo Medical and Dental University (Approval Number: D2016-088). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

GT and YS: conceptualization. GT and MH: methodology and formal analysis. TU: validation. GT, MH, SO, YT, HC, and AN: investigation. GT: data curation, writing—original draft preparation, and funding acquisition. YS and MH: writing—review and editing. TU and YS: supervision. SO: project administration. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest: SO was employed by Yamaha Corporation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
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Towards a Holistic Understanding of Musician's Focal Dystonia: Educational Factors and Mistake Rumination Contribute to the Risk of Developing the Disorder

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Musicians' Focal Dystonia (MFD) is a task-specific neurological movement disorder, affecting 1–2% of highly skilled musicians. The condition can impair motor function by creating involuntary movements, predominantly in the upper extremities or the embouchure. The pathophysiology of the disorder is not fully understood, and complete recovery is extremely rare. While most of the literature views the condition through a neurological lens, a handful of recent studies point out certain psychological traits and the presence of adverse playing-related experiences and preceding trauma as possible contributors to the onset. The nature and the frequency of these factors, however, are under-researched. The present quasi-experimental study aimed to compare musicians with and without MFD in terms of the frequency of various adverse psychosocial and psychological factors to explore their contribution to the onset of the condition. Professional musicians with MFD (n = 107) and without MFD (n = 68) were recruited from online platforms, musicians' unions, and organisations to fill out a survey. The survey was based on two previously conducted interview studies and included the Student-Instructor Relationship Scale (SIRS), the Mistake Rumination Scale (MRS), the Trauma History Screen, and self-constructed questions about the received music education, early success, and personal experiences. To identify potential risk factors, independent samples t-tests were conducted and found that there are significant differences in musicians with and without MFD in terms of mistake rumination, early success, and the received music education. A logistic regression showed that six factors contributed to the construct to various extents; we observed a significant model [$\chi^2_{(80)} = 22.681$, $p < 0.001$], which predicted 71.2% of the cases correctly. This exploratory study shows that psychological and psychosocial factors might play a role in the development of MFD. Understanding these in more detail could inform preventative strategies and complement the current therapeutic approaches to support this vulnerable population better.

Keywords: musician's focal dystonia, psychosocial risk factors, mistake rumination, holistic model, music education

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INTRODUCTION

In the past decades, there is a growing awareness of the occupational problems and disorders of performing musicians (Schuele and Ledermann, 2004; Kok et al., 2016). Among these, Musician's Focal Dystonia (MFD), a task-specific neurological movement disorder, seems to be the most elusive in terms of origins and triggering factors. The condition impairs the fine motor control of body parts that contribute to the sound production, most frequently the upper extremities and the embouchure (Jankovic and Ashoori, 2008; Altenmüller and Jabusch, 2010; Termsarasab and Frucht, 2016), but sometimes even affects the lower extremities (Lee and Altenmüller, 2014). The symptoms manifest themselves in the form of cramps, tremors, and tension in specific muscle groups, and result in involuntary movement patterns. MFD appears to be highly task-specific with only a small percentage of sufferers developing non-task-specific symptoms (Hofmann et al., 2015). It is estimated that it affects about 1–2% of highly accomplished musicians (Altenmüller and Jabusch, 2010), however, this number might be even higher because it is challenging to diagnose the disorder, moreover, some musicians might not seek medical help and their problem remains undiscovered (Rosset-Llobet et al., 2009; Sussman, 2015).

While our understanding evolved greatly of the genetic predisposition of the sufferers (Schmidt et al., 2009) and the maladaptive neurological changes that take place (Elbert et al., 1998; Byl et al., 2000; Candia et al., 2003, 2005; Haslinger et al., 2010), the aetiology it is still unclear (Altenmüller and Jabusch, 2009) which makes the treatment and the development of preventative strategies challenging.

To clarify the origins and the multifactorial network of triggering factors, researchers broadened the field of inquiry by exploring the individual characteristics of the sufferers and found that certain psychological traits, cognitive patterns, and practice behaviours might be contributing factors in the onset (Altenmüller et al., 2014; Sadnicka et al., 2018). A string of studies showed that musicians with MFD have higher levels of anxiety, perfectionism, and social and other types of phobias than healthy musicians and musicians with chronic pain (Jabusch and Altenmüller, 2004; Jabusch et al., 2004; Enders et al., 2011), and it has been concluded that these are pre-existing characteristics rather than psychoreactive traits responding to the onset (Altenmüller and Jabusch, 2009; Enders et al., 2011).

Anxiety, perfectionism, and phobias are closely associated with maladaptive cognitive strategies, such as overfocusing and reinvestment, which were also suggested as triggering factors (Altenmüller et al., 2014), and are known to interfere with the execution of motor movements in various settings (Wulf, 2013), including music performance (Duke et al., 2011; Mornell and Wulf, 2019). It is plausible that these characteristics informed the practice behaviours of the musicians, prompting over-involvement in the task, to the level of motor fatigue and overuse injuries, which can be initial indicators of the onset as well (Altenmüller et al., 2014).

All of these possible psychological, cognitive, and behavioural contributing factors are usually discussed in the literature as highly individual traits and behaviours; however, they do not develop in a vacuum. The social and cultural context, in which the individual is embedded plays an important role in the development and cultivation of the personality and behaviours (Wulf and Lewthwaite, 2016), therefore, these external (sociocultural and psychosocial) influences should not be overlooked.

As an example, there is a rich literature on how social expectations can increase maladaptive perfectionism (Damian et al., 2013), especially in the context of close and influential relationships, such as family systems (Rasmussen and Troilo, 2016). The phenomenon has been examined in sports settings, due to the close relationship between athletes and coaches, and the findings show that coach pressure is an even stronger indicator of long-term perfectionism than parental pressure (Madigan et al., 2019). In instrumental tuition, the student is similarly reliant on their instrumental teacher as an athlete on their coach: the tuition is delivered individually, most often following a master-apprentice model (Haddon, 2009), so much so that instrumental teachers have been called musical parents (Creech and Hallam, 2003). Therefore, it is possible that the frequently reported perfectionism of MFD sufferers is, at least partially, induced or reinforced in the educational setting. Mental problems, such as heightened levels of anxiety also develop in a social and cultural context and were argued to be "functional responses to adversity" (Syme and Hagen, 2020, p. 104) rather than just maladaptive innate traits or inherited conditions. Reinvestment and over-focusing can also be prompted by external factors; these cognitive strategies intensify when there is a perceived danger of being negatively evaluated (Masters et al., 1993). In other words, these characteristics in musicians with MFD might be aggravated by the demands of the professional environment.

The frequently mentioned over-involvement in practice which often results in overuse and motor fatigue in this population (Altenmüller et al., 2014), can be prompted by the aforementioned psychological traits and cognitive patterns, but again, the professional environment possibly also plays a role. It seems logical that the instrument-related behaviours are learned in the instrument-related context, and the performance and practice behaviours are modelled from the specific environment, presumably from the teachers and peers.

The idea of external factors influencing the onset of the condition is further reinforced by the fact that the onset often follows a traumatic experience (Tubiana, 2003). To the best of our knowledge, there is no in-depth investigation into the nature of these events and how they influence the individual, but there is some evidence that many musicians encounter a triggering incident that elevates stress levels before the first symptoms appear (Schmidt et al., 2013).

Yet, the majority of the literature considering psychological and behavioural factors in the onset largely neglects how these characteristics evolved in musicians. These features are examined in isolation, with little regard for the highly specialised environment in which they developed. This leads not only to a limited understanding of the condition but also, perhaps unknowingly, results in a narrative that holds the sufferers at least

partially responsible for their condition, by highlighting their maladaptive psychological and behavioural traits. Liley (2019), when examining the narrative around injured pianists, concluded that the negative portrayal of the sufferers is counterproductive in terms of supporting the population and steers the conversation away from important contributing factors, such as the quality of the received training. Therefore, it is important to understand what shaped these musicians' behaviours, cognitions, and even emotions in connection to their instruments, music-making, and careers.

To explore this under-researched area, we initially approached the topic with an open and qualitative methodology (Détári et al., 2022) to gather data directly from the source, namely, the personal experiences of MFD sufferers, which was followed by a semi-structured interview study with practitioners who treat the condition frequently (Détári and Egermann, in press). These studies reinforced the hypothesis that some of the frequently cited characteristics of this population might develop under the influence of external factors.

Given that the symptoms of MFD evolve and are experienced in a professional setting, most often affecting only the movements associated with performance (Hofmann et al., 2015), it was quite unsurprising that the findings were closely associated with the educational context and work environment. The data from these studies show that the musicians with MFD had unfavourable experiences with their music tuition: they were exposed to socially prescribed perfectionism and authoritative teaching styles in a strict, sometimes even abusive social environment, which expressed little or no regard for performance-related pain or injury. This often prompted anxiety, perfectionism, and mistake rumination in the participants, which led to unhealthy practice behaviours.

The aim of the present study is to examine the topic further by testing the hypotheses generated through the two qualitative interview studies (Détári and Egermann, in press; Détári et al., 2022) in a large-scale quasi-experimental study. We want to identify the most frequent risk factors within the MFD population by comparing them with a control group of healthy musicians without MFD. The goal was to understand how the educational settings, the professional environment, and cognitive strategies might contribute to the development of the condition. The findings can have important implications for music education and for developing more efficient preventative strategies.

MATERIALS AND METHODS

Design, Setting, and Participants

The questionnaire study is the final stage of a larger mixed-method study. The previously conducted interview studies with MDF sufferers (Détári et al., 2022) and practitioners (Détári and Egermann, in press), which retrospectively explored the personal experiences of MFD sufferers prior to the onset, served as a basis for the present survey study. The topics were selected from this rich qualitative material and aimed to cover themes that were strongly supported by both interview studies and were unexplored by previous literature. We also attempted to link this content to previously established concepts and use validated scales when available.

The questionnaire was administered online, and apart from identifying as a musician with or without MFD, we set no exclusion criteria. Participants were recruited from online support groups and social media platforms, and various organisations and practitioners were asked to share the information and the links in their networks. A total of 240 musicians (125 with MFD and 115 healthy) answered the survey. After omitting unfinished and partial responses, 175 cases were considered for further analysis. To allow for a more precise comparison, a pairwise matching between participants with and without MFD was conducted based on gender, age, and instrument group, which resulted in a subset of 88 musicians. Information about the mean age, gender ratio and instruments played in the sample and the subset is presented in **Tables 1**, **2**.

Study Variables

We collected sociodemographic information (age, gender, instrument played, level of education, and profession), and questions were administered about the participants' experience with the received music education, performance-related mistake rumination, lifetime prevalence of trauma, and other stress-inducing experiences. Additionally, we inquired about the location of the symptoms of MFD and the received diagnosis in the MFD group.

Instruments

The first main topic of the investigation was the experience with the received music education. In the absence of a measurement tool specifically developed for this construct, we choose to use the Student-Instructor Relationship Inventory (SIRS) (Creasy et al., 2009; Creasey et al., 2009) and asked the participants to report about one instrumental teacher with whom they worked with and found most influential. The SIRS measures the relationship between the student and teacher on an anxiety-connectedness axis and has been reported to have good psychometric properties ($\alpha = 0.87$ in the anxiety factor and $\alpha = 0.92$ in the connectedness factor) (Creasy et al., 2009). Additionally, it has the benefit of targeting college-level students–the age group where most of the professional teaching is happening–making this measurement tool even more appropriate. Since there were many topics in the interview studies relating to the profession-specific aspects of instrumental teaching, we added self-constructed questions to the survey. These were aimed at the content of the received teaching, with topics like received information about healthy playing technique and performance-related injuries, authoritative teaching style, socially prescribed perfectionism, and technique-focused teaching. In addition, following the qualitative data, we also included questions about the participants' early accomplishments and the difficulty of the played material in relation to their peers. The 24 self-constructed items are presented in Appendix A (**Supplementary Material**).

We also inquired about performance-related mistake rumination using the Mistake Rumination Scale (MRS) (Flett et al., 2020), which was strongly supported by the qualitative

TABLE 1 | Age and gender characteristics of the samples.

Group	Age	Gender distribution			
	M (SD)	Female	Male	Non-binary	Prefer not to say
Full sample (*N* = 175)	42.5 (14.3)	79 45.1%	93 53.1%	1 0.5%	2 1.1%
Full MFD sample (*N* = 105)	44.4 (14.2)	40 38%	63 60%	0 -	2 1.9%
Full healthy sample (*N* = 70)	39.5 (13.9)	39 55.7%	30 42.8%	1 1.4%	0 -
Selected subset (*N* = 88)	42.3 (13.5)	46 52.2%	42 47.7%	0 -	0 -
Selected MFD cases (*N* = 44)	42.5 (13.6)	23 52.2%	21 47.7%	0 -	0 -
Selected healthy cases (*N* = 44)	42.1 (13.6)	23 52.2%	21 47.7%	0 -	0 -

The standard deviation is presented after the means in parentheses. The percentages are calculated in relation to the group size which is presented in the first column. MFD = Musician's Focal Dystonia.

TABLE 2 | Instrument distribution of the samples.

Group	Instrument distribution					
	Wind	Brass	Strings	Percussion	Piano	Plucked
Full sample (*N* = 175)	42 24%	44 25.1%	20 11.4%	8 4.5%	33 18.8%	28 16%
Full MFD sample (*N* = 105)	22 20.9% (8–7.6% with ED)	30 28.5% (25–23.8% with ED)	8 7.6%	6 5.7%	17 16.1%	22 20.9%
Full healthy sample (*N* = 70)	20 28.5%	14 20%	12 17.1%	2 2.8%	16 22.8%	6 8.5%
Selected subset (*N* = 88)	26 29.5%	18 20.4%	18 20.4%	4 4.5%	12 13.6%	10 11.3%
Selected MFD cases (*N* = 44)	13 29.5% (3–6.8% with ED)	9 20.4% (9–20.4% with ED)	9 20.4%	2 20.4%	6 13.6%	5 11.3%
Selected healthy cases (*N* = 44)	13 29.5%	9 20.4%	9 20.4%	2 20.4%	6 13.6%	5 11.3%

MFD, Musician's Focal Dystonia; ED, Embouchure Dystonia.

data. This scale was tested on five samples (Flett et al., 2020) and was found to be valid to measure the construct ($\alpha > 0.81$ and all items loading 0.50 or greater in all samples).

Data was collected about the experienced trauma over the lifetime with the Trauma History Screen (Carlson et al., 2011), and additional self-constructed questions were added about significant changes in the participants' lives. These included events listed by the participants in our interview study (Détári et al., 2022), such as changing instruments, teachers or workplaces, and other personal events, such as becoming a parent or getting divorced. These potential risk factors and all scales employed are presented in **Table 3**.

Procedure

After the participants received a link to the questionnaire, they were presented with a downloadable information sheet and were asked to give consent to the research team to use their anonymised data. Without consent, they could not proceed to the survey questions. The survey was open for 2 months.

Data Analysis

For data analysis, SPSS and R software were used. First, responses with more than three data points missing were omitted manually. In the following analyses, the remaining missing values were replaced by means. The open questions regarding the instruments played were dummy coded twice, firstly, all different instruments were assigned a different number, and secondly, the instruments were grouped into six categories (woodwind, brass, string, piano, percussion, and plucked instruments) with one assigned number for each category. The location of the MFD symptoms in the group with MFD was also coded into three categories (upper extremities, embouchure, and other).

TABLE 3 | Topics and scales.

Topic	Used scales
Experiences with music education	Student-Instructor Relationship Inventory (SIRS) (Creasy et al., 2009)
	Self-constructed questions (about teaching style, body mechanics, technique-focused teaching, and early success)
Mistake rumination	Mistake Rumination Scale (MRS) (Flett et al., 2020)
Trauma and change	Trauma History Screen (Carlson et al., 2011)
	Self-constructed questions

Following this, descriptive tests were run to explore the sociodemographic variables.

In the second stage of the analysis, the instruments were inspected: Exploratory Factor Analyses (EFAs) and Confirmatory Factor Analyses (CFAs) were run on the scales to evaluate them and to test their internal consistency.

To map the differences in risk factors between the groups, we conducted *t*-tests on each variable and tested the relationship between them with a Pearson r correlation. In order to create a comprehensive model of the variables, a logistic regression was used using the presence of MFD as a dependent variable. A detailed description of the tests and the procedure are presented in the result section.

Ethical Considerations

Musicians who suffer from dystonia are vulnerable to psychological distress when asked to recall details about the condition which endangers both their livelihood and artistic outlet. The information sheet and accompanying documents were phrased with this in mind, avoiding negative language, and providing resources of support at the conclusion of the survey. Ethical approval was obtained from the Arts and Humanities Ethics Committee at the University of York, United Kingdom.

RESULTS

Descriptive Statistics of Participant Sample Characteristics

The average age of musicians with MFD ($N = 105$) was 44.46 years (SD = 14.29) ranging from 21- to 83-year-old, and the average age of the onset was 35.57 years (SD = 16.743). They started playing the instrument at 13.09 years of age (SD = 7.14), although this number is skewed by some amateur players, who started playing between the ages of 35–50. After removing these outliers, the average age of starting instrumental education was 12.20 years. The participants suffered from the onset of MFD after 21.13 years of playing on average (SD = 13.491). 64.7% of the musicians considered themselves professionals with a further 15.2% responding "maybe," and 20% of the sample was amateurs. Responses to the open question added at this point suggested that many professional musicians reported "maybe" because they were unable to pursue their profession full time due to their symptoms at the time of their responses. 63.8% of the musicians were diagnosed by a neurologist, further 9.5% by another practitioner, 4.7% by fellow sufferer or musician, and 21.9% were self-diagnosed. There were 31 participants (29.5%) with embouchure problems in the sample with the rest reporting problems with their upper extremities, most often their fingers.

Factor Analytic Scale Construction

Self-Constructed Music Education Scale

20 items were examined for factorability. Half of the items were worded to express the opposite of the targeted construct to avoid participant bias; the scores for these items were reversed for the analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.788, above the commonly recommended value of 0.6, and Bartlett's test of sphericity was significant [$\chi^2_{(190)} = 1199.250$, $p < 0.001$]. All items correlated at least with one other (>0.3), showing that each item had some level of common variance with the other items, which suggested acceptable factorability. **Table 4** presents the results of an Exploratory Factor Analysis with Promax rotation, using parallel analysis (Vivek et al., 2017) and loading values below 0.40 were suppressed (Hair, 2009). For this procedure, we used the full sample ($N = 175$); the higher number of responses provided more data to establish the factors.

Three underlying factors were identified, Low health support and encouragement, Technique focused teaching, and High teacher demands and authoritative style, explaining 27.1, 12.9, and 7.7% of the variance respectively. Two items were omitted because they did not meet the criteria of minimum loading of 0.40, and one because it cross-loaded on two factors. A confirmatory factor analysis was subsequently conducted on the remaining items and reinforced that the factor model was a good fit [$\chi^2_{(113)} = 345.861$, $p < 0.001$], and the three factors showed acceptable internal consistency ($\alpha = 0.783$, $\alpha = 675$, $\alpha = 757$, respectively). This CFA model was used to calculate the factor scores for each factor and each participant, and these scores were used in the subsequent analysis. The items in the three factors are presented in Appendix B (**Supplementary Material**).

Early Success Scale

A second factor analysis was conducted on the items relating to early success on the instrument. The items were moderately correlating with each other (0.453–0.666) showing common variance, but uniqueness. Kaiser-Meyer-Olkin measure of sampling adequacy (0.767) and the Bartlett's test of sphericity [$\chi^2_{(6)} = 248.514$, $p < 0.001$] showed that the items met the requirements for factor analysis. The EFA was run on the full sample ($N = 175$), with the use of parallel analysis and Promax rotation, and with the sample size and degrees of freedom in mind, the loading values below 0.40 were suppressed. The analysis and the following CFA showed one underlying factor clearly accounting for 65.4% of the variance with good internal consistency ($\alpha = 0.818$) and was dubbed as "Early success." The loading table and the correlation table are presented in **Tables 5**, **6**.

Two further CFAs were run on the selected items of the SIRS and the modified Mistake Rumination Scale. The CFAs

TABLE 4 | Factor loadings–EFA pattern matrix "music education".

	Low health support and encouragement	Technique focused teaching	High teacher demands and authoritative style
Tech		0.53	
No posture	0.79		
Own technique (Rev.)		0.79	
Expression (Rev.)	0.46		
Avoid injuries (Rev.)	0.76		
Unsatisfied			
Too much asked			0.59
First try			0.68
No health support	0.55		
Give time (Rev.)	0.66		
Unsure expectations			
Prescription			0.74
Clear instructions (Rev.)	0.62		
Encouragement (Rev.)	0.53		
Concern over discomfort (Rev.)	0.74		
Technical difficulty		0.47	
Solving issues (Rev.)	0.80		
Changed technique		0.81	
Own approach (Rev.)		0.41	
Self-efficacy (Rev.)			

reinforced the two underlying factors in the SIRS: anxiety around the tutor (α = 0.913) and connectedness to the tutor (α = 0.922) [$\chi^2_{(103)}$ = 337.490, $p < 0.001$], and one underlying factor in the Mistake Rumination Scale (α = 0.897) [$\chi^2_{(14\ )}$ = 60.026, $p < 0.001$]. In both scales, means were used as scores for each participant and each factor in the subsequent analysis.

Comparing Risk Factors of Matched Samples of Musicians With and Without Musicians' Focal Dystonia

Independent samples t-tests were conducted to identify mean differences between both sub-samples (Healthy vs. MFD, n = 88) in all potential risk factor variables (**Table 7**). The analysis showed that musicians with dystonia suffered from more performance-related mistake rumination and had significantly more success in their early careers. In addition to this, they had significantly lower health support and encouragement (Factor 1.) and more demands were placed on them with an authoritative teaching style (Factor 3.).

TABLE 5 | Loading table–EFA pattern matrix, "early success".

	Component 1.
Easy start	0.770
Early success	0.765
Quick improvement	0.866
Ahead of class	0.831

Correlations Between Risk Factor Variables

To test the shared variance in the risk factor variables a correlation table was created which shows a strong correlation between the self-constructed scale's factors (Health and encouragement, Autonomy in instrumental technique, Demands and authoritative teaching) and the SIRS scale's "anxiety around tutor" factor (**Table 8**). Moreover, there is a strong negative correlation between connectedness to the tutor (SIRS scale) and the first factor (Health and encouragement) of the self-constructed scale, and a positive correlation between anxiety around the tutor (SIRS scale) and the mistake rumination scale.

Logistic Regression

Considering the rather frequent moderate to high correlations between risk factor variables, we subsequently run a logistic regression on the matched subsample of MFD sufferers and healthy musicians (n = 88), in order to identify the most relevant risk factors for developing MFD. As an outcome variable, we coded being affected by MFD with 1 and not being affected with MFD 0. All nine predictor variables were added to the model: anxiety around the tutor (SIRS scale, factor 1), connectedness to the tutor (SIRS scale, factor 2), performance-related mistake rumination, Health and encouragement (self-constructed scale, factor 1), Autonomy in instrumental technique (self-constructed scale, factor 2), Demands and authoritative teaching (self-constructed scale, factor 3), early success, trauma frequency, and significant life event frequency. We also included the age and gender variables in the model to control for their possible effects.

TABLE 6 | Pearson r correlation matrix "early success".

	Easy start	Early success	Quick improvement	Ahead of class
Easy start	1.000			
Early success	0.45	1.000		
Quick improvement	0.60	0.51	1.000	
Ahead of class	0.46	0.54	0.67	1.000

TABLE 7 | Comparison between musicians with and without musicians' focal dystonia (MFD).

Risk factor variable	Healthy *M* (SD)	MFD *M* (SD)	*t*	df	*p*	Cohen's *d*
SIRS Anxiety around tutor	2.40 (0.93)	2.78 (1.06)	1.78	86	0.078	0.28
SIRS Connectedness to tutor	3.74 (0.88)	3.49 (0.87)	1.35	86	0.180	0.38
Mistake rumination	2.17 (0.72)	2.75 (0.85)	3.45	86	<0.001***	0.73
Low health support and encouragement (Factor scores for factor 1)	–0.27 (0.90)	0.10 (0.77)	2.12	86	<0.005**	0.45
Autonomy in instrumental technique (Factor scores for factor 2)	–0.15 (0.96)	0.12 (0.99)	1.33	86	0.184	0.28
Demands and authoritative teaching (Factor scores for factor 3)	–0.11 (0.88)	0.24 (0.75)	2.03	86	<0.005**	0.43
Early success	3.30 (1.00)	3.92 (1.02)	2.83	86	0.006**	0.60
Trauma frequency	1.81 (2.04)	1.95 (1.79)	0.33	86	0.740	0.07
Significant life event frequency	2.04 (1.65)	2.52 (1.54)	1.39	86	0.166	0.29

*Standard deviations are presented in parentheses. SIRS, Student-Instructor Relationship Scale; MFD, Musician's Focal Dystonia; **p < 0.01, ***p < 0.001.*

TABLE 8 | Pearson r correlation matrix for risk factor variables.

Variable	SIRS connect	SIRS anxiety	Mist. ruminat.	Low health supp.	Autonomy	Demands	Early success	Trauma
SIRS connect	–							
SIRS anxiety	–0.54*							
Mist. ruminat.	–0.14	0.48**						
Low health supp.	–0.68**	0.44**	0.17					
Autonomy	–0.16	0.51**	0.26*	0.12				
Demands	–0.09	0.52**	0.37**	0.18	0.22*			
Early success	–0.14	0.22	0.13	0.12	0.01	0.06		
Trauma	0.15	0.16	0.21*	–0.12	0.07	0.15	0.10	
Change	–0.05	0.24*	0.27*	–0.002	0.15	0.26*	0.29*	0.28**

*SIRS = Student-Instructor Relationship Scale; probability values are calculated, and r correlations marked with * where values lower than 0.005 and with ** where values lower than .001.*

TABLE 9 | Musicians' focal dystonia (MFD) risk factor coefficients from logistic regression.

		Confidence interval			Wald test		
	Coefficient estimate	Odds ratio	Lower bound	Upper bound	Wald statistics	df	*p*
(Intercept)	–2.78	0.06	–5.29	–0.28	4.74	1	0.029
Mist. ruminat.	0.94	2.56	0.24	1.64	6.95	1	0.008
Early success	0.66	1.94	0.16	1.16	6.82	1	0.009
Low health supp. (F.1.)	0.63	1.89	–0.036	1.31	3.44	1	0.064
SIRS anxiety	–0.72	0.48	–1.53	0.09	2.98	1	0.084
Autonomy (F.2.)	0.37	1.45	–0.21	0.96	1.55	1	0.212
Demands (F.3.)	0.43	1.55	–0.25	1.12	1.54	1	0.213

Group with MFD coded as class 1. SIRS, Student-Instructor Relationship Scale.

Following this, in order to simplify the model and to avoid over fitting, risk factor variables with Wald statistics lower than 1 (SIRS connectedness to the tutor, trauma frequency, change frequency, age, and gender) were excluded from the analysis in a backwards fitting approach.

The results indicate that there are two highly influential, significant risk factor variables contributing to the construct: Mistake Rumination and Early success, two variables showing non-significant trends and two non-significant variables where the estimates show the predicted direction. With the inclusion

of these risk factor variables, we observed a significant model ($[\chi^2_{(80)} = 22.681$, $p < 0.001]$, Nagelkerke $R^2 = 0.306$), which predicted 71.2% of the cases correctly. The coefficient table is presented in **Table 9**.

DISCUSSION

The present study approached the question of the aetiology of MFD from a new perspective, placing it in a broader context. We concluded that there is evidence that apart from the frequently cited genetic predisposition (Schmidt et al., 2009), personality traits, maladaptive cognitive strategies, and overuse (Altenmüller and Jabusch, 2009; Enders et al., 2011; Altenmüller et al., 2014; Sadnicka et al., 2018), external social factors might also play a part. We found significant differences between musicians with MFD and healthy musicians in terms of the education they participated in; musicians with MFD were more likely to receive less information about healthy playing technique, higher demands were placed on them with an authoritative teaching style, were less encouraged, and excelled at their instrumental studies, playing more demanding materials than their peers. We also added performance-related mistake rumination to the already suggested maladaptive cognitive strategies and have shown that it is a potential risk factor. Two of these factors were highly significant contributors to the logistic regression model, mistake rumination and early success; other educational factors showed significant differences between the groups in the *t*-tests and were not-significant trends, showing the predicted direction in the regression model.

Given that MFD is a highly task-specific condition (Hofmann et al., 2015), it seems difficult to fully understand it without considering the context in which the affected skill was learned, practised, and performed. The process of movement acquisition can provide further clues for understanding the condition's aetiology, moreover, it might help us to understand the task-specific nature of the disorder; a characteristic that the current models cannot fully explain (Sadnicka et al., 2018).

Playing Mechanisms

Much has been written about how years of excessive repetition of the motor skill is a prerequisite for being affected by MFD: the onset usually happens to trained professionals after many years of practice and performance, most often in their mid-30s (Altenmüller and Jabusch, 2010; Sussman, 2015). However, what kind of movement patterns are being repeated, i.e., the quality of the playing mechanisms might be equally important as the quantity of the practice hours. Many musicians practise excessively without being affected by MFD; one explanation for this is the presence of genetic predisposition (Schmidt et al., 2009), however, it is possible that repeating less efficient movement patterns might also play a role. The quality, i.e., the way how the playing task is executed is largely determined by how it was learned in the first place. Our investigations into the educational context show that there are some distinct characteristics of the received tuition of musicians who later were affected by MFD.

Training professional musicians requires a special setting that largely differs from traditional classroom education. Through the frequently delivered individual sessions, the instrumental teacher gains a profound influence over a limited number of students (Gaunt, 2011; Patston, 2014). This master-apprentice model of teaching happens in relative isolation (Haddon, 2009), is mostly unsupervised, and has no in-built mechanisms for quality control (Kemp, 1996). The content of the teaching is often the replication of the teacher's own education or personal experience (Mills and Smith, 2003; Visentin et al., 2008), and the centre of the attention is the musical output with much less attention to the physical movements or the posture the musicians use to create it (Chan and Ackermann, 2014). Moreover, music educators are often not well-informed about anatomically correct and instrument-specific body mechanics (Visentin et al., 2008), so students' unhealthy postures and inefficient techniques might be undetected and unchallenged, especially if the individual is still able to produce the expected output. As a prominent example, Glenn Gould played flawless concerts with a clearly distorted and unhealthy posture, and while he had not been diagnosed with MFD in his lifetime, the movement patterns observed in video recordings led experts to believe that he was affected by the condition (Wilson, 2000).

What is clear, however, is that inefficient playing mechanics can overload the joints and the musculature, and lead to physical problems (Chan and Ackermann, 2014). There are strong established links between playing-related musculoskeletal disorders, overuse, and unhealthy postures in musicians (Steinmetz et al., 2010), and overuse has been proposed as a triggering factor for MFD as well (Baur et al., 2011; Altenmüller et al., 2014). This suggests that the biomechanical quality of the playing technique might play a part in developing the condition.

Results from the self-constructed scale's first factor, "low health support and encouragement" shows the tendency that teachers of the musicians who later developed MFD cared less about educating their students about healthy playing technique and correct posture and were less concerned about performance-related pain or injury. We know that pain or discomfort experience can modify established movement patterns (Sterling et al., 2001) to avoid pain- or discomfort-triggering movements, moreover, the intensified somatosensory input may "lead to a degradation of sensorimotor representations at several levels of the sensorimotor circuits" (Altenmüller and Jabusch, 2009, p. 146). Fatigue and pain can also lower the motor system's capacity to meet the demands of the performance. As Sadnicka et al. (2018) noted, these alterations of muscle recruitment, which can be inappropriate and inefficient, can have neurological consequences: if the neural representation of the skill cannot accommodate the new movement pattern, the performance will be impaired. In other words, unhealthy playing mechanisms, especially the ones which lead to pain or injury, can lead to developing compensatory movement patterns, and simultaneously, neurological changes. Unfortunately, many musicians keep playing with pain and injury, furthering this deterioration, due to the "no pain, no gain" culture among professional musicians and the stigma around performance-related pain which discourages musicians to seek help for their

discomfort or pain (Ackermann, 2017). The primary music teacher's role in compensating for this negative message is extremely important because they can have a profound effect on their students' health and instrument-related behaviours, and at a younger age, students are more malleable to change maladaptive habits (Cruder et al., 2020).

Early Success

Apart from the decreased motor capacity following pain, there are other situations in which the young musician is challenged to play more difficult materials they are capable of: during the learning process. While the instrumental technique is still developing, choosing an adequate repertoire, which requires enough challenge for development but does not overwhelm the student, is extremely important (Patston, 2014). If the developmental trajectory of the student is not kept in sight, and the student is pushed over the boundaries of normal motor development, a similar discrepancy between skill and demand presents itself, which can pose a risk for MFD (Sadnicka et al., 2018).

In our dataset, musicians with dystonia reported significantly more early success (i.e., playing more demanding materials than their peers and facing challenging performance opportunities). Assigning difficult materials to students might be due to misinterpreted levels of capability from the teachers' part, but it is also possible that these young students showed great aptitude. This idea is further reinforced by the fact that musicians affected by the condition are often soloists (Lim and Altenmüller, 2003; Sussman, 2015) or playing in other esteemed positions, which suggests outstanding talent.

Also, the rapid advancement in playing the instrument might also be linked to the age these musicians began their instrumental studies: the average starting age for our participants with dystonia was 12.20 years (after removing the amateur outliers who started over 35). Children's learning strategies undergo certain changes as their metacognition and verbal working memory develop. Very young children learn based on mimicking and repeating: the process is mostly unconscious and is not accompanied by cognitive verbal processes (Masters et al., 2013). This is called implicit learning or external focus of attention in the literature, and it produces robust, and rapidly automatised movement patterns, underpinned by neural efficiency (Zhu et al., 2014). Examples of these might be walking, manipulating objects, or riding a bicycle. As the child develops a more and more substantial capacity for metacognition, more cognitive skills are used in the process: conscious, analytical planning and testing out certain movement patterns. This is an explicit way of approaching the task at hand, with more conscious control involved in the process. This change in the way of learning is dependent on the task and there are individual differences, however, the ability rarely develops fully before the age of 11 (Gathercole et al., 2004; Masters et al., 2013). The fact that the average starting age in the sample was 12.20 years, and the literature reported similar findings across several samples of musicians with MFD (Schmidt et al., 2013; Altenmüller et al., 2014) suggests that musicians who later developed MFD employed a more explicit strategy, and more internal focus when acquiring the skill. While the literature clearly shows the superiority of implicit learning or external focus (Wulf, 2013) providing evidence that learning with an external focus enhances efficiency (Zachry et al., 2005), effectiveness (Wulf and Lewthwaite, 2010), technical precision, and musical expressivity in music performance (Mornell and Wulf, 2019), the findings regarding the attention of focus in the early stages of learning have been so far inconclusive (Stambaugh, 2017). It has been hypothesised that children with high motor ability benefit from explicit learning (Maxwell et al., 2017), therefore, it is possible that a more explicit strategy provided an asset in the early years of education, helping these young musicians to improve quickly, even if the strategy is not advantageous long-term, especially after the basics of the skill are acquired. Additionally, in late starters, peer pressure also might play a role in playing complex materials early: observing the accomplishments of other students of the same age might prompt both the teacher and the student to try to "catch up."

What is clear, however, is that there are neurological consequences of the late start: the networks underpinning the complex movements needed for playing are developing more optimally if the individual starts playing before the age of seven (Altenmüller et al., 2014), therefore, the late start has been identified as a risk factor for developing MFD (Schmidt et al., 2013; Altenmüller et al., 2014).

In summary, playing challenging materials without fully mastering the required motor skills is a risk factor in developing MFD. The reasons for choosing such a repertoire might be manifold: late start, which can be associated with different learning strategies and possibly peer pressure, or simply, the aptitude of these students. Nevertheless, both a late start and the mismatch between the established motor skills and the requirements of the repertoire seem to put musicians at risk of developing MFD.

Lack of Encouragement and Authoritative Teaching Style

Apart from how and what is being learned in the educational context, the atmosphere and the teaching style also seem very influential. Items relating to the received encouragement, and positive feedback were found to be significantly different between the groups with musicians with dystonia reporting a less favourable and less supportive environment. Moreover, the SIRS's subscale, "anxiety around the tutor" approached statistical significance, with the dystonic participants reporting more anxiety around their teachers, which also points toward an adverse experience with the individual tuition. The relationship between motor learning and feedback has been examined in sports settings: Avila et al. (2012) found that encouraging and positive feedback enhances the learning and the performance of the motor task. It also seems logical that if the motor skill is repeated with a negative connotation and emotional content, it might influence the future recall of the skill (Juhan, 2003) as well as the learning process. The link between negative emotions and the onset of the disorder in musicians with already existing anxiety and perfectionism has been suggested; as Altenmüller and Jabusch (2009): "It is possible that emotionally

induced motor memory consolidation may facilitate the onset of dystonia in the subgroup of patients with these psychological conditions" (p. 151).

This unfavourable environment was also underpinned by a prescriptive and authoritative teaching style and high demands. Strict constraints on the performance are an inevitable part of playing classical music: many aspects of the performance are subscribed to the player, especially in group settings, such as orchestral or chamber music work, leaving little room for spontaneous changes. These musical constraints make classical musicians more vulnerable to developing MFD than jazz or pop musicians who have more freedom to modify the played material (Altenmüller and Jabusch, 2009).

As inevitable as some restrictions are, there are aspects where the musician should be able to make their own decisions, especially in an educational setting, in order to explore their individual interpretation of the pieces and their technical capabilities (Jørgensen, 2000). The autonomy of the student is an important contributor to optimal learning (Wulf and Lewthwaite, 2016; Katz and Westera, 2019): it has been associated with self-efficacy, motivation, attention, and positive cognitive processes during the task (Lemos et al., 2017).

If the general restrictions of classical music are furthered by the teacher's expectations, and the students must play in a prescribed way, the required precision also increases, and with it, the risk for developing MFD. The more highly specialized a skill's neural representations are, the less ability they have to adapt to different task requirements (Sadnicka et al., 2018). Moreover, demanding one specific way of performance and interpretation makes the difference between success and failure even smaller. The neurological consequences of placing demands on students that they are not able to meet have already been discussed, but it also has psychological consequences. Trying to meet unattainable demands can provoke anxiety, which has already been linked to the onset of MFD (Enders et al., 2011), perfectionism, a trait which has been repeatedly reported as a typical characteristic of musicians with MFD (Jabusch and Altenmüller, 2004; Jabusch et al., 2004), and rumination, especially following negative feedback (Nepon et al., 2011).

Mistake Rumination

There are established links between socially prescribed perfectionism, anxiety, and rumination (Flett et al., 2002), and the importance of the social and interpersonal aspect in developing distressing, intrusive thoughts have been thoroughly discussed in the literature (Nepon et al., 2011). To put this into the context of music performance, we inquired specifically about performance-related mistake rumination and found that musicians with dystonia ruminate over performance mistakes significantly more than their healthy counterparts. It seems feasible that apart from the individual and innate trait of perfectionism which makes the individual more sensitive to negatively perceived feedback (Hewitt et al., 2006), the social environment also plays a role, given that the ruminative thoughts often appear in response to an external trigger. How these distressing events are processed, and the content and amount of rumination are dependent on the levels of social anxiety, but also, on the received feedback following the event (Morgan and Banerjee, 2008). In other words, the already mentioned unfavourable educational context might have contributed to the mistake rumination which developed in the musicians who later were affected by MFD.

Trauma and Change

We were not able to show any significant differences between the samples, in spite of the fact that preceding traumatic events or significant change have been repeatedly mentioned in the literature (Tubiana, 2003; Schmidt et al., 2013), and also in our preceding interview study (Détári et al., 2022). One possible reason for this is the chosen tool: the Trauma History Screen (THS) is quite general, listing various traumatic events, from which some are not specifically linked to interpersonal relationships or music performance, such as accidents and natural disasters. Also, measuring the frequency of the suffered traumas might not provide sufficient data on the impact they had on the individual. It is clear from the literature about Post Traumatic Stress Disorders (PTSDs), that personality, gender, genetic predisposition, and the available support system can all alter how much the individual is affected (Broekman et al., 2007; Elwood et al., 2009). A recent paper (Alpheis et al., 2021) compared the childhood experiences of musicians with and without MFD using the Adverse Childhood Experiences Scale (ACE-S) and found that MFD sufferers experienced more emotional neglect during their childhood; this research tool specifically focuses on the family environment and does not include any other potential sources of trauma. Therefore, it seems that the early development and experiences in terms of trauma can be risk factors, however, other types of traumas are not significant predictors in the development of the disorder. We also added a self-constructed scale, listing significant events which were found to be influential by the interview study. These included change in marital status, jobs, or teachers, becoming a parent, death of a close relative and similar items. We, again, were not able to show any significant differences in the groups. One reasonable explanation for this is that musicians with dystonia were asked to report about the year prior to the onset, while the healthy sample about the previous year. Since we administered the survey while the COVID 19 pandemic was still significantly influencing the lives of performing musicians, many healthy participants experienced more life-altering changes than they would have under normal circumstances.

In conclusion, while there is a growing amount of literature on the psychological and behavioural triggering factors in MFD, these have not yet been explored in a social and playing specific context. While this study has not been able to show very strong and conclusive evidence, it still seems important to examine the developmental trajectories of these risk factors. This approach can not only enhance music educational practices in a broader sense but can specifically inform preventative strategies. It also has the added benefit of changing the narrative around the sufferers of the condition and shifting it toward a more compassionate and holistic understanding of the personal experience of the musicians.

Limitations

The most obvious limitation of this study is that it uses to some degree self-constructed, previously not tested scales. We had to proceed with this method because of the lack of scales measuring the constructs highlighted in the interviews. Therefore, the development and validation of scales measuring the quality of the received music education are suggested to create a more reliable and valid understanding of the phenomenon.

Only 63.8% of the musicians with MFD were diagnosed by a medical professional, therefore, we cannot state with complete confidence that all the participants who reported having MFD are indeed experiencing symptoms of the disorder and not some other form of performance-related problem. However, as more and more information is available describing the condition's unique and peculiar symptoms, we decided to include all participants in the analysis who claim to have MFD.

Also, musicians with MFD were asked to recall personal memories, feelings, and psychological states prior to the onset. This was necessary because we were interested in contributing factors, but obviously, it might not be fully reliable and carries possible personal bias. Moreover, there might be some other underlying psychological constructs that are contributing to these differences; systematic and holistic research including all these factors could offer further clarification. Nevertheless, this exploratory study highlights the importance of researching not only currently present traits in sufferers but also the developmental trajectory of these.

CONCLUSION

In conclusion, mistake rumination and playing challenging materials prematurely possibly contribute to the onset of the disorder. Moreover, we found significant differences between the education of musicians with MFD and healthy musicians: it seems that those who developed the disorder learned less about healthy technique, were encouraged less, more demands were placed on them, and the received tuition followed a more authoritative style.

The musicians' lives who are struggling with the condition have to be viewed as complex, continuously evolving systems that are influenced by the environment. This can help us to clarify the aetiology of the condition and can inform preventative strategies.

This is only an early exploration, the first step toward these goals. We need more refined methodologies, to assess various contributing factors and more research to explore how these might impact the individual musicians. Also, as our second interview study (Détári and Egermann, in press) shows, these characteristics and experiences greatly influence rehabilitation as well, so a clearer understanding seems essential in order to enhance the treatment strategies and provide better care for this vulnerable population.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Arts and Humanities Ethics Committee, University of York, United Kingdom. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AD recruited the participants, collected the data, and conducted the initial analysis and wrote the first draft of the manuscript which was then amended following HE's feedback and suggestions. HE was overseeing the final analysis. Both authors contributed to the study design and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.882966/full#supplementary-material

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Exploring the Interpersonal Level of Music Performance Anxiety: Online Listener's Accuracy in Detecting Performer Anxiety

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Music performance anxiety (MPA) affects musicians at various stages of a performance, from its preparation until the aftermath of its delivery. Given the commonality and potentially grave consequences of MPA, it is understandable that much attention has been paid to the musician experiencing it. Consequently, we have learned a great deal about the intrapersonal level of MPA: how to measure it, treatments, experimental manipulations, and subjective experiences. However, MPA may also manifest at an interpersonal level by influencing how the performance is perceived. Yet, this has not yet been measured. This exploratory online study focuses on the listener's perception of anxiety and compares it to the musician's actual experienced anxiety. Forty-eight participants rated the amount of perceived anxiety of a pianist performing two pieces of contrasting difficulty in online-recital and practice conditions. Participants were presented with two stimulus modality conditions of the performance: audiovisual and audio-only. The listener's perception of anxiety and its similarity to the musician's experienced anxiety varies depending on variables such as the piece performed, the stimulus modality, as well as interactions between these variables and the listener's musical background. We discuss the implications for performance and future research on the interpersonal level of MPA.

Keywords: music performance anxiety, multimodal perception, musical background, musical sophistication, empathic concern, shared understanding

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INTRODUCTION

Music performance anxiety (MPA) affects musicians at various stages of a performance, from its preparation until the aftermath of its delivery (Kenny, 2011). Its prevalence varies from 16.5 to 60% (Fernholz et al., 2019). MPA originates from the interaction of generalized biological vulnerabilities, psychological vulnerabilities due to negative early experiences, and specific life events which establish conditioning triggers of anxiety responses (Barlow, 2000; Kenny, 2010, 2011). More recent studies focusing mostly in tertiary education students are expanding the possible dimensions involved in the development of MPA. Some of these include self-efficacy,

social support (from parents, teachers, and peers), motivation, and optimism, all related to better performances or the reduction of MPA while playing (Zarza-Alzugaray et al., 2016a, 2020; Orejudo et al., 2021). Additional considerations may include the relation between the age in which musical training began and MPA (starting musical training at age 7 or younger showed lower levels of anxiety than later onsets; Zarza-Alzugaray et al., 2016b), and even the music institution students belong to Zarza-Alzugaray et al. (2016b).

In severe cases, MPA can lead to the abandonment of the otherwise promising careers (Hernández et al., 2018; Fernholz et al., 2019) or to even more dire consequences such as the development of a mood disorder (Kenny, 2011). Therefore, musicians may incur in dangerous practices, such as consuming drugs and alcohol excessively, to mitigate the debilitating symptoms of MPA (Taylor and Wasley, 2004; West, 2004; Brugués, 2011a,b; Hernández et al., 2018). Given the commonality and potentially grave consequences of MPA, it is understandable that much attention has been paid to the musician experiencing it. As a result, we have a better understanding of ways of measuring it, treatments, experimental manipulations, and its subjective experiences.

On the intrapersonal level, MPA manifests as a combination of physiological, cognitive, behavioral, and affective symptoms (as reviewed in Chang-Arana, 2015[1], Unpublished license thesis; Chang-Arana, 2021): Physiological symptoms include accelerated heart rate, increased sweating, and higher electromyographic activity (Kim, 2008; Yoshie et al., 2008). Cognitive symptoms include catastrophic thinking, internal negative dialogues, self-destructive criticism, and a mismatch between the outcome performance and the expected level by the musician (Deniz, 2007; Kirchner et al., 2008; Brugués, 2011a). Behavioral symptoms include voluntary changes in tempo, avoidant behaviors, trembling, and in pianists contracting the shoulders (Yoshie et al., 2008, 2009; Juncos and Pona, 2018). Finally, affective symptoms include negative apprehension, subjective tension, fear of failure or guilt (Kirchner et al., 2008; Nagel, 2010; Brugués, 2011a; Kenny, 2011; Ruth et al., 2012).

On the interpersonal level, MPA can affect a musician's performance. Performing in front of audiences or evaluators decreases performance quality scores given by juries, when comparing live vs. rehearsal performing conditions. In addition, musicians also show higher physiological arousal and increased self-reported anxiety (e.g., Brotons, 1994; LeBlanc et al., 1997; Yoshie et al., 2008, 2009; Wells et al., 2012; Kwan, 2016, Unpublished master thesis[2]). Yet, it is interesting that despite musicians' concern about the outcome of their performances, and despite the risky measures they are willing to take to improve them little is known about whether such concerns can be detected by the listener and, if so, what drives that perception (Kwan, 2016, Unpublished master thesis, see footnote 2). It is similarly unclear whether the listener's perception of anxiety corresponds to that of the musician. Understanding the listener can lead performers to focus on crucial performing aspects when preparing a performance. To the best of our knowledge, no previous study has addressed this question. Yet, the perceptual processes and individual variables which influence the listener's judgment and their accuracy have been mostly unexplored (Kwan, 2016, Unpublished master thesis, see footnote 2). The listener's judgment and the accuracy of their inferences of a performance may be affected by, for example, multimodal perception (Section "Multimodal Perception"), their musical background (Section "Musical Background and Musical Sophistication"), and dispositional empathy (Section "Dispositional Empathy"). In Sections Multimodal Perception and Musical Background and Musical Sophistication, we revisit sources first reviewed by Kwan (2016, Unpublished master thesis, see footnote 2) and complement these with other works.

Multimodal Perception

The literature on multimodal music perception and ancillary gestures, i.e., movements which are not primarily needed to produce sounds, suggests that both observing and hearing a performance provide the listener with more information than alternative stimulus modalities (audio-only or video-only; Davidson, 1993; Vines et al., 2006; Juchniewicz, 2008; Huang and Krumhansl, 2011; Platz and Kopiez, 2012; Thompson and Luck, 2012; Vuoskoski et al., 2016). Moreover, when assessing a musical performance of a soloist, chamber ensemble or orchestra, people rely more on vision rather than hearing to judge their quality, even if the latter is believed to be the most determining factor (Tsay, 2013, 2014). The role of visual information is also important in perception of expressivity (Davidson, 1993; Vuoskoski et al., 2014), coordination (Chang et al., 2017) and interpersonal synchrony in musical interactions (Jakubowski et al., 2020), emotional tension (Wanderley et al., 2005; Vines et al., 2006), phrasing, dynamics, rubato, overall musical performance (Juchniewicz, 2008), interest on the performance (Broughton and Stevens, 2009), intensity, fluency, and professionalism (Nusseck and Wanderley, 2009; Waddell and Williamon, 2017).

Kwan (2016, Unpublished master thesis, see footnote 2) raised the argument that if a performer's sound properties change as a result of different induced emotions, it is quite possible that MPA would affect a musician's musical output as well as body language, and these changes could be noticeable to listeners. Previous studies have found changes in musicians' body movements and musical outputs (e.g., articulation, timbre, and dynamics) when the musician was induced with emotions such as sadness, happiness, and anger (Dahl and Friberg, 2007; Vines et al., 2011; Van Zijl et al., 2014). Emotions have been induced by asking performers to imagine a tragic scenario or performing a piece with different expressive intentions. Therefore, can the MPA experienced by a musician be strong enough for listeners to distinguishing differences on their body

[1]Chang-Arana, Á. M. (2015). Adaptation and psychometric properties of the Kenny-Music Performance Anxiety Inventory (K-MPAI) (Unpublished license thesis). University of Lima: Peru. Retrieved from https://repositorio. ulima.edu.pe/handle/20.500.12724/1081

[2]Kwan, P. Y. (2016). The effect of music performance anxiety, context, modality and observers' music expertise on judgment of musical performances (Unpublished master thesis). University of Jyväskylä. Available at: https://jyx.jyu.fi/handle/123456789/50620

movements and musical outputs across sensory modalities? According to Kwan (2016, Unpublished master thesis, see footnote 2), expressivity and performance quality were particularly impaired when listeners rated mid- and high-anxious performers in video-only conditions when compared to audiovisual and audio-only conditions. The perception of anxiety and expressivity was affected by visual stimuli (i.e., audiovisual and video-only), and performance quality was by audio stimuli. Furthermore, musical features, such as tempo, mode, or intensity, must be considered since they can also influence a perceived emotional expression (Gabrielsson and Lindström, 2010).

Musical Background and Musical Sophistication

Musical background can have a noticeable effect on music perception. Judgments of a performance are influenced by musical training (Stanley et al., 2002; Wapnick et al., 2004; Broughton and Stevens, 2009), familiarity with the music (Flôres and Ginsburgh, 1996), and enjoyment of the piece being rated (Thompson, 2006). Musicians can detect differences in expressivity by watching the audiovisual recording or just audio recording, while non-musicians can detect differences only in the audiovisual recordings (Davidson, 2005; Huang and Krumhansl, 2011). Musicians are also capable of distinguishing differences in performance quality of ensembles of various skill levels (Geringer and Johnson, 2007; Johnson and Geringer, 2007). Some evidence also suggests that the instrument musicians play may influence their ability to detect musical quality differences of their own instrument vs. other instruments (Wapnick et al., 2004; Broughton and Davidson, 2014). Some other studies suggest that musical training might not provide advantage in detecting emotional intentions in performances (Juslin, 1997; Gabrielsson and Juslin, 2003). Kwan (2016, Unpublished master thesis, see footnote 2) first reported differences on the listener's perception of expressivity and performance according to their musical background. But no differences in perceived anxiety were found regardless of the stimulus modality or the performance context.

However, the dichotomic categorization of musical background (non-musicians vs. musicians) has been questioned lately. Most classifications of musical background in Western societies rely on the ability of playing an instrument and the musician's expertise in Western art music (Levitin, 2012; Müllensiefen et al., 2014; Zhang et al., 2018; Zhang and Schubert, 2019). Yet, contemporary understanding of musicianship has expanded the understanding of musical background. Therefore, we prefer using concept of musical sophistication of Müllensiefen et al. (2014, p. 2) defined as a "psychometric construct that can refer to musical skills, expertise, achievements, and related behaviors across a range of facets that are measured on different subscales."

Dispositional Empathy

Dispositional or trait empathy can influence the accurate detection of emotions. Higher scores of empathic concern defined as "a tendency for the respondent to experience feelings of warmth, compassion and concern for others undergoing negative experiences" (Davis, 1980, p. 6) predict higher accuracy for discriminating spontaneous from authentic laughs (Neves et al., 2018). Trait empathy factors such as perspective-taking and fantasy may be involved in the enjoyment and intensity of emotions experienced when listening to sad music (Vuoskoski and Eerola, 2012; Clark et al., 2015). Higher affective and overall empathy relate to more accurate inferences of a quartet's expressive intentions (Wöllner, 2012). Moreover, listeners with diverse levels of musical background detect live improvisations just out of audio-tracks, while those with higher empathy levels are more sensitive (Pesquita et al., 2014).

Aims, Research Questions, and Hypotheses

This study focuses on two aspects of the interpersonal level of MPA. First, we investigate the degree to which a listener can perceive the anxiety of a pianist. More specifically, we studied how the perceived anxiety of the pianist is influenced by the stimulus modality (audio-only vs. audiovisual), performance condition (practice vs. recital), and the piece performed (Second movement vs. Third movement), while considering the listener's musical background. We address the following two research questions:

RQ1: How is the listener's perceived anxiety of the player influenced by the stimulus modality, performance condition, and piece performed, while considering the listeners' musical background?

- *Hypothesis 1.1*: There will be differences in perceived anxiety of the player depending on the stimulus modality, performance condition, and piece performed.
- *Hypothesis 1.2*: The anxiety of the player will be perceived differently depending on the listener's musical background.

Second, we compare the listener's perceived anxiety to the pianist's experienced anxiety. We explore whether the difference between them is affected by the stimulus modality, performance condition, and piece performed, while considering the listener's musical background and their disposition of empathic concern:

RQ2: Is the perceived vs. experienced anxiety influenced by the stimulus modality, performance condition, and piece performed, while considering the listener's musical background and empathic concern?

- *Hypothesis 2.1*: There will be differences in the perceived vs. experienced anxiety depending on the stimulus modality, performance condition, and piece performed.
- *Hypothesis 2.2*: There will be differences in perceived vs. experienced anxiety depending on the listener's musical background.
- *Hypothesis 2.3*: The differences in the perceived vs. experienced anxiety will be related to the listener's empathic concern.

MATERIALS AND METHODS

Ethical Approval

The aims and methods of this study have been approved by Aalto University Research Ethics Committee.

Participants

Forty-eight participants took part in the online study [female = 30 (62.5%) male = 16 (33.3%), Trans man = 1 (2.1%), and Gender non-conforming = 1 (2.1%)]. The sample's mean age was 30.27 (Min = 18, Max = 62, *SD* = 11.51). The subjects identified themselves as White [*n* = 33 (68.8%)], Black [*n* = 9 (18.8%)], Mixed [*n* = 3 (6.3%)], Asian [*n* = 2 (4.2%)], and Other [*n* = 1 (2.1%)]. Following Zhang and Schubert (2019), we allowed participants to self-identify as non-musicians, amateur musicians, or semiprofessional or professional musicians (Zhang et al., 2018; Zhang and Schubert, 2019). Twenty-one (43.8%) were non-musicians, 19 (39.6%) amateur musicians, and 8 (16.7%) semiprofessional or professional musician. All participants were native or fluent English speakers. Respondents were British [*n* = 27 (56.3%)], American [*n* = 8 (16.7%)], Irish [*n* = 4 (8.3%)], South African [*n* = 4 (8.3%)], and Canadian, Finn, Italian, Nigerian, and Portuguese [each one *n* = 1 (2.1%)]. Eleven participants reported playing the piano (22.9%), 26 other instruments (e.g., violin, ukulele, percussion, etc., 54.2%), and 11 none (22.9%). All participants were recruited through Prolific (Peer et al., 2017)[3] and complete the study on the online platform Gorilla (Anwyl-Irvine, et al., 2020).[4] At the time this article was conceived, the COVID-19 pandemic limited the possibility of recruiting participants in university facilities.

Stimuli

The selection of the stimuli is based on the study of Kwan (2016, Unpublished master thesis, see footnote 2). In that study, musicians performed pieces of their choice in rehearsal (without an audience) and in concert (in front of an audience). The recorded performances were edited to short audio-only, video-only, and audiovisual stimuli. These were presented to observers who were instructed to rate all clips on three dimensions: expressivity of the performer, overall quality of the performance, and performer's anxiousness. The method used in our study followed most of design of Kwan (2016, Unpublished master thesis, see footnote 2), with some modifications described below.

The first author of the present study prepared a performance of Beethoven's piano sonata no. 6 in F major, op. 10, no. 2 from memory. The first author is a semiprofessional pianist who has been playing the piano for 17 years, received tertiary education in piano performance in Peru and Finland, and records and performs occasionally. We focused on the piano because evidence suggests musicians playing solo instruments (such as the piano) show an increase in MPA as they approach the end of their studies, when compared to orchestral musicians (e.g., violinists; Casanova et al., 2018). The piece was recorded fully in two performance conditions: practice and recital. During the practice condition, he was allowed to play the piece as many times as necessary until obtaining a satisfying recording within 1 h. No audience was present. During the recital condition, the first author invited colleagues from his department as well as other viewers with music performance background to join through Zoom. A total of 10 people witnessed the performance. The presence of the audience was intended to create the feeling of a real performance and increase the player's anxiety, but no data was collected. The pianist wore the same clothes, played on the same piano, and recorded the performance using the same camera and microphones positioned at the same distance. The intention was to make the appearance of the practice recordings indistinguishable from the online recital recordings, so future raters would not realize the clips came from two different performance contexts.

The Second (Allegretto) and Third (Presto) movements of op. 10 no. 2 were selected given their contrasting characters in tempo, mode, and technical challenge (The complete set of stimuli can be obtained from **Supplementary Material**). The recordings were edited using Shotcut software (Meltytech) to obtain an approximately 1-min sample from each piece. Previous studies have also used short samples (Kwan, 2016, Unpublished master thesis, see footnote 2) because evaluations of the first sections are not that different from the entire performances (McPherson and Schubert, 2004). The face of the pianist was blurred to keep him anonymous. Each stimulus was further edited to two versions: an audiovisual and auditory-only. Although usually a video-only condition is included (Davidson, 1993), we chose not to for two reasons. First, performances where the musician plays but no sound is produced is unnaturalistic; thus, we aimed to have a more naturalistic design (Broughton and Stevens, 2009; Huang and Krumhansl, 2011). Second, participant attrition tends to be prevalent in online studies (Zhou and Fishbach, 2016), so keeping the design simpler was a way to prevent this problem.

To determine whether the performances contrasted in terms of amount of movement, we asked five professional pianists with extensive piano performance experience (mean years of experience as pianist = 28.20, *SD* = 7.36, range 18–38) to watch all four audiovisual clips of the pianist presented in counterbalanced order. After each clip, they had to rate using a 10-point Likert scale "how much did the pianist move?" (1 = "Not at all," 10 = "Very much"). The judges perceived more movement in the Second vs. Third movement. However, there were no salient differences between two versions of the same movement (**Table 1**).

The inter-rater reliability of the judges was calculated through intraclass correlation (ICC). ICC estimates and their 95% CI were calculated based on a mean-rating (*k* = 5), consistency, two-way-mixed-effects model, ICC = 0.88, 95% CI [0.49, 0.99]. The judges' inter-rater reliability is "poor" (although approaching

TABLE 1 | Perceived intensity of pianist's body movements.

	"How much did the pianist move?"			
	II movement—practice	II movement—recital	III movement—practice	III movement—recital
Pianist 1	5	5	2	2
Pianist 2	7	7	4	4
Pianist 3	8	7	2	4
Pianist 4	3	3	2	2
Pianist 5	8	7	6	3
Total scores	23	29	16	15

[3]www.prolific.co
[4]www.gorilla.sc

to "moderate" reliability) to "excellent" (Koo and Mae, 2016, p. 160–161).

After the stimuli were created, the pianist rated each of them on six dimensions using a continuous scale ranging from 0 to 100. The dimensions were expressivity, control, attention, anxiety, worry, and enjoyment. The selection of dimensions was based on Kwan (2016, Unpublished master thesis, see footnote 2). However, in this study, we only report the results of the two items we used to measure anxiety:

1. How was your inner state?—This refers to how anxious the pianist was while in their playing.
2. How worried were you during the performance?—This refers to how worried or concerned was the pianist while in their playing.

Materials

The performances were recorded using a Canon Legria HF R606 placed at 210 cm away from the middle C (C4) of the keyboard, aiming at the right side of the performer. The audio was recorded with the internal microphone of an iPhone 7 iOS 14.6 placed at 290 cm away from the keyboard. The piano was an upright Hellas Amadeus.

Perceptual Study Procedure

Participants gave their informed consent. They were asked to complete the study in a quiet place, using headphones and their laptops/desktops. They could take as many breaks as needed between trials with unlimited duration. The aim was to allow them to complete the study in conditions similar to listening to an online recital. They were presented with the instructions and a practice trial to familiarize themselves with the task and rating system, as well as adjusting the sound volume to a comfortable level.

The participants were randomly presented with audio-only and audiovisual versions of the pieces during the practice and recital conditions. The participants did not know that the pieces came from different performance conditions. After each clip, all six evaluations were made, but we only report here the analyses of the anxiety-related responses. After completing the perceptual experiment, the participants filled the Interpersonal Reactivity Index (Davis, 1980), the Goldsmith Music Sophistication Index (Müllensiefen et al., 2014), a demographic questionnaire, and a feedback form where participants could share their experience about the study and suggest improvements for future versions.

Questionnaires

Perceived Anxiety Scales

The same anxiety scales described in the Stimuli subsection were used. These were rephrased in the third person. For example, instead of asking "how was your inner state?," participants were presented with "how was the pianist's inner state?." The definition of each parameter was the same as the one the pianist used (Kwan, 2016, Unpublished master thesis, see footnote 2).

The Interpersonal Reactivity Index

A 28-item scale, which measures four independent constructs: Fantasy, Perspective-taking, Empathic Concern, and Personal Distress. The scale has been extensively used since its creation and is under constant assessment (Wang et al., 2020). In this study, we focused our analysis on the Empathic Concern sub-scale (Davis, 1980).

The Goldsmith Musical Sophistication Index

A 39-item self-report scale which also includes two musicality tasks. It measures musical sophistication in general Western populations through five first-order factors (i.e., active engagement, perceptual abilities, musical training, singing abilities, and emotions) and one higher-order factor (i.e., general musical sophistication). This questionnaire does not require respondents to have a musical background, measures musical sophistication as a continuum, and has produced high internal consistency and test–retest (Müllensiefen et al., 2014).

Data Analysis

Data were analyzed using SPSS Statistics version 27. We adjusted the p value following conceptualization of family-wise error of Rubin (2017, p. 273). That is, "the 'family' that is used to estimate the familywise error rate should consist of different tests of the same hypothesis."

We extracted acoustic features (duration, tempo, pulse clarity, and intensity) from the four recorded pieces using the MATLAB (2021)-based MIRtoolbox (Lartillot and Toiviainen, 2007). To get the duration in seconds, we divided the total samples of each excerpt with the sampling rate (44 kHz). To detect the tempo of the four pieces, we used the *mirtempo* function which detects "periodicities in a range of beats per minutes, and choosing the maximum periodicity score for each frame separately" (Lartillot, 2021, p. 103). The pulse clarity was detected by the *mirpulseclarity* function (Lartillot et al., 2008). It "estimates the rhythmic clarity, indicating the strength of the beats estimated by the mirtempo function" (Lartillot, 2021, p. 114). Finally, to detect the intensity of the pianist's playing on each piece, we used the *mirattackleap* function. It estimates the "amplitude difference between the beginning and the end of the attack phase (Lartillot, 2021, p. 120).

The extracted musical features are summarized in **Table 2**. Overall, these are very similar. The biggest difference is that the tempo (bpm) was faster in the recital conditions when compared to the practice conditions in both pieces performed.

TABLE 2 | Extracted musical features.

Piece		Duration (seconds)	Tempo (bpm)	Pulse clarity	Attack leap
Second movement (Allegretto)	Practice	57.93	50.82*	0.30	0.16
	Recital	57.25	55.43*	0.32	0.12
Third movement (Presto)	Practice	94.11	130	0.32	0.16
	Recital	89.33	133.12	0.31	0.17

**The MIRtoolbox presents some difficulties when calculating the tempo of ternary metrics in pieces like the Second movement.*
Original values were corrected by dividing them by 3.

Preliminary Analyses and Testing Assumptions

Given that the perceived anxiety and perceived worry scales seemed to be measuring the same construct, we tested if they could be combined into a single score. Each participant gave eight scores of perceived anxiety and eight scores of perceived worry. These scores were aggregated in an average to obtain two composite scores: one for perceived anxiety and another for perceived worry. We calculated the means of the composite perceived anxiety scores ($M = 40.17$, $SD = 11.39$, 95% CI [36.86, 43.47]) and the composite perceived worry scores ($M = 36.66$, $SD = 11.39$, 95% CI [33.28, 40.01]). Two Kolmogorov–Smirnov normality tests (D) were conducted on these composite scores. The perceived anxiety scores were approximately normally distributed, $D(48) = 0.09$, $p = 0.20$. The perceived worry scores were significantly non-normal, $D(48) = 0.17$, $p = 0.002$. Based on the central limit theorem, we considered the perceived worry scores as approximately normally distributed, given that the number of observations was above 30 (Field, 2009). A Pearson correlation analysis revealed a very strong significant association between the composite perceived anxiety scores and the composite perceived worry scores, $r = 0.84$, $p < 0.001$. Furthermore, a reliability analysis using Cronbach's alpha revealed an internal consistency of 0.91. Based on the correlation analysis and the very high internal consistency suggesting that both composite anxiety and worry scores measure a single construct, we decided to further combine them into a single variable. From now on, it will be referred to as "perceived anxiety score." Before participating in the study, 39 participants had not heard the Second movement and 36 participants had not heard the Third movement ($n = 36$).

We further explored the relation between music sophistication and musical background. A one-way ANOVA revealed significant differences between the scores of the GMSI general score according to the three levels of musical background (semiprofessional or professional, amateur, and non-musician), $F(2, 47) = 15.98$, $p < 0.001$, $\omega^2 = 0.62$. Planned contrasts revealed that non-musicians ($n = 21$, $M = 61.76$, $SD = 20.26$, 95% CI [52.54, 70.99]) differed significantly in their GMSI general scores from amateur and semiprofessional or professional musicians, $t(45) = 5.64$, $p < 0.001$ (one-tailed), $r = 0.64$. However, the GMSI general scores were roughly equal among amateur musicians ($n = 19$, $M = 89.32$, $SD = 17.76$, 95% CI [80.76, 97.87]) and semiprofessional or professional musicians ($n = 8$, $M = 99.00$, $SD = 17.94$, 95% CI [84.00, 114.00]), $t(45) = 1.12$, $p = 0.231$ (one-tailed), $r = 0.18$. Because amateur and semiprofessional or professional musicians did not differ in their GMSI general score, we decided to combine both groups. Thus, our variable "musical background" was recoded into two levels: non-musicians ($n = 21$) and musicians ($n = 27$).

RESULTS

> *RQ1*: How is the listener's perceived anxiety of the player influenced by the stimulus modality, performance condition, and piece performed, while considering the listeners' musical background?

In RQ1, we used one test on the same hypothesis (i.e., ANOVA). Therefore, our p value was set to 0.05.

We conducted a 2 (Second movement vs. Third movement) × 2 (practice vs. recital) × 2 (audio-only vs. audiovisual) mixed repeated-measures ANOVA, with musical background (non-musicians vs. musicians) as between-subjects variable, and the listener's perceived anxiety scores as dependent variable.

The perceived anxiety scores did not differ significantly between non-musicians and musicians, $F(1, 46) = 0.52$, $p = 0.48$, $\eta_p^2 = 0.01$.

The perceived anxiety scores were significantly affected by the piece being rated when ignoring the performance condition and stimulus modality, $F(1, 46) = 6.35$, $p = 0.015$, $\eta_p^2 = 0.12$. Contrasts showed that the perceived anxiety scores of the third movement ($M = 40.24$, $SE = 1.99$, 95% CI [36.23, 44.25]) were significantly higher than the perceived anxiety scores of the second movement ($M = 35.50$, $SE = 1.76$, 95% CI [31.95, 39.04]), $F(1, 46)$ 6.35, $p = 0.015$, $r = 0.35$.

The perceived anxiety scores were significantly affected by the stimulus modality when ignoring the piece and performance condition, $F(1, 46) = 4.95$, $p = 0.031$, $\eta_p^2 = 0.10$. Contrasts showed that the perceived anxiety scores in the audio-only condition ($M = 39.62$, $SE = 1.89$, 95% CI [35.82, 43.42]) were significantly higher than the perceived anxiety scores in the audiovisual condition ($M = 36.12$, $SE = 1.72$, 95% CI [32.65, 39.59]), $F(1, 46) = 4.95$, $p = 0.031$, $r = 0.31$.

A significant two-way interaction was found between the piece performed and the musical background of the listener, $F(1, 46) = 9.37$, $p = 0.004$, $r = 0.41$. This means that the perceived anxiety scores on each piece were different according to the musical background of the listener. The interaction figure (**Figure 1**) shows that the perceived anxiety scores of non-musicians were approximately the same in the Second ($M = 37.21$, $SE = 2.64$, 95% CI [31.89, 42.52]) and Third ($M = 36.19$, $SE = 2.99$, 95% CI [30.18, 42.21]) movements. However, musicians reported higher perceived anxiety scores in the Third movement ($M = 44.30$, $SE = 2.64$, 95% CI [38.99, 49.60]) when compared to the Second movement ($M = 33.79$, $SE = 2.33$, 95% CI [29.10, 38.48]).

A significant two-way interaction was found between the piece performed and the stimulus modality, $F(1, 46) = 8.66$, $p = 0.005$, $r = 0.40$. This means that the perceived anxiety scores on each piece were different according to the stimulus modality. The interaction figure (**Figure 2**) shows that the perceived anxiety scores in the audio-only conditions were approximately the same in the Second ($M = 39.19$, $SE = 2.17$, 95% CI [34.82, 43.55]) and Third ($M = 40.06$, $SE = 2.23$, 95% CI [35.56, 44.55]) movements. However, in the audiovisual conditions, the Third movement received higher perceived anxiety scores ($M = 40.43$, $SE = 2.12$, 95% CI [36.16, 44.70]) when compared to the Second movement ($M = 31.81$, $SE = 2.04$, 95% CI [27.70, 35.92]).

> *RQ2*: Is the perceived vs. experienced anxiety influenced by the stimulus modality, performance condition, and piece performed, while considering the listener's musical background and empathic concern?

In RQ2, we used four tests on the same hypothesis (i.e., two t-tests, one homogeneity of regression slopes test, and one ANCOVA). Therefore, our p value was set to 0.013.

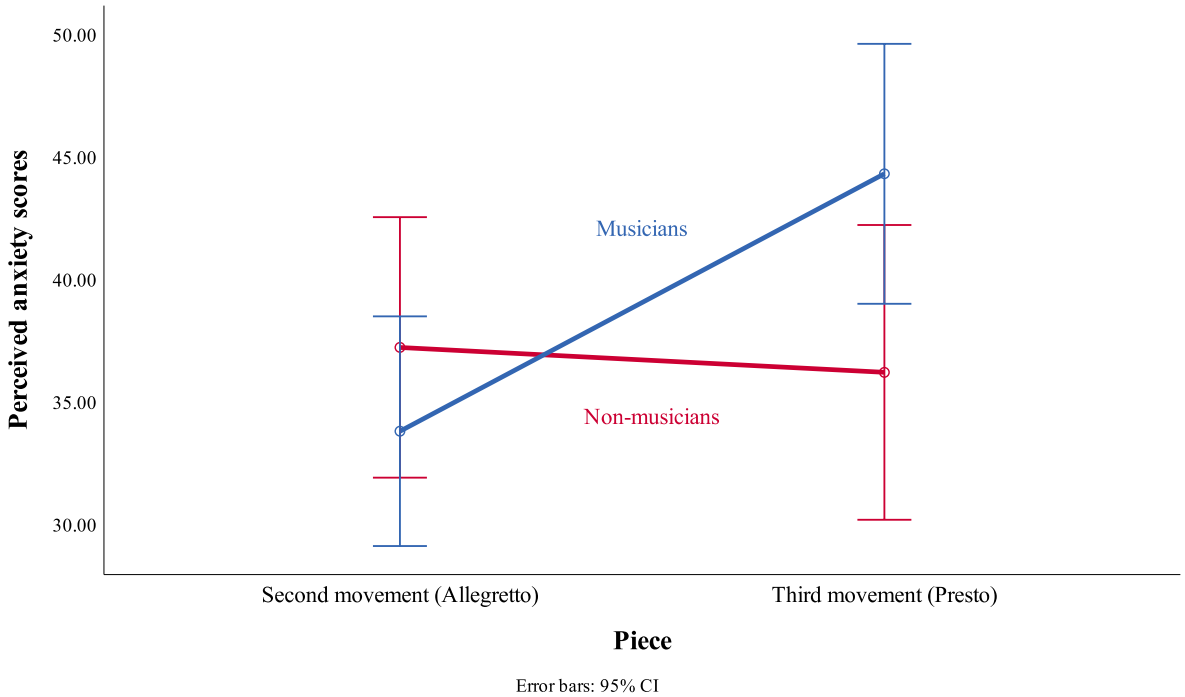


FIGURE 1 | Interaction effect of piece performed and musical background.

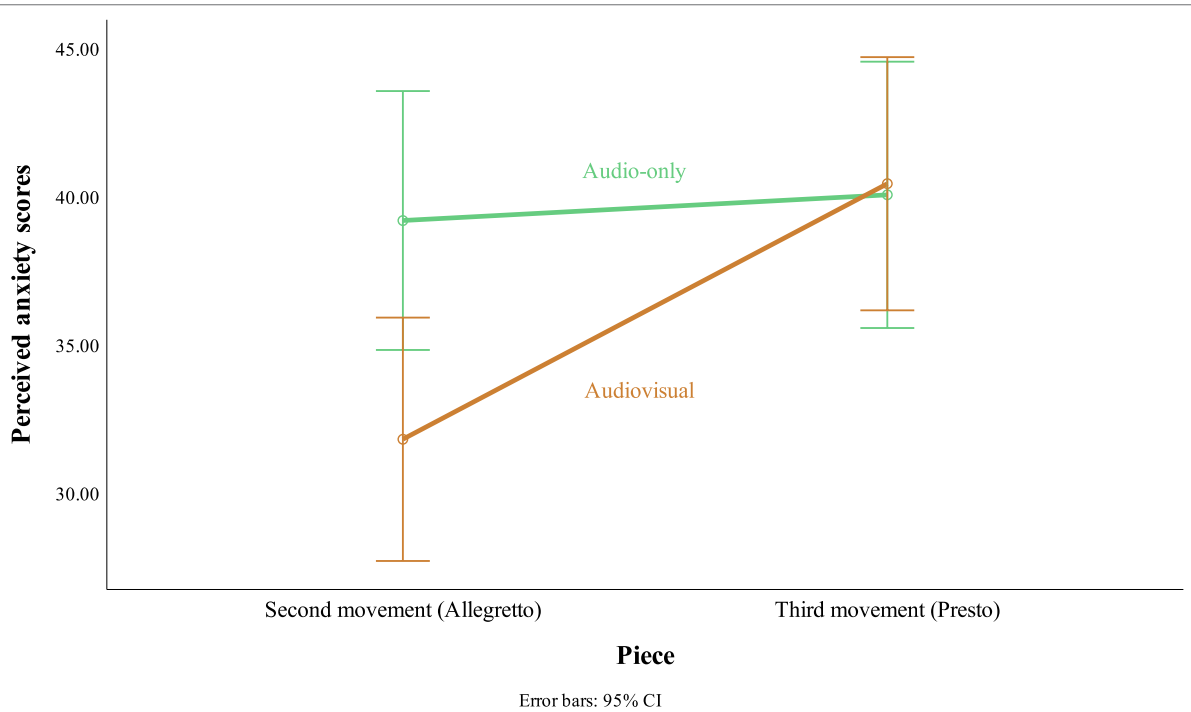


FIGURE 2 | Interaction effect of piece performed and stimulus modality.

We calculated the difference between the listener's perceived anxiety scores and the musician's experienced anxiety scores. This difference was squared and then squared rooted to transform the scores into positive values. Values closer to 0 indicate higher accuracy. Conversely, values larger than 0 indicate lower accuracy. This new variable was named "anxiety-inference accuracy."

In **Table 3**, we present a summary of the aggregated and averaged scores of the listener's perceived anxiety scores and the pianist's experienced anxiety scores. We observe that the difference between these scores is negative. That indicates that across stimuli, the listeners underestimated how anxious the pianist was feeling.

We tested the ANCOVA assumptions of independence from experimental manipulation and homogeneity of regression slopes for the anxiety–inference accuracy. Using two independent sample *t*-tests, we tested if our covariates (empathic concern, and general factor of musical sophistication) were independent from the experimental manipulation (musical background). Levene's test suggests that the variances of empathic concern, $F(46) = 0.01$, $p = 0.93$, and musical sophistication, $F(46) = 0.82$, $p = 0.37$, are equal according to musical background. The listener's empathic concern, $t(46) = -0.37$, $p = 0.72$, was roughly the same in the musical background groups. However, the listener's general factor of music sophistication varied according to the musical background groups, $t(46) = -5.49$, $p < 0.001$. Thus, the general factor of music sophistication is not appropriate to use as a covariate in the analyses.

We tested if the relationship between our dependent variable (anxiety–inference accuracy) and our covariate (empathic concern) is the same in each of the musical background groups. We observed that the interaction between empathic concern and musical background was non-significant, $F(1, 44) = 4.75$, $p = 0.211$. Therefore, the assumption of homogeneity of regression slopes was met for empathic concern.

We conducted a 2 (Second movement vs. Third movement) × 2 (practice vs. recital) × 2 (audio-only vs. audiovisual) mixed repeated-measures ANCOVA, with musical background (non-musicians vs. musicians) as between-subjects variable, empathic concern as covariate, and anxiety–inference accuracy as dependent variable.

A significant two-way interaction was found between the piece performed and the musical background of the listener, $F(1, 45) = 7.60$, $p = 0.008$, $r = 0.38$. This means that the anxiety–inference accuracy on each piece was different according to the musical background of the listener. The interaction figure (**Figure 3**) shows that, when adjusting for the empathic concern of the listeners, the anxiety–inference accuracy of non-musicians ($M = 22.11$, $SE = 1.99$, 95% CI [18.11, 26.11]) and musicians ($M = 21.79$, $SE = 1.75$, 95% CI [18.27, 25.32]) was approximately the same in the Second movement. However, the anxiety–inference accuracy significantly decreased for non-musicians in the Third movement ($M = 26.17$, $SE = 2.04$, 95% CI [22.07, 30.27]), while significantly increasing for musicians in the Third movement ($M = 18.51$, $SE = 1.80$, 95% CI [14.90, 22.13]).

There were no significant differences in the anxiety–inference accuracy according to musical background, even after partialling out the effect of empathic concern, $F(1, 45) = 2.93$, $p = 0.094$, $\eta_p^2 = 0.06$.

Empathic concern was not significantly related to the listener's anxiety–inference accuracy, $F(1, 45) = 4.75$, $p = 0.035$, $\eta_p^2 = 0.10$.

DISCUSSION

Research in MPA mostly focuses on its intrapersonal level, that is, on the psychological processes of a musician experiencing it. As a result, we have learned much about how to measure MPA, how to treat it, its subjective experiences, how to manipulate it experimentally, and its symptoms. However, MPA has been understudied at the interpersonal level, that is, how the experienced anxiety of a musician is perceived by an audience. In this study, we explored whether listener's perceived anxiety corresponds to the musician's experienced anxiety. We investigated the listener's perception through multimodal perception, while taking into account their musical background and dispositional empathic concern. Listener's perception of performance anxiety was affected by the piece being rated (the Third movement receiving the highest perceived anxiety scores) as well as the stimulus modality (the audio-only condition receiving the highest perceived anxiety scores). Additionally, interaction effects showed that musicians perceived anxiety differently than non-musicians, and that audiovisual stimuli of the Third movement received higher perceived anxiety scores when compared to the Second movement. Listeners' anxiety–inference accuracy was affected by the interaction of listeners' musical background and the piece performed (Musicians showed the highest accuracy in the Third movement).

RQ1: How is the listener's perceived anxiety of the player influenced by the stimulus modality, performance

TABLE 3 | Listener's mean perceived anxiety scores and musician's self-rated anxiety.

Piece	Performance condition and stimulus modality	Listener's mean perceived anxiety scores	Pianist's self-rated anxiety	Difference	*SD*	95% CI	
						Lower	Upper
Second movement (Allegretto)	Practice audio	37.95	50.00	−12.05	18.82	−17.52	−6.59
	Practice audiovisual	32.5	57.00	−24.50	18.25	−29.80	−19.20
	Recital audio	40.03	44.50	−4.47	15.51	−8.97	0.04
	Recital audiovisual	30.66	60.50	−29.84	16.98	−34.77	−24.91
Third movement (Presto)	Practice audio	40.67	44.00	−3.33	15.16	−7.73	1.07
	Practice audiovisual	40.94	44.50	−3.56	17.50	−8.64	1.52
	Recital audio	40.53	67.00	−26.47	22.49	−33.00	−19.94
	Recital audiovisual	40.86	71.50	−30.64	17.70	−35.78	−25.49

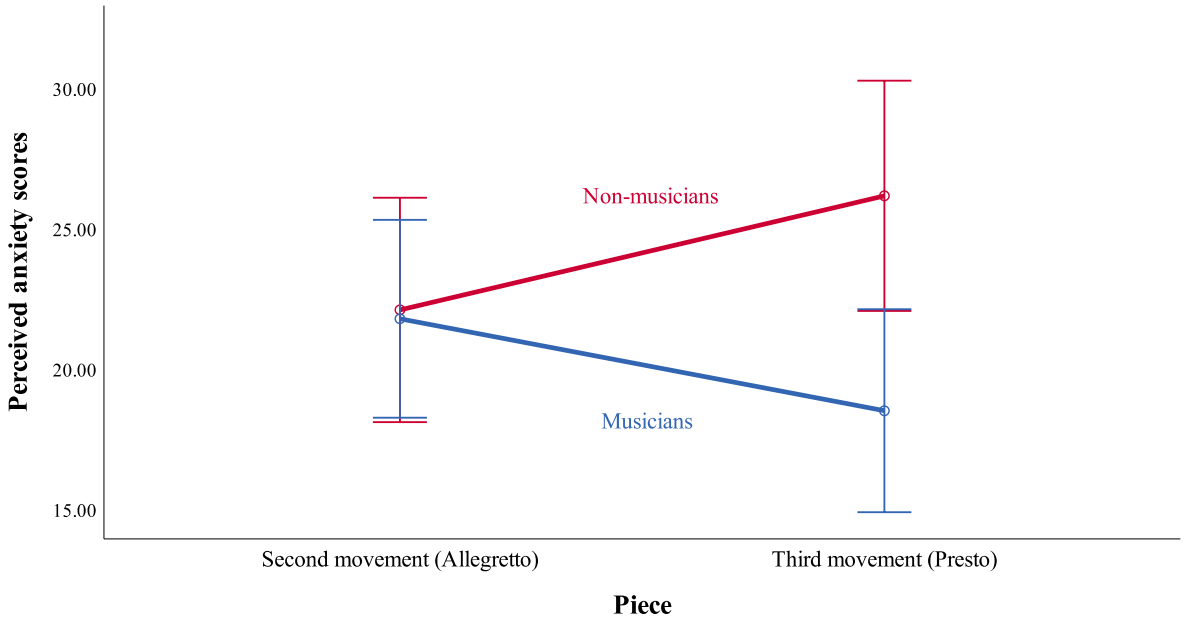


FIGURE 3 | Interaction effect of piece performed and musical background.

condition, and piece performed, while considering the listener's musical background?

Hypothesis 1.1: There will be differences in perceived anxiety of the player depending on the stimulus modality, performance condition, and piece performed.

There were differences in the listener's perceived anxiety scores according to stimulus modality and piece performed, but not according to performance condition. Furthermore, there were interactions between the piece performed and stimulus modality. Thus, we found partial support for Hypothesis 1.1. Next, we discuss these findings.

Results showed main effects of the piece performed, and stimulus modality on the perceived anxiety scores. The perceived anxiety scores were higher in the Third movement when compared to the Second movement. This corresponded with the subjective experience of the pianist, who considered the Third movement as more challenging than the Second movement. Moreover, this claim gains support due to the interaction effect we detected between the piece performed and the musical background of the listener (**Figure 1**). Non-musicians gave similar perceived anxiety scores regardless of the piece presented with. However, musicians reported higher perceived anxiety scores in the Third movement. This indicates that musicians may have recognized the technical difficulties demanded to play the Third movement, whereas non-musicians lacked the technical background to judge one piece as more challenging (hence more anxiety-inducing) than the other.

The listener perceived higher anxiety in the musician during the audio-only vs. audiovisual clips. This might be explained by the "protective effect" of the ancillary gestures that the listener could observe in the audiovisual stimuli. When the ancillary gestures increase, performances are judged as more expressive and they elicit positive musical experiences, such as expressiveness, interest, dynamics, phrasing, and overall musical performance (Juchniewicz, 2008; Broughton and Stevens, 2009), although some contrary evidence exists (Vines et al., 2011; Vuoskoski et al., 2016). Yet, in the study of Platz and Kopiez (2012) meta-analysis suggests that the visual component in music performance has a Cohen's *d* medium effect size of 0.51 SD. Furthermore, the interaction between piece performed and stimulus modality (**Figure 2**) adds support to the protective effect of ancillary gestures. The perceived anxiety scores in audiovisual stimuli were much lower in the Second movement than in the Third movement. The difference of body movements between the Second and Third movements could explain this. In the Third movement, the pianist's ancillary gestures were constrained, and he adopted a stiffer position in comparison with the Second movement, which allowed for more liberty of body movements. This claim is further supported by our judges who perceived more body movements in the Second movement when compared to the Third movement. In the absence of the visual component, the perceived anxiety scores in audio-only stimuli were roughly the same in both pieces.

We did not find a main effect or interaction effects of the performance condition on the perceived anxiety scores. This contradicts the subjective experience of the pianist, who felt much more anxious when performing for an online

audience. The measures of this study could not capture the anxiety experience by the performer, or the anxiety cues were so subtle that the listeners were unaware of them. However, the extracted musical features (**Table 2**) showed that the tempo of the Second movement played in the recital condition was faster (55 bpm) than in the practice condition (50 bpm). The recital condition of the Third movement also had faster tempo (133 bpm) than the practice condition of the Third movement (130 bpm). This increase in speed may reflect the anxiety of the musician. However, the other musical features did not show major distinguishable differences.

Computational analysis of the sound properties could be an interesting additional source of information to the subjective (e.g., self-rating scales) and physiological signals (e.g., EMG, ECG, and GSR) already used to measure the manipulation of anxiety. Sound properties have shown to change depending on the performing condition or emotional state of the performers (Thompson and Luck, 2012; Van Zijl et al., 2014). Studies of social anxiety disorders suggest that changes in pitch voice could be another physiological indicator of social anxiety disorder (Weeks et al., 2012). Thus, we could find a musical equivalent in future studies with a larger sample of musicians. For example, we could investigate acoustical features such as tempo and loudness of pianists performing during high-stress conditions in comparison with lower-stress ones. Previous studies have shown that individuals with panic disorder and social phobia tend to speak faster during public speaking (Hagenaars and van Minnen, 2005; Laukka et al., 2008).

> *Hypothesis 1.2*: The anxiety of the player will be perceived differently depending on the listener's musical background.

There were no significant differences between non-musicians and musicians on their perceived anxiety scores. However, musical background did influence the perceived anxiety scores when interacting with the piece performed. Thus, we found partial support for Hypothesis 1.2.

As explained in Hypothesis 1.1, listeners with musical background may have had more tools to judge the technical demands of the two movements. Musicians perceived the Third movement as more challenging (more anxiety-inducing) than the Second movement. In contrast, non-musicians could not distinguish these technical challenges and thus gave similar perceived anxiety scores regardless of the piece presented with.

> *RQ2*: Is the perceived vs. experienced anxiety influenced by the stimulus modality, performance condition, and piece performed, while considering the listener's musical background and empathic concern?

> *Hypothesis 2.1*: There will be differences in the perceived vs. experienced anxiety depending on the stimulus modality, performance condition, and piece performed.

We did not find main effects of stimulus modality, performance condition, and piece performed, on the listener's anxiety–inference accuracy after partialling out their empathic concern (but see **Supplementary Material** for an alternative outcome and discussion). These results seem to conflict what the data suggest in **Table 3**, where the listener and the musician had quite different experiences when it comes to anxiety. The musician consistently reported experiencing anxiety levels much higher than what the listener perceived, suggesting that the listener underestimated the anxious experience of the performer. Larger differences were observed between the experienced and perceived anxiety in audiovisual vs. audio-only conditions. This supports the idea that seeing the musician performing can create a protective effect against being perceived anxious. In the absence of visual information, the listener was more accurate in their inferences. Lastly, the differences of shared understanding of anxiety observed between the Second movement and the Third movement may be driven by the ancillary gestures of the musician: The Second movement had more pronounced body gestures than the Third movement. Yet, the results of the mixed ANCOVA suggest that the anxiety–inference accuracy was not significantly affected by manipulating our main independent variables.

> *Hypothesis 2.2*: There will be differences in perceived vs. experienced anxiety depending on the listener's musical background.

There were no significant differences between non-musicians and musicians on the listener's anxiety–inference accuracy. However, musical background did influence the listener's anxiety–inference accuracy when interacting with the piece performed. Thus, we found partial support for Hypothesis 2.2.

In the Second movement, non-musicians and musicians had roughly the same anxiety–inference accuracy. However, in the Third movement, the accuracy of non-musicians decreased and the accuracy of musicians increased. This result can be interpreted similarly to Hypothesis 1.2. Musicians could detect the technical challenges of the Third movement and deem these as more complex than the technical challenges of the Second movement. This coincides with the pianist's own appreciation of the higher difficulty of the Third movement in comparison with the Second movement.

Future studies should recruit participants with a stronger musical background, specifically with piano, to see how well our results generalize. In our sample, we had seven pianists who had some musical background (Only two were semiprofessional or professional musicians.). This is not enough for a valid comparison. However, this is an important question to address since previous studies report that the instrument musicians play may influence their ability to detect musical quality differences of their own vs. other instruments (Wapnick et al., 2004; Broughton and Davidson, 2014).

In our study, listeners with musical background were more accurate in detecting the experienced anxiety of the musician when playing the Third movement, and regardless of the

stimulus modality. However, musical background by itself or in interaction with other variables did not make a difference in the anxiety–inference accuracy. This suggests that the pianist should not worry too much about being perceived as anxious by the audience. Similarly, during public speaking the audience do not seem to detect the speakers self-felt anxiety (Goberman et al., 2011).

Possibly, judging if a musician is anxious is not in the focus of a listener during a concert. It could be mainly a concern of the performer and goes largely unnoticed by the audience, even if specifically paid attention to. Perceiving anxiety might be harder through video recordings. Perhaps being present in the same space allows using some cues which are not transmitted through video recordings.

> *Hypothesis 2.3*: The differences in the perceived vs. experienced anxiety will be related to the listeners' empathic concern.

The listener's empathic concern did not influence how accurately they inferred the musician's experienced anxiety. Interestingly, this null result aligns with past research in interpersonal accuracy tests: Perceiver's self-reported empathic dispositions do not correlate with their empathic accuracy skills (Ickes, 2001; Stueber, 2019). In **Supplementary Material**, we retest RQ2 without empathic concern as a covariate. Those results suggest that the listener's anxiety–inference accuracy was affected by the performance condition (the practice condition obtained the highest accuracy) as well as the stimulus modality (the audio-only condition obtained the highest accuracy). Other interactions were detected, suggesting that the listener's anxiety–inference accuracy varied greatly. This would align best with the claim that musicians and listeners "inhabit" different perceptual musical worlds (Schober and Spiro, 2016).

Limitations and Future Work

Several limitations need to be pointed out. Even though, we instructed participants to complete the experiment in a quiet space and while wearing headphones, ultimately it was not possible to control adequate conditions. However, since listening to music through online platforms became quite common during the pandemic, it may be that the conditions under which participants completed the study were naturalistic. Future work could have a mixed sample of online and in-site participants completing the study and compare how results differ.

Next, we will cover limitations on the stimuli design. It may be questionable that the first author of the study was also the pianist displayed in the stimuli. Even if the first author was aware of the danger of biases, it could have been inevitable to be affected by them, particularly when it came to rate his own performances. However, this choice also allowed important learning. First, even though the pianist did feel much more anxious when performing on the online condition when compared to the practice, the metrics used by the participants did not capture this difference. Second, being an active part of this pilot study gave an experiential feeling of what future musicians would go through and thus inform best research practices with them.

We acknowledge that not including video-only conditions may have blinded us from a wider picture of multimodal perception of MPA. We hardly observe a performance where no sound is present, and thus, we decided to exclude video-only conditions from our design. This ecological validity argument has precedent on the literature (Broughton and Stevens, 2009; Huang and Krumhansl, 2011). Future studies under more controlled physical conditions may consider including video-only condition as well. However, it is worth remembering that including another stimulus condition would result in an exponential increase in the experiment's duration, which could cause fatigue on the participants.

Not showing the facial expressions of the musician may have deprived participants of an important source of information, especially music being mostly a form of nonverbal communication. Waddell and Williamon (2017) reported low-performance quality assessment of a pianist when an aural mistake was paired with a negative facial expression. Even though the first author would have agreed to show his face, we decided to blur it because our future study is considering having more musicians. For data protection purposes, we decided to blur the faces of these future musicians. Thus, keeping the face blurred in all cases will enable some sort of comparison between studies.

Regarding the results, we emphasize that these apply to only one pianist and for our convenient sample. We believe an inherent limitation of this kind of multimodal experiment in music is its time demand. Participants took approximately 30 min to complete the ratings for one pianist being displayed in audio-only and audiovisual conditions. Adding more conditions results in longer tasks, which may discourage participants to answer conscientiously. Thus, it would be a logistical problem displaying the performances of a larger number of musicians, if what we seek is generalization. If so, measures would have to be expanded over time with the risk of participants dropping the study or responding mindlessly. Related to the results, given the nested nature of our data (several measures nested within a participant), hierarchical linear modeling would have provided a better statistical approach to analyzing our results. Yet, since we did not have missing data and the sphericity assumption was not a problem (given that our independent variables had only two levels each and at least three levels are needed for sphericity to be calculated; Field, 2009), our linear approach for examining repeated measures is viable (Heck et al., 2014).

Another limitation is that data came from judging approximately 1-min clips. The pianist and the participants did not give a judgment of the whole performance. Moreover, it does not capture how judgments evolve over time. A continuous moment-to-moment rating would be interesting as well, however, that limits the number of metrics one can use probably to one metric per watch.

As suggested in Hypothesis 1.1, extraction and analysis of musical features could be important in MPA research. We found

a consistent difference in the pianist's tempo during the recital conditions. He played faster, probably as a result of the experienced anxiety. However, listeners did not notice the difference. Thus, MIR may reveal differences, which are not detected by performers or listeners.

Future studies could control the practice effect by comparing the perception of anxiety when musicians play well-known pieces and completely new pieces. In this study, the pianist performed a well-rehearsed piece. Yet, musicians find themselves often in situations where they have little time to prepare before a performance. It is a shared believe that preparation is an important way to deal with anxiety. In the future, this could be tested by judging well-rehearsed pieces against less-rehearsed ones.

Experimental studies on MPA should be aware of the listener's psychology. As this study suggests, the listener is not a passive evaluator of a performance. In fact, their perception is influenced by a combination of variables which should be taken into consideration in future MPA studies.

Lastly, future studies could keep a continuous measure of musical background, but still ensure that there is approximately the same number of participants of different musical backgrounds. We follow Zhang and Schubert (2019) for establishing a self-identified musical background (i.e., non-musician, amateur musician, and semiprofessional or professional musician). Thus, it would be ideal to have approximately the same number of participants per category.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, while complying to GDPR regulations.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Aalto University Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ÁC-A obtained the ethical approval, designed and implemented the study, and wrote the manuscript. AM wrote the *MIRtoolbox* script and detected and solved the Second movement ternary-metric tempo issue. NP helped with and provided the contact of pianists for rating the body movements. MS, AM, and MT edited the manuscript. All authors provided feedback and recommendations to improve the study design. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.838041/full#supplementary-material

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Injury Prevention Considerations for Drum Kit Performance

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For any skilled performer to deliver their optimal performance, preparation must extend beyond task-specific skill development to include psychological skills training, physical conditioning, and injury prevention. The keynote lecture upon which this article is based (delivered at the International Symposium on Performance Science 2021) explored current research that demonstrates the importance of physical conditioning and injury prevention for drummers (i.e., percussionists who play the drum kit). Early results revealed that professional drummers' heart rates during live performances can reach similar levels to those of other professional athletes during competitions. They also established that playing-related musculoskeletal disorders (PRMDs) are very common in drummers, particularly those affecting the upper limbs such as tendinitis and carpal tunnel syndrome. Evidence from laboratory-based studies supports non-neutral postures, repetitive movements, and exposure to hand-arm vibration as risk factors for the development of these injuries in drummers. Embedding injury prevention education within drum kit curricula is a promising strategy for reducing the rates at which drummers report experiencing PRMDs, and the barriers and facilitators that drum kit educators encounter when attempting to do so are currently under investigation. When drummers include both physical conditioning and injury prevention within their overall preparation regimen, they will maximize their potential to deliver their peak performance.

Keywords: drummer, drum kit, playing-related musculoskeletal disorders, risk factors, injury prevention, education, performance

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INTRODUCTION

Becoming an elite performer of any task or activity takes years of intensive preparation. The preparation required to achieve this level of performance includes four domains. *Task-specific skill development* is where performers spend the bulk of their preparation time, for obvious reasons: one must be highly skilled at the task to deliver an elite performance. *Psychological skills training* helps performers prepare to handle the psychological demands of the task, such as learning how to manage performance anxiety. *Physical conditioning* involves developing the physical capacity to perform a task through specialized training programs, such as strength or endurance training. Finally, *injury prevention* involves taking steps to identify and manage the risks of injury associated with a task. All these domains of preparation contribute to the ability to deliver an optimal or peak performance, but the keynote presentation upon which this article is based focused on the importance of physical conditioning and injury prevention

for drummers (delivered at the International Symposium on Performance Science 2021: https://youtu.be/oFCrd1Pc9Qc).

PHYSICAL CONDITIONING

Skilled drummers possess many performance-enhancing physical and cognitive attributes compared to non-drummers, such as greater movement speed (Fujii and Oda, 2006), lower levels of muscular co-contraction (Fujii et al., 2009), enhanced motor readiness and proactive inhibitory control (Bianco et al., 2017), and enhanced error detection (Petrini et al., 2011). Although no studies have compared strength, fitness, or endurance attributes between skilled drummers and non-drummers, the former most likely possess superior cardiovascular fitness and endurance, given the substantial physiological demands imposed upon them while drumming. Professional and semi-professional drummers expend approximately 500–600 kilocalories per hour (De La Rue et al., 2013; Brown, 2016; Romero et al., 2016; Azar, 2021a), which is considered "vigorous" physical activity [American College of Sports Medicine (ACSM) et al., 2018]. Based on heart rate (HR) data collected during live performances, De La Rue et al. (2013) suggested that drumming was an intermittent activity that relied on both the aerobic and anaerobic energy systems. Furthermore, my own data (Azar, 2021a) demonstrated that the average HR of professional drummers during live performances was comparable to that of professional soccer players during competitive match play when expressed as a percentage of maximum HR [79% (Azar, 2021a) vs. 86% (Torreño et al., 2016)].

These studies clearly showed that playing the drums is a high-intensity and intermittent activity, and that professional drummers are likely to exceed current recommended exercise targets for healthy adults [Garber et al., 2011; Canadian Society for Exercise Physiology (CSEP), 2020] while they are out on tour. Therefore, they should consider engaging in cardiovascular endurance and high-intensity interval training to prepare their bodies to handle the physical demands of their profession and to deliver their peak performance. Unfortunately, this is an area that is overlooked by many drummers (Azar, 2021b). This is problematic because physical conditioning is not only important for achieving peak performance, but also an important component of injury prevention.

INJURY PREVENTION

Effective injury prevention strategies can only be achieved when the mechanisms by which musculoskeletal disorders develop and the factors that lead to (or prevent) their development (i.e., risk factors) are understood. Musculoskeletal injuries occur when the demands placed on a tissue exceed its capacity to meet them (Price, 2021). The greater the demands, and the lower the capacity, the greater the risk that an injury will occur. Musculoskeletal injuries can manifest in two ways. Acute injuries occur when a single event loads a tissue beyond its capacity (Potvin, 2011; e.g., a slip on an icy sidewalk resulting in a wrist fracture). Chronic injuries are the result of repeated sub-maximal loading (Potvin, 2011) that wears down the tissue so that over time, its capacity to handle loading is reduced to the point where a load that was once acceptable is no longer tolerated and an injury occurs (e.g., stress fractures in long distance runners). Playing-related musculoskeletal disorders (PRMDs) fall into the latter category. They develop over time as a direct result of playing an instrument and interfere with a musician's ability to play their instrument at the level to which they are accustomed (Zaza et al., 1998). Examples include tendinitis, carpal tunnel syndrome (CTS), bursitis, and low back pain (Whiting and Zernicke, 2008).

If injuries occur when demands exceed capacity (Price, 2021), then to reduce the risk of developing PRMDs, one must reduce the demands placed on the musculoskeletal tissues and increase the tissues' capacity to meet those demands. Tissue capacity can be increased through engagement in physical conditioning, but this alone may not be enough to match demands to capacity and prevent an injury (Price, 2021). There are several possible approaches to matching demands to capacity, one of which involves identifying one's exposures to PRMD risk factors and reducing them to levels that are within one's capacity. Injury prevention initiatives are most likely to be successful when a combination of these (and other) approaches is implemented (Price, 2021). However, very little research has examined PRMDs and identified their risk factors in percussionists, and even less has focused on these issues for drummers, specifically. The following sub-sections describe the research my laboratory has undertaken to identify drummer-specific rates and patterns of PRMDs and the biomechanical risk factors that may lead to (or reduce the risk of) their development. These data will ultimately be used to develop prevention strategies to reduce the prevalence and burden of PRMDs in this population.

Rates and Patterns of PRMDs in Drummers

The lifetime prevalence of PRMDs in percussionists (including drummers) was previously reported to be 74–77%, and the upper limbs and the low back tended to be affected the most (Sandell et al., 2009; Hawkins, 2015). However, the results of these and other studies are difficult to apply to drummers for a variety of reasons (e.g., study populations consisting of mixed percussion groups, small sample sizes, and lack of inclusion of diverse musical genres). Therefore, I designed a study to address these limitations (Azar, 2020), the goal of which was to determine the rates and injury patterns of PRMDs specifically in drummers and to identify characteristics that might put drummers at risk for (or protect them from) developing PRMDs.

The methods and results of this study are described in detail elsewhere (Azar, 2020). Briefly, I developed an electronic survey that included three types of questions. The first section asked about respondent characteristics (e.g., age, gender, and years of playing experience). The second section included a definition of PRMDs and asked participants about their

experiences with PRMDs (e.g., injury history, pain levels, and how much the injury interfered with their ability to play). It also included a body map so participants could indicate which body parts were affected, and a question asking them to list the medical diagnosis they had received, if any. The definition I provided to the participants is as follows (adapted from Zaza et al., 1998):

> *Playing-related musculoskeletal problems are defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play the drums at the level to which you are accustomed." This definition does not include mild playing-related aches and pains that come and go, nor does it include pain unrelated to playing your instrument (e.g., pain from injuries sustained in a car accident, sports injuries, and slipping and falling on an icy sidewalk).*

The third section of the survey asked a series of questions about drumming- and lifestyle-related characteristics (e.g., practice and performance habits and how often they engaged in warm-ups/cool-downs and exercise).

The survey was distributed through social media and online for a period of 3 months, yielding 831 valid responses. 90% of the respondents self-identified as being male, and the mean age was 40 years (SD = 14 years). The data were analyzed using qualitative and quantitative approaches where appropriate, and the primary results were as follows:

Sixty-eight percent of the respondents reported a lifetime history of PRMD. This was lower than the rates reported previously in guitar players (Fjellman-Wiklund and Chesky, 2006: 81%) and non-percussion orchestral musicians (Berque et al., 2016: lifetime prevalence of 80% when percussionists were removed from the sample), but was consistent with the rates reported previously in brass instrumentalists (Chesky et al., 2002: 61%), and most relevantly, in drummers/percussionists (Hawkins, 2015: 77%; Sandell et al., 2009: 74%). The respondents also reported similar body regions where PRMDs developed, particularly the upper limbs and the back. Twenty-three percent of the respondents reported having experienced a PRMD within the 7 days prior to completing the survey. These respondents were also asked to rate how much the PRMD interfered with various aspects of their drumming and their daily lives, and the average rating was five out of 10 (i.e., a moderate level of interference). Considering the high stakes involved in a career as a musician (Sandell et al., 2009), a moderate degree of PRMD interference is concerning. Other alarming findings included the large proportion of respondents who reported a lifetime history of multiple PRMDs (59%) and that only 42% of the respondents with a history of PRMDs received diagnoses from a medical professional. The two most common were tendinitis and CTS.

This study confirmed that PRMDs are a significant health problem for drummers. This is compounded by a lack of extended healthcare benefits, as most survey respondents reported that they do not have these benefits (35%), or they get them through other employment (36%). This highlights the importance of determining the risk/protective factors for these injuries to reduce their burden. The data also clearly showed that the upper limbs were where most of the problems were occurring and that the most common injuries were tendinitis and CTS. This provided a roadmap for additional studies to examine the potential risk factors for PRMDs in more depth.

Drummer-Specific Biomechanical Risk Factors for PRMDs

Biomechanical risk factors are the mechanical demands placed on the body that increase one's risk of injury (e.g., forceful exertions, repetitive movements, non-neutral or static postures, and exposure to vibration). In the cases of tendinitis and CTS, both are associated with forceful exertions, repetitive movements, and non-neutral postures, especially when they occur in combination (Bernard, 1997). CTS has also been associated with exposure to hand-arm vibration (HAV; Bernard, 1997). Although several studies have examined the biomechanics and motor control of drumming (e.g., Fujii et al., 2009, 2011; Dahl, 2011; Chong et al., 2016; Mutio et al., 2017; Eriksen et al., 2018), only three have examined this data in the context of injury prevention. Salvalaio et al. (2011) used thermography to examine leg muscle activation in one drummer during two double-kick pedal techniques. Based on the thermographic profiles, the authors concluded that both techniques were likely to lead to muscular fatigue and repetitive stress injuries with prolonged use. Cuden et al. (2015) used self-reported anthropometric data from male Filipino drummers (ages 14–30 years) and information about the frequency of use of various drum kit elements to propose guidelines for drummers to set up their drum kits to promote more neutral upper limb postures while drumming. However, they based their study on the assumption that drummers assume non-neutral upper limb postures while playing and did not quantify drummers' postures themselves. Roseiro et al. (2018) quantified hand-arm vibration (HAV) exposure in six drummers, and they reported HAV exposures at levels that could put drummers at increased risk of developing PRMDs. However, their study was limited by a small sample size and by a short data collection time (180 s), and they did not specify whether the drummers played an actual song or just a repeated pattern. Thus, these are two areas in which my research laboratory is working to fill the gap.

Non-neutral Postures and Repetitive Movements

Recently, we used three-dimensional motion capture technology to document the movement patterns of drummers' upper limbs while playing (Flammia and Azar, 2021). Eleven drummers participated in this study, nine of whom yielded useable data. Once instrumented (Xsens MVN Awinda, Xsens Technologies B. V, Enschede Netherlands), participants played four songs in randomized order. Three songs were pre-determined by the research team for standardization, and one was chosen by the participants to represent their typical performance style. Joint angle-time histories were exported for the primary axes of rotation of the shoulder, elbow, and wrist joints (bilaterally). The average, minimum, and maximum joint angles, the total

ranges of motion (ROM), and the percent of playing time spent in non-neutral joint postures were calculated for each standardized song individually and for all three songs combined.

One notable finding from this study was how much time the drummers spent not only with their wrists outside of neutral flexion/extension postures (mean: 90% for both hands), but with their wrists in extension (mean: 95% for the right hand and 96% for the left hand; see **Figure 1**). Similar patterns were observed for wrist radial/ulnar deviation and for some shoulder movements.

These data also highlighted the presence of repetitive movements, especially at the wrists. Each peak and valley on the graph in **Figure 1** indicate a change in the direction of the motion of the wrist within a single, three-minute song. Thus, the data from this study suggest that non-neutral postures and repetitive movements are likely to be contributing factors for tendinitis and CTS in drummers, especially given that they occur in combination.

HAV Exposure

My laboratory is building on the study conducted by Roseiro et al. (2018) by monitoring HAV exposure in more drummers in more authentic playing conditions (Durward, in progress). The participants were instrumented with a triaxial integrated circuit piezoelectric accelerometer to record accelerations (m/s^2) in the anteroposterior, mediolateral, and longitudinal directions at the hand (SEN041F, PCB Piezotronics Inc.; Provo, Utah, United States). They then played three songs of their choosing that represented their typical playing style. The data were extrapolated based on the participants' self-reported daily playing time and compared to recognized industrial standards for hand-arm vibration exposure [American Conference of Governmental Industrial Hygienists (ACGIH), 2019].

Preliminary results from six participants revealed HAV exposures that exceeded the American Conference of Governmental Industrial Hygienists (ACGIH), (2019) action limit of $2.5\,m/s^2$, and four participants' exposures exceeded the threshold limit value (TLV) of $5.0\,m/s^2$. If vibrations of these magnitudes were recorded during an industrial task, the company would have to remove the tool from the workplace until a new tool could be selected and/or the task could be redesigned to bring the exposure level to within the TLV (Wasserman, 2008). Although preliminary, the data from this study suggest that drummers' exposures to HAV while playing are likely to play a role in the development of CTS in this group.

Modifying the Risk of PRMDs

There are several steps that can be taken to reduce exposures to these risk factors, even if they cannot be eliminated completely. For example, it is not possible to eliminate repetitive motion from drumming, but it is possible to reduce the influence of the repetitive motions by introducing breaks during practices

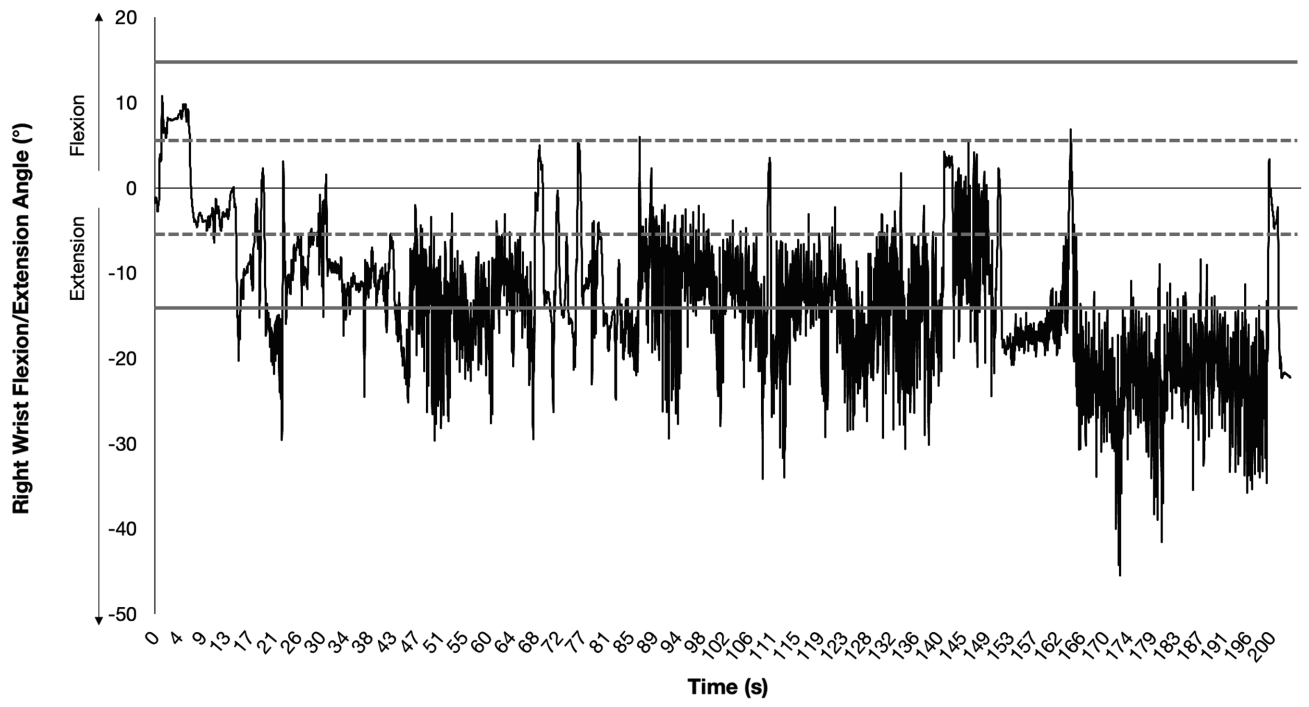


FIGURE 1 | Flexion/extension posture of a drummer's right wrist over the course of playing a single song (approximately 180 s duration). The horizontal axis represents time, and the vertical axis represents the angle of a drummer's wrist flexion/extension posture. Flexion angles are positive and extension angles are negative. The area between the dotted lines is the range of wrist flexion/extension angles that were considered "neutral" wrist posture, and the areas between the dotted and thick solid lines is the range of wrist flexion/extension angles that were considered "mildly non-neutral" wrist posture. Participants spent a substantial amount of time with their wrists extended well beyond this range, clearly in the territory that would be considered non-neutral and even extreme.

and taking microbreaks during the pauses between songs during performances. The best time to take these steps is before an injury develops, rather than trying to deal with them reactively. Thus, drummers should learn about injury prevention early in their drumming careers, and this is where the role of drum kit educators becomes apparent.

Injury Prevention Education

Embedding health promotion/injury prevention within post-secondary instrumental music programs can positively influence music students' knowledge and attitudes toward health and engagement in healthy behaviors (Spahn et al., 2001; Barton and Feinberg, 2008; Zander et al., 2010; López and Martínez, 2013; Árnason et al., 2018; Matei et al., 2018) and reduce the frequency and severity of the symptoms of PRMDs (Spahn et al., 2001; López and Martínez, 2013; Davies, 2020). These studies were not specific to drum kit education, but a second analysis of the data from the PRMD survey suggested that this might also be the case for drummers.

The methods and results of this analysis are described in detail elsewhere (Azar, 2021b). Briefly, I separated the survey respondents into two groups based on whether they had received injury prevention education (PrevEd) during their formal drum training. I then compared the rates of reporting both lifetime and current PRMDs between the groups and calculated odds ratios to determine the magnitudes of the effects.

Eighty-one percent of the survey respondents reported having received formal training (FT) on the drums, but only 42% of those reported that they had received PrevEd. Within the "PrevEd" group (i.e., the group that reported having received PrevEd during FT), the proportion who reported a lifetime history of PRMD was significantly smaller than the proportion who reported no lifetime history of PRMD ($p < 0.05$). The opposite trend was observed in the "NoPrevEd" group (i.e., the group who reported they did not receive PrevEd or had not undertaken FT). Drummers who had not received PrevEd were approximately twice as likely to report a lifetime history of PRMDs than those who had (odds ratio = 1.97). The same trends were observed in respondents who reported they were currently experiencing a PRMD (odds ratio = 1.64). Drummers in the "PrevEd" group also reported engaging in warm-ups, cool-downs, and exercise significantly more often than those in the "NoPrevEd" group ($p < 0.05$).

However, the "NoPrevEd" group also included drummers who had received FT. These participants were likely trained in the use of proper drumming technique, posture, movement qualities, etc. Even if these were not specifically presented as techniques to reduce the risk of PRMDs, it is possible that this training could have had this effect. To account for this, I separated the "NoPrevEd" group into three sub-groups: "FT, no PrevEd received" ("FT-NoPrevEd"), "FT, unsure whether PrevEd received," and "no FT/no response." When I re-ran the analysis, I found that the trend held as: in the "FT-NoPrevEd" group, the proportion who reported a lifetime history of PRMD was significantly larger than the proportion who reported no lifetime history ($p < 0.05$). This trend also held for those reporting a current PRMD. These data suggest that FT alone might not be enough to reduce the rates of PRMDs in drummers and that educators must specifically address injury prevention to have a substantial impact on the rates at which drummers report PRMDs.

In addition to the quantitative analysis, I also conducted a qualitative analysis of the participants' responses to a question asking them to describe what they were taught about injury prevention during their FT. The responses were grouped into various themes and categories, but many were too generic to yield much insight. For example, one participant simply stated "stretching." However, the type (i.e., static or dynamic), timing (i.e., before or after playing), and duration of the stretching can influence its effects on both performance and injury prevention (Chaabene et al., 2019; Emery and Panasen, 2019). Drummers may not experience the full benefits of these activities if they are not engaging in their optimal forms. Further to this point, the respondents who reported receiving PrevEd were less likely to report a history of PRMD, but their rates of reporting PRMDs were still high, and even though they engaged in injury prevention behaviors more often than the other groups, they still did so infrequently. They reported that they warmed up before playing "about half the time," they cooled down after playing "sometimes" or "never," and they engaged in exercise "less than 1 h" per week. This suggests that the respondents might not have engaged in these behaviors often enough, or they might not have optimized how they engage in these behaviors, to reap their full benefits.

Barriers and Facilitators to Including PrevEd Within Drum Kit Curricula

PrevEd alone might not be the "magic bullet" for reducing the rates of PRMDs in drummers, but research suggests that it can have an impact beyond that of FT alone. The fact that so few of the survey respondents reported having received PrevEd from their instructors was both intriguing and concerning. The recommendations to include musician wellness and occupational health within music education have been around for at least two decades (Palac, 2008). Thus, there appears to be a gap between what could be considered "best practice" and what is occurring in actual practice. Therefore, the next step in my laboratory's research plan is to identify the barriers and facilitators to include PrevEd within drum kit curricula. We will interview 30 drum kit educators about the reasons why they do or do not teach their students PrevEd, and what resources are available or are needed to help them to do so effectively. This work will guide the creation of resources and strategies that will empower these educators to develop or enhance this aspect of their curricula. Over time, as more educators begin including PrevEd in their curricula, we expect to see a reduction in rates of reporting PRMDs and in the burden of PRMDs from both economic and quality of life perspectives.

SUMMARY AND CONCLUSION

Playing the drums is a physically demanding task, and physical conditioning to be able to handle the demands is essential. PRMDs are very common in drummers, particularly in the

wrists and the low back. The two most frequently reported medical diagnoses for these injuries are tendinitis and CTS, and evidence that the known biomechanical risk factors for these two injuries are present in drumming at levels that could lead to their development is beginning to accumulate. PrevEd taught by drum kit educators shows promise as a PRMD prevention strategy, but more information about the reasons why these educators do or do not include it in their teaching, and what resources they might need to be able to do so effectively, is needed to maximize the potential of this strategy to reduce the burden of PRMDs in drummers.

Earlier, I described four domains of preparation to achieve elite performance: Task-specific skill development, psychological skills training, physical conditioning, and injury prevention. These last two domains are complementary, because physical conditioning is an important component of injury prevention. To reduce the risk of developing a PRMD, the demands placed on musculoskeletal tissues must be reduced and their capacity to handle those demands must be increased. Over time, engaging physical conditioning will increase tissues' capacity to handle demands. At the same time, taking steps to identify and reduce exposures to risk factors for developing PRMDs will reduce the demands being placed on the tissues. When drummers include both physical conditioning and injury prevention within their overall preparation regimen, they will maximize their potential to deliver their peak performance.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because participants only gave consent to the use of their data within the author's own research group. The data cannot be added to repositories or made available by request. Questions regarding the datasets should be directed to azar5@uwindsor.ca.

ETHICS STATEMENT

The studies involving human participants were reviewed and cleared by the University of Windsor Research Ethics Board University of Windsor, Windsor, ON, Canada. The participants in the laboratory-based and field studies provided their written informed consent to participate in these studies. Survey respondents implied their consent when they completed and submitted their survey responses.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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One Year on: The Impact of COVID-19 on the Lives of Freelance Orchestral Musicians in the United Kingdom

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Before the drastic disruption caused by the sudden emergence of the COVID-19 pandemic, 85% of the United Kingdom's 14,000 orchestral musicians were self-employed freelance workers, engaged in busy and varied portfolio careers comprising a combination of orchestral, West End theatre, chamber music, and commercial recording work. Between May and June 2020 we carried out a first study examining the impact of the pandemic on the lives of 24 self-employed orchestral musicians, all established freelancers. Twelve were mid-career and 12 were late-career (described in that study as "seasoned"). They all reported having lost their much-loved performing careers, missing music making and colleagues, and being anxious about the future of the music profession. However, there were some differences between the two groups: the late-career participants demonstrated greater financial and emotional resilience, while the mid-career musicians reported distress, confusion, and anxiety about their identity as musicians. In the present follow-up study, we aimed to examine the impact of the first year of the pandemic on the lives of 21 of the same musicians. We found that while all the mid-career participants remained committed to their performing careers, many late-career participants aged 54–59 had developed interests in non-performing music work, and the older late-career participants, aged 65 and over, feared that they might already, *de facto*, have retired. We discuss the findings with reference to the precarity of freelance orchestral musicians' lives, lifespan models of musicians' careers, self-determination theory and post-traumatic growth, and their implications for music colleges and musicians' support organizations.

Keywords: coronavirus, portfolio career, identity, music performance, post-traumatic growth, self-employed

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INTRODUCTION

The COVID-19 pandemic has drastically disrupted the performing and creative arts industries in the United Kingdom (Creative Radar, 2021; Spiro et al., 2021). Whereas the internationally respected UK music industry contributed £5.8 bn to the UK economy in 2019 before the pandemic, this sum fell by 46% to £3.1 bn in 2021, and the number of people supporting themselves by working full time in music fell by 35%, from 197,000 to 128,000 (UK Music, 2021). Pre-pandemic,

there were approximately 14,000 professional orchestral musicians in the United Kingdom (Association of British Orchestras, (ABO), 2019). Unlike most European countries where they tend to be salaried, over 85% of orchestral players in the United Kingdom were self-employed as members of freelance orchestras, on short term contracts as extra or deputy players, or on an *ad hoc* basis (Teague and Smith, 2015; Association of British Orchestras, (ABO), 2019; Willis et al., 2019). These freelance musicians built busy portfolio careers comprising a rich and varied combination of performing activities including orchestral and chamber music, West End shows, community work, commercial and recording sessions, and teaching (Bartleet et al., 2019). Although some studies carried out before the pandemic found that self-employment is more strongly associated with job and life satisfaction than employment by a single employer (Warr, 2018), other studies have shown that, for freelance classical musicians, lack of financial security associated with self-employment is linked to increased anxiety (Dobson, 2010; Oakland et al., 2012; Petriglieri et al., 2019).

Classical musicians tend to be highly motivated (McPherson and Zimmerman, 2011; McPherson et al., 2019), having spent thousands of hours developing their skills (Ericsson et al., 1993), and are deeply emotionally invested in and identified with their work (Teague and Smith, 2015; Bonneville-Roussy and Vallerand, 2020). Pre-pandemic, freelance orchestral musicians enjoyed high levels of wellbeing (Ascenso et al., 2017) and job satisfaction (Brodsky, 2006; Gembris et al., 2018). Given, however, that self-employed freelance musicians often experience anxiety about the insecurity of their jobs (Bennett and Hennekam, 2018) and that musicians, generally, can find involuntary career transitions traumatic and a threat to their wellbeing (Maitlis, 2009; Oakland et al., 2012; Hennekam and Bennett, 2016), freelance orchestral musicians were likely to be very vulnerable when faced with the sudden loss of work and career brought about by the pandemic.

Lifespan models of orchestral musicians' working lives show that they are often very long (Allmendinger et al., 1996; Brodsky, 2011) and can be divided into three different stages (Manturzewska, 1990; Bennett and Hennekam, 2018; López-Íñiguez and Bennett, 2020). The first stage is early career (approximately ages 20–30, with fewer than 10 years of professional experience), characterized by the challenge of establishing oneself in the profession and the search for employment. The second is mid-career (approximately ages 30–45, with 10–25 years of professional experience), described as "a stage of artistic and professional expansion, and of the greatest achievements" (Manturzewska, 1990, p.135), and also characterized by the challenge of consolidating one's professional achievements and the difficulty of obtaining a work/family balance (Teague and Smith, 2015). The third is late career (approximately age 55 and over, with 25 or more years of professional experience), when musicians concentrate more on teaching, social responsibility, acknowledging their achievements, and potentially managing a decline in their ability to perform (Gembris et al., 2018). Manturzewska (1990) suggests that musicians tend to "surge forward in their musical career until they are in their mid-forties and then begin to register the first signs of physical and psychic fatigue" (p. 136), at which point a shift begins, from a focus, mid-career, on their own performing achievements to an increased interest in teaching and a greater sense of social responsibility (Manturzewska, 1990; Bennett and Hennekam, 2018), which peaks between the ages of 55 and 65 in a period of optimum teaching achievement.

To investigate the impact of the first lockdown and its immediate aftermath on the lives of freelance orchestral musicians, we conducted an interview study in May and June 2020 of 12 mid-career (aged 35–45) and 12 late-career freelance orchestral musicians (aged 53 and over, but with more than 25 years' professional experience. In that study, we referred to these participants as "seasoned"). We were interested in examining whether previously successful mid-career musicians interrupted in the middle of what would normally be a period of professional expansion and peak performance might be experiencing this challenging period differently from those who had already enjoyed many years of successful professional achievements. The aims of that first interview study were to examine (1) how freelance orchestral musicians were experiencing the impact of the pandemic on their lives, and (2) the similarities and differences between the experiences of mid- and late-career musicians. As we wanted to investigate the impact of the pandemic on musicians who had already established successful, busy, and freelance careers prior to the sudden arrival of the pandemic, we didn't include in our sample early-career musicians, who might still have been in the process of trying to establish their careers as freelancers.

In that first study (Cohen and Ginsborg, 2021), we found that the first lockdown had brought about enormous, negative changes and challenges to the lives of the participants; without exception, they felt the sudden loss of their much-loved, previously successful careers, and anxiety about their finances and future careers. While these findings reflected those of a large survey of people working in the performing arts in the United Kingdom (Spiro et al., 2021), we also found some differences between the mid- and late-career groups: mid-career participants reported greater emotional distress, more anxiety about money, less engagement in music making, and more confusion about their identity as musicians and their future careers than late-career participants, creating an overall picture of a group of mid-career musicians in crisis. By comparison, late-career participants felt they had already achieved a great deal. They were less anxious about money, and many were more focused on teaching and helping their students. As a group, they demonstrated greater emotional and financial resilience.

More than two years on, the pandemic is still with us. Subsequent lockdowns, social distancing rules and restrictions on live performance continued throughout much of 2020 and 2021 in response to new variants of the SARS-Cov-2 virus and ever-changing infection rates [World Health Organization (WHO), 2021].[1] A year after we conducted our study there was still very little work for musicians giving live performances (BBC, 2021a), and as a consequence, freelance musicians' lives and livelihoods were still very far from returning to normal. The impact of the pandemic has been found to be more severe on people who are self-employed than employees. Incomes and

[1]Although restrictions were lifted in March 2022 and free testing was abandoned in April 2022, infection rates continued to rise; it is too early to say what the impact of these decisions will be on musicians and the general public.

profits from self-employment are well below pre-pandemic levels (Blackburn et al., 2021), and people who are self-employed now experience lower happiness and wellbeing than their counterparts in employment (Yue and Cowling, 2021). We therefore conducted a second, follow-up interview study to examine the longer-term impact of the pandemic on the lives of the participants in the first study. Its aims were to examine (1) how these freelance orchestral musicians had experienced and were still experiencing the pandemic in the year since they were first interviewed and (2) the similarities and differences between the experiences of the two groups of mid- and late-career musicians.

MATERIALS AND METHODS

Participants

Of the 24 participants in our first study, all but one responded to the invitation to participate in the present study. All 12 of the mid-career group and nine of the late-career group took part in a single one-to-one interview on Zoom. One of the remaining three was unable to participate due to health issues, the second was no longer performing but working as a full-time teacher and administrator in a music college, and the third didn't respond. In our first study, mid-career participants had to be aged 35–45 in 2020, with a minimum of 10 years of professional playing experience; a year later they were aged 36 to 46 ($M = 41.75$, SD = 3.96) with an average of 18.92 years of professional playing experience (SD = 3.68). Similarly, late-career participants had to be aged 50 or older with a minimum of 25 years of professional playing experience; a year later, they were aged 54 and over ($M = 61.78$, SD = 7.34), with an average of 38.22 years (SD = 7.22) of professional playing experience. In the present study, four of the late-career group were aged 66 or more; we refer to these individuals as older late-career participants. The overall age range was 36 to 74 ($M = 50.33$, SD = 11.54), with an average of 27.19 years (SD = 11.14) of playing experience. There were 12 women and 9 men, 13 string, 5 woodwind, and 3 brass players (see **Table 1** for participants' demographic details). They all met the remaining inclusion criteria for our first study, designed to ensure that participants' careers, pre-pandemic, were relatively homogenous: they were registered as self-employed, based within an hour's drive of London, and had earned at least two-thirds of their income from music performance.

Procedure and Data Collection

Ethical approval having been granted by the RNCM Research Ethics Committee, we invited the 24 participants in the first study *via* email and/or Facebook Messenger to take part in single, one-to-one follow-up interviews with the first author on Zoom. These took place between June and August 2021, lasted approximately one hour, and were recorded on Zoom. Each video recording was deleted immediately after the interview and the audio recording was saved on the first author's password-locked computer. The interview was semi-structured and contained questions focusing on the impact of the pandemic on participants' lives over the past year and their thoughts about the future. Participants were asked if they were currently performing and about their experiences of doing so; how they were managing financially; and about their hopes and fears about continuing to work in the music profession. The full interview guide can be found in **Appendix A**.

Data Analysis

The interviews were transcribed verbatim and analyzed using a five-stage inductive, recursive thematic approach (Braun and Clarke, 2006, 2019). The first author took the lead; the second author analyzed five (just under 25%) of the interviews independently. First, they read through the transcripts several times. Second, they coded the transcripts for meaningful phrases within and between the participants. Third, they grouped the codes into themes characterizing the impact of the pandemic on musicians' lives. Fourth, they grouped the themes into overarching themes and examined similarities and differences between themes arising from the interviews with the two groups of participants. Fifth, they discussed, reviewed, and agreed on the final codes, themes, dominant theme, and overarching themes, and the similarities and differences between the mid- and late-career participants. The criterion of trustworthiness (Lincoln and Guba, 1986) was met by involving both researchers in the analysis; this also allowed for a richer and more nuanced reading of the data (Braun and Clarke, 2019) than if only one researcher had carried out the analysis.

RESULTS

The analysis produced a final set of 22 sub-themes that clustered into one central dominant theme *Uncertainty of future freelancing career* and three lower-order overarching themes: (1) *Returning to performing*, (2) *Coping strategies and maintaining wellbeing,* and (3) *Growth*. Three further latent themes were identified: *Awareness of others, Self-motivated learner,* and *Feeling fortunate*. These themes are summarized in **Table 2** and represented graphically in **Figure 1**, illustrating the centrality of the dominant theme *Uncertainty of future freelancing career*. Quotations from interviews in the description of each theme, below, are attributed to mid-career (*M*) and late-career participants (*L*), respectively.

Uncertainty of Future Freelancing Career

This dominant theme was linked to the three lower-order overarching themes and encompassed four groups of sub-themes: *Anxiety about the fragility of freelance work, Cancelations and touring, How to make money,* and *Maintaining identity and motivation.*

All 21 participants described *anxiety about the fragility of freelance work,* and all but two had done almost no performing in the year since their first interview: "I had one date, yeah. You know, you are talking nothing really" (M11). Many were very anxious about whether and when freelance work would resume, and one was finding the current situation intolerable: "I feel that I can't, I can't carry on doing what I do as a freelancer,

TABLE 1 | Summary of participant information.

Career stage	Participant	Instrument family	Age range (years)	Professional playing (years)	Children at home/ dependants
Mid-career	M1	Brass	35–40	16	–
	M2	Strings	35–40	17	–
	M3	Woodwind	41–45	22	1
	M4	Brass	41–45	18	2
	M5	Strings	41–45	21	2
	M6	Woodwind	46–50	23	–
	M7	Brass	46–50	24	4
	M8	Strings	41–45	22	–
	M9	Woodwind	35–40	13	–
	M10	Strings	41–45	19	2
	M11	Strings	35–40	13	–
	M12	Strings	46–50	19	1
Late career	L2	Strings	66+	41	–
	L3	Strings	66+	34	2
	L4	Strings	56–60	34	2
	L5	Woodwind	66+	51	–
	L6	Strings	51–55	33	–
	L8	Woodwind	66+	49	–
	L9	Strings	51–55	31	3
	L11	Strings	56–60	35	1
	L12	Strings	56–60	36	–

M, Mid-career musician and L, late-career musician.

because I, this year has been absolutely devastating […] I love playing, I really do, and I can't imagine not playing [my instrument], but I also can't imagine being this stressed and this unhappy for the rest of my life" (M1). At the time of the follow-up interviews, lockdown and social distancing restrictions had started to ease according to the delayed Step 4 of the UK government's roadmap (Institute for Government, 2021) and, while participants reported now having a small number of tentative bookings, they would be insufficient to sustain a career. Participants observed that there were fewer freelance work opportunities than pre-pandemic, partly because the self-employed members of major orchestras were currently doing all the work offered to them thus leaving little deputizing work for freelancers, and partly because symphony orchestras were unable to book extra string players to boost their string sections (a regular practice pre-pandemic) because of the space restrictions imposed by compliance with social distancing rules: "I used to do a lot of freelance extra playing with the major sort of symphony orchestras and that is not happening, because they can't get enough strings on the stage to use their own sections, let alone to use extras" (M5).

Several participants reported that conditions and fees had deteriorated as competition for limited opportunities increased. One string player worked on a West End show: "In these times, beggars can't be choosers. So, obviously I show up, smile my best smile and play as well as I can […] What is a shame is that behind every freelance musician is another even more desperate musician, willing to step up at any moment, to work for practically nothing" (M12). Another was offered "exposure" in lieu of a fee for performing but turned it down: "We definitely expect to be paid. If the catering staff are being paid, we expect to be treated fairly, and not [for management] to take the mick, just because we've lost a lot of work" (M2).

Many of the participants were damning about the government's lack of support for the performing arts and understanding of their work: "At no point in any of this […] has anything that I do been (a) recognized, or (b) valued or (c) understood" (L11); "We are the ones who've been most broadly shat on […] classical music doesn't get mentioned really. Do we exist? Oh god!" (L6). They despaired at the general public's lack of awareness of what it means to work in the music industry, despite evidence that 74% of more than 1,000 adults surveyed for UK Music reported that music listening is important to their quality of life, 57% said that it had helped them cope during lockdown, and 39% said that music had become more important to them over the past year (Public First, 2021). "The biggest, almost kick in the teeth really, is that people do not know where it [music] comes from […] I've had somebody say to me 'oh why don't you just get another job?' I said 'well, I have trained for an awfully long time to do this, and also if the music profession stops, where's all the music on the TV, the films, your gym list where is all the music going to come from?'" (M8).

All participants reported *cancelations* of work at short notice, with no cancelation fee. This was particularly distressing, given the scarcity of work: "Those are the only concerts I've got […] I've got nothing else, it seems, it feels like a much bigger deal if it is cancelled. Partly because of the money, but also just the wanting to play and wanting to perform" (M8). They acknowledged that the circumstances were exceptional and that orchestral fixers had to use "force majeure" clauses when making last-minute alterations due to illness, quarantine, and ever-changing rules and timelines (Institute for Government, 2021), but many complained that there was

TABLE 2 | Central dominant theme, overarching themes, sub-themes, group, and number of participants for each sub-theme.

Overarching themes	Sub-themes	*N* (Total)	*M*	*L*
Central dominant theme: Uncertainty of future freelancing career				
	Anxiety about fragility of freelance work	21	12	9
	Cancelations and touring	20	12	8
	How to make money?	18	12	6
	Maintaining identity and motivation	21	12	9
Overarching theme 1: Returning to performing				
	Love of music and colleagues	21	12	9
	Apprehensions and preparations	15	9	6
	COVID safety	21	12	9
	Online performing	20	12	8
Overarching theme 2: Maintaining wellbeing and coping strategies				
	Emotionally challenging	18	11	5
	Support networks	16	9	7
	Cognitive strategies	18	11	7
	Routines	12	6	6
	Exercise and physical health	14	7	7
	Social media	10	3	7
Overarching theme 3: Growth				
	New opportunities and skills	15	10	5
	Resourcefulness	15	11	4
	Insights	18	10	8
Early signs of post-traumatic growth (PTG)				
	Appreciation of life	8	2	6
	Openness to new possibilities	13	9	4
	Personal strength	8	6	2
	Relating to others	9	6	3
	Spiritual change	4	2	2
Latent themes				
	Awareness and concern for others	20	11	9
	Being a self-motivated learner	21	12	9
	Feeling fortunate	21	12	9

N, total number of participants mentioning theme, M, number of mid-career participants, and L, number of late-career participants.

no reciprocity, and orchestral managers and fixers lacked sensitivity when canceling work. One participant experienced repeated cancelations although she had been a loyal Principal player with the same orchestra for many years:

> If I don't say "yes" to at least 70% of the work they offer me, I'm out of the orchestra […] I feel so bound to have to take the work they offer me, but at the same time, they are clearly not bound to keep the dates they give me […] I've put in all the work to be prepared, and then the orchestra have just turned round and said "oh sorry, we're changing the programme"[…] it's just devastating not being part of it […] I rang management and cried on the phone […] and said "this can't be, you've cancelled all of our work […] what are we meant to do, how are we meant to survive? (M1).

Several participants described double- or even triple-booking themselves, in the hope that at least one piece of work might materialize: "Usually I would have just gone 'well I'll just take the one that I really want to do' […] but I just thought, 'well actually, if you're going to put me on hold, I'm going to put you on hold as well' […] so I took everything on, and waited to see what the restrictions would do" (M3). In the current climate, musicians are expected to be flexible and to understand that dates may have to be postponed or canceled without compensation. It would be helpful, during this period, if orchestral managers and fixers could reciprocate by not penalizing musicians whose availability may change at short notice.

They all expressed concerns about *touring*, with only four of the mid-career group (three women and one man) having performed outside the United Kingdom since the start of the pandemic: "I think the combination of Brexit and COVID has absolutely knocked the whole of foreign touring on the head" (L8). Many commented that the pandemic was currently masking the impact of Brexit, and they were all concerned that once the pandemic was over, working abroad would be much harder because of Brexit: "If you were going to be asked for a festival, they'll just see your name or your nationality and just think 'oh it would just be so much easier to ask this French [player] or this German [player]'" (L9). The Musicians' Union (MU) is now campaigning for the United Kingdom government to provide a special musicians' passport in their #WorkingInTheEU campaign (Musicians' Union, MU, 2022a), to ease the difficulty of working in the EU post-Brexit.

In the first study, which took place during the first lockdown, nearly all the participants were extremely concerned about *how to make money*: "I went into complete like survival mode when the whole thing happened, and I was like 'What are we going to do? How are we going to eat? How are we going to pay the bills?' We had to do the universal credit[2] at the beginning as well […] I felt awful" (M3). In the present study, only one mid- and one late-career participant said that their earnings from performance had returned to their pre-pandemic levels. They had all managed financially, however, typically from a combination of government grants, state pensions, teaching, non-music work, using savings, and cutting back on spending.

Twenty-one of the original 24 participants had applied for government self-employment income support scheme (SEISS) grants.[3] Of these 21, eight (four men, four women) were ineligible and therefore struggled financially. This figure reflects the 38% of respondents to the MU's much larger survey who were in the same position and suggests that the criteria for eligibility should now be revised. Recipients of SEISS grants were grateful, although several had found it complicated to apply for the fifth one, and two were worried that applying

[2]A payment to help with the living costs of people on a low income or out of work (https://www.gov.uk/universal-credit).

[3]https://www.gov.uk/guidance/claim-a-grant-through-the-coronavirus-covid-19-self-employment-income-support-scheme

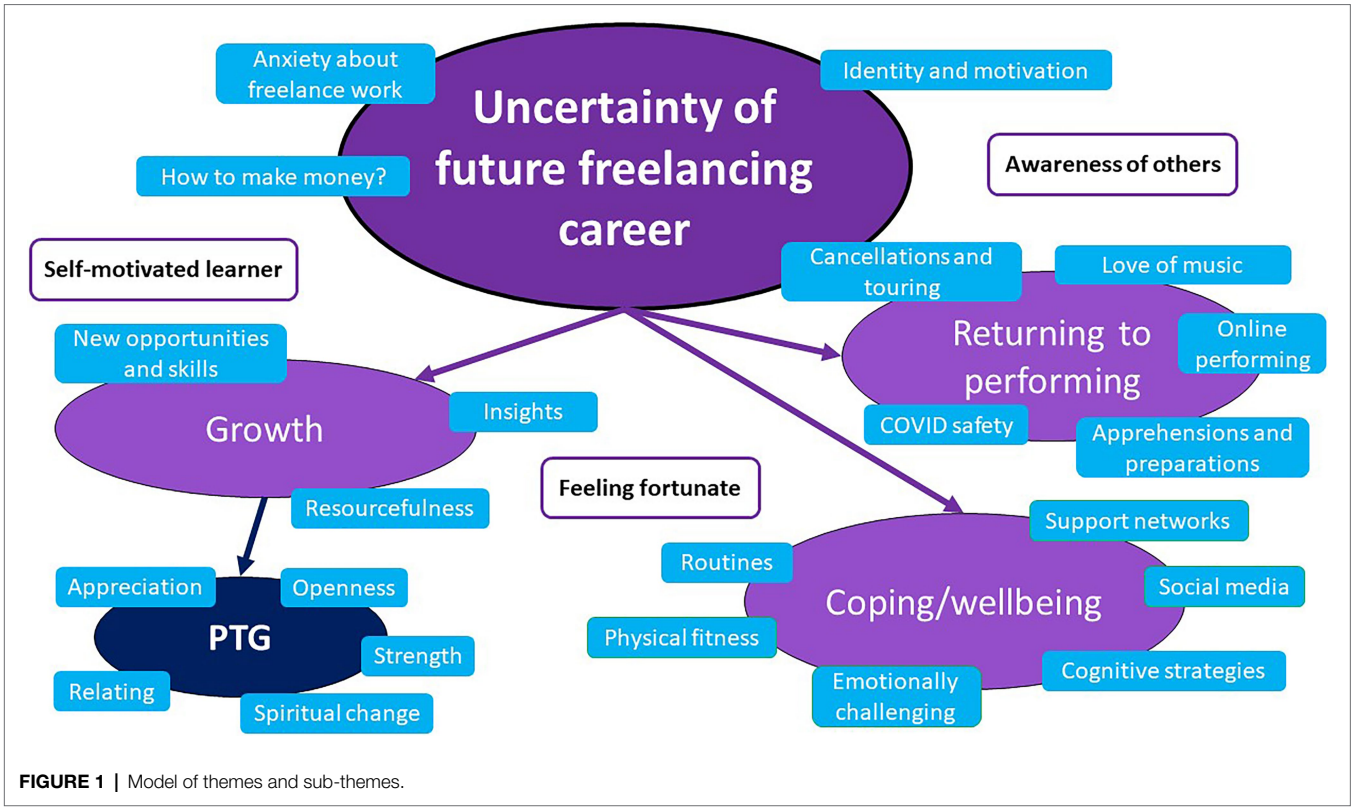


FIGURE 1 | Model of themes and sub-themes.

for an SEISS grant might affect future applications for a mortgage. Four of the older late-career participants (three men and one woman) received a state pension, but nearly all the late-career group considered themselves better off, financially, than their younger colleagues: "I think it's less of an issue for somebody like me than for somebody younger, who I mean, yeah, I'm very well heeled, with a house and instruments and stuff like that" (L6).

Teaching provided a major source of income for most of the participants ($M = 11$, $L = 6$). Nine of the mid-career group (seven women and two men), but none of the late-career group, had taken on extra teaching to make up for lost income from performing. Most valued teaching not only for the regular income it provided but also for the opportunity to carry on working as a musician: "I'm hoping that the bits of teaching work […] is sort of going to you know, keep the wolf from the door because it's what I've tried to have as security" (M3). However, four mid-career female participants were unhappy about teaching full time in place of performing: "I'm very fortunate in that I'm working pretty much full time, but it's all teaching, which is not what I want to be doing, but it has kept a roof over our heads […] I don't really like it that much […] so that's quite tough to sort of look at" (M5). By contrast, five late-career participants (three women and two men) reported providing their music college students with extra lessons, in addition to much-needed emotional support, because, in some cases, they were the only people their students (particularly those from overseas) were seeing, in person, from one week to the next. This demonstrates their commitment to teaching, supporting lifespan models suggesting that in the later stages of their careers musicians tend to focus on teaching and taking social responsibility (Manturzewska, 1990; López-Íñiguez and Bennett, 2020).

Nearly a third of the participants ($M = 2$, $L = 4$) had developed other income streams from non-performance but music-related activities, including writing articles for a music teachers' magazine, using music-based activities when teaching English as a foreign language, museum curation, and selling instruments. Two were beginning to use music more therapeutically and two had taken advantage of the government bounce-back loan scheme: one to buy new recording equipment so as to perform online and the other to keep their instrument-selling business afloat. Three mid-career participants had worked in the hospitality industry (e.g., in pubs, bars, and cafés) to support themselves, and three had been couriers doing food deliveries: "I was in floods of tears by the end of my shift when I was handed the mop and bucket to mop the gents' toilets floors of the pub, and I thought, I was doing it and I thought 'what have I [done], I can't believe 12 years [of professional playing] has come down to this" (M11). Other mid-career participants started a home distillery business, sold their landscape paintings, re-qualified as a teacher of English as a foreign language, and moved to a European country (see "Growth").

The question of *maintaining identity and motivation* as a musician when unable to earn a living from performing arose

in all the follow-up interviews. A year earlier it had been predominantly the mid-career participants who were in crisis about their professional identities, with seven actively considering leaving professional performing and the late-career participants appearing more emotionally and financially robust. Now, however, all 12 mid-career musicians were still committed to continuing careers as performers: "It doesn't feel like it's right for me to leave music, because this is, this is my lifeblood" (M12). The late-career participants were less committed. Besides the two who contributed to the first but not the present study, one had suffered serious injury and was not currently playing. Three older participants (one woman and two men), aged 66 and over, were contemplating retirement: "It's been difficult to hang on to the idea that I am a professional musician, quite honestly […] I thought, 'gosh I'm not sure I really want to go on doing this'" (L2); "I have reservations about struggling with work, having to make the profession work for me […] I don't think I could go back to running around like I did before […] the idea of jumping in the car and driving to Truro[4] to do one concert and then driving back seems like an effort […] I know that I don't really want to retire yet, which is not to say that I might not retire" (L3) (see *Apprehensions and preparations*, below).

All the participants had continued to practice their instruments over the past year, although nearly half ($M = 5$, $L = 5$, five men and five women) described periods of struggling with motivation in the absence of performing opportunities: "I can't say I enjoy it very much at the moment. I mean I do it because that's what you do, it's like you brush your teeth in the morning, it's unthinkable just not to play" (L8); "This year, love for [my instrument] just went out the window, just the lack of work […] it was all very doom and gloom. It just got to the point where I thought 'what's the point? what am I practising for?'" (M11). One mid- and one late-career participant were enjoying having more time for playing and developing their skills: "I was getting study books out that I wouldn't normally have had time for […] the motivation just was always there" (L9). Others wanted to be "match fit" for demonstrating to students and returning to performing when possible; indeed, several mid-career participants had organized online performances as a way of ensuring that they would have to practice, and one was a member of a support group in which musicians reported their daily practice to each other. In this way, they demonstrated both resourcefulness and understanding of their own motivations (López-Íñiguez et al., 2022).

Returning to Performing

The overarching theme *Returning to performing* comprised four sub-themes: *love of music and colleagues*, *apprehensions and preparations*, *working in a COVID-19 safe environment,* and *online performing*.

Participants were emotional when they spoke about their *love of music and colleagues*. Of their few experiences of working during the past year, one said, "It was joyful and incredibly emotional, there were a lot of us bawling our eyes out all the way through (laughs), but it felt like a, just a snippet of our old lives, who we were, what we're supposed to be doing, and I sort of feel a bit goose-bumpy even talking about it now. It's, it was just, it was really wonderful, really wonderful" (M8). Such accounts illustrate musicians' love for and emotional investment in their work (Bonneville-Roussy and Vallerand, 2020).

Participants' *apprehensions and preparations* for returning to performing work centered on being able to play and dealing with the logistics of freelancing after such a long break. Many ($M = 9$, $L = 5$, seven men and seven women) doubted their competence: "I thought 'I'm not sure I can still play this.' I certainly used to be able to play it, I've done it lots of times, but erm, I, I practised it quite a lot, which, I don't normally do […] I did find stamina a real issue" (L8). Others experienced music performance anxiety, known to be widespread among professional orchestral musicians (Kenny et al., 2014; Cohen and Bodner, 2019): "Walking back in there, I felt nervous, sick, sounds a bit strange […] but I felt nervous seeing colleagues again after such a long time […] playing in front of people" (M8). The mid-career participants were able to overcome their initial apprehensions, one saying "I was worried to begin with: 'am I going to be able to play [my instrument]?' but it quickly came back" (M3). This was not the case for three of the older late-career participants: "I am actually sort of wondering whether I really want, maybe the time has come, just to stop completely, you know. Suddenly the stresses and strains of concerts coming up after 15 months without anything, erm, it all looks a bit different" (L2); "I would feel very differently if I was 20 or 30 years younger, because I'd feel incredibly frustrated that I wanted to get out there playing, you know, have all this energy and stuff wanting to play. And I don't feel that now at all, you know, I feel I've done it you know, and so it's not like I'm itching to get back to it at all" (L8). These comments illustrate the change in focus that can occur in the late stage of a musician's career (Manturzewska, 1990; López-Íñiguez and Bennett, 2020).

Pre-pandemic, retirement from orchestral life was already an issue of concern (Brodsky, 2011). In the absence of a statutory retirement age, both musicians and managements are uncertain when and how retirement should take place, and discussions between them can be difficult; there has been an increase in claims of unfair dismissal on the basis of age discrimination (e.g., Bonfiglio, 2018). Further research is urgently needed to identify the needs of both parties and develop guidelines addressing their expectations, setting out procedures, and ensuring appropriate support for musicians at this stage of their careers.

Logistics were a source of anxiety for five mid-career participants (three women and two men) who had not had to cope with the irregular demands of freelancing for over a year: "It was like this impossible Rubik's cube that I just don't know how we ever did that […] that caused me a lot of stress" (M4); "…the night before, I got myself in a real, not a state, but I was just like, what do I need? what time do I leave? […] All of those things that I wouldn't have batted an eyelid about before suddenly are a big deal, and I didn't sleep very well" (M8).

[4]A city in the south-west of England, far from London.

Most participants prepared for returning to work by obtaining and practicing their parts in advance, which they would not necessarily have done pre-pandemic: "I've just said to people 'look, I need to have a look at it, because I'm not, you know, not on form, and if I don't have a look at it I won't be able to play it, so please can you send me the music'" (M5). The lives of professional performers are intrinsically stressful (Kegelaers et al., 2021), and comments such as "A lot of musicians are going to find the next parts of life psychologically tough, mentally tough, because we haven't done it for such a long time" (M8) suggest that resilience training for music students (Matei and Ginsborg, 2021) and specialist psychological support for professionals (Gross and Musgrave, 2020) are both warranted.

Working in a COVID-19 safe environment: All the participants were double-vaccinated and accepted the need for testing, although this could cause anxiety: "[before playing in a West End show] you had to go into a room to be tested and depending on what the result was, you could go to work or not […] I was really nervous […] I was thinking 'if I'm positive then I won't be able to work, and there won't be any money this week'" (M3). While several were anxious about the risk of infection when traveling to work on the tube, none felt it was risky to perform as masks and social distancing were mandatory, although disturbing: "[Wearing a mask] you lose your peripheral vision, that you don't realise that you have been using until you haven't got it […] it's hot, it's quite hard to just stay calm and breathe" (M5); "String players generally are like those penguins in Antarctica in the winter you know, it's like how close can you get? […] all you hear really [distanced] is yourself, and so people, the tendency is to play less, but then when you play less, everyone else hears less, so it's a self-defeating situation" (L12). One wind player demurred, however: "We're used to playing at a distance in an orchestra, that's what we do" (L8).

Most participants ($M = 12$, $L = 7$) reported that the length of concerts had been reduced to an hour with no interval. To mitigate smaller, socially distanced audiences, concerts were repeated but with no additional fee for the musicians: "Now we have to play the concert twice […] for the same amount of money, and that's slightly insulting" (L11). Social distancing rules affected not only their working conditions but also its social aspects, shown in the first study to be very important to musicians: "…what's really awful is there's no social life. I mean you can't go to the canteen and have a cup of tea and biscuit in the break […] you just sit there in dead silence in the studio […] it's a horrible experience" (L8); "…that comradeship between you and your colleagues, a lot of it just hasn't happened at all, it just hasn't been possible […] I suppose it has felt quite lonely at times" (M6).

All but one of the participants had been involved in *online and live-streamed performances*, albeit generally unpaid (see *Maintaining identity as a musician*, above) and had developed home-recording skills. Some would not have done so, had it not been for the pandemic, and were glad: "…you know you're taking care of the whole damn lot, the sound, the production […] I was quite proud that I managed to do that […] I mean I'm a complete virgin to all that kind of thing" (L6). For others, performing online was fraught with problems: "…just putting it together was the worst nightmare of my life, in fact we didn't manage to put it together. In the end we had to send [the recording engineer] all the bits at five in the morning, and it was just the most stressful thing" (M2). Technological hiccups during live-streamed performances were experienced as particularly frustrating: "I had [the software] or whatever it's called. I tested it, I got it to work, it was very painstaking, and then on the day, it just wouldn't, Facebook wouldn't link with [the software], and it just wouldn't work" (M2), "[for a planned live-streamed independent orchestral concert] there was a problem with the, with the line-out, with the recording, so nobody saw it really. It was such a shame" (L3). In this case, no tickets were sold and consequently the players received no fee. Five mid-career participants described the difficulty of trying to make money out of online performing, an issue currently being addressed by the Fix Streaming campaign (Musicians' Union, MU, 2022b).

Maintaining Wellbeing/Coping Strategies

All the participants reported that the past year had been *emotionally challenging*; to maintain their wellbeing, they had used a variety of coping strategies including *support networks of family and friends*, *cognitive strategies*, *routines,* and *exercise and physical health*. Although, after a year, they were no longer reeling from the shock of losing their much-loved livelihoods, and their distress and anxiety were generally less intense, more than two-thirds of the participants in the present study ($M = 11$, $L = 5$, 10 women and six men) described some extremely *emotionally challenging* periods, reflecting the recent finding that women experienced greater psychological distress during the pandemic (Di Blasi et al., 2021): "Lockdown has been the equivalent of being locked in a padded cell, so you were really shut away with your own thinking and you know, I think if there was anything that was not right in your soul, you'd find, it would start, the worm would start to eat straight through you" (M12); "I reached a point where I was really, really struggling to function at all […] on those days I've sat in bed because I couldn't do anything else" (M5). Several late-career participants feared that they would not be able to resume their careers: "You put up an armouring against it just to survive, just to be able to protect yourself from the pain of it all […] you get really tired of saying '*hopefully* we'll be able to do it next year,' '*hopefully* it will be alright,' well we said that last year!" (L6). According to recent findings, women have been particularly vulnerable to loneliness throughout the pandemic (Bu et al., 2020), and this was reported by three women without partners or family: "I just sit there thinking 'god I'm just on my own'… feeling flat and it's really hard to pick yourself up" (M3). Again, specialist psychological support for these groups is warranted.

More than two-thirds of participants ($M = 9$, $L = 7$) valued *support networks of friends, family, and colleagues*. Four mid-career participants reported obtaining professional counseling during the pandemic. Although organizations such as Help Musicians, the MU, and the Incorporated Society of

Musicians provided free online counseling sessions, only one participant reported using them; this suggests they could be advertised more effectively. Of the 10 participants with dependent children at home ($M = 6$, $L = 4$), all six mid-career participants (three men and three women) described the stress of looking after young children while simultaneously trying to find a way of earning a living: "It's been challenging timewise in you know, finding people to look after him, that's been hard when we've been both having to teach online" (M3). Commenting on the difficulty of dealing with home-schooling, another said: "…that home-schooling rubbish, it's luckily so hard to remember […] whatever it was, was not the best" (M10); this illustrates the finding that the pandemic put intense strain particularly on those with younger families (Spinelli et al., 2020). The lockdowns did, however, offer an opportunity for families to spend more time together, and most of these participants ($M = 5$, $L = 3$, four men and four women) enjoyed seeing more of their children: "the real joy of having family around and having more family time […] so it's a very heady cocktail of emotions" (L9). Others were coping with older parents' ill-health at a time when there was little access to healthcare and, reflecting evidence of increased break-ups and divorces during the pandemic (BBC, 2020), three participants reported that their marriages or long-term relationships had collapsed: "I know for a fact that I'm not the only one going through a divorce, erm, I think it has put a strain on a lot of people and opened cracks that were already there" (M11).

The use of *cognitive strategies*, such as positive and soothing self-talk, was described by two-thirds of the participants ($M = 9$, $L = 5$, seven men and seven women): "I know it's slow for everybody […] it's not like everyone else is suddenly back to normal and I'm not" (M4). Others reframed their experiences ($M = 5$, $L = 5$): "You just have to keep saying that this isn't forever, this is a very temporary thing […] It will be better next year" (M2). The remainder were not aware of using any strategies: "I just sort of fly by the seat of my pants and worry a lot" (M5). Again, specialist psychological support is warranted for this group.

Nearly half the participants ($M = 6$, $L = 6$, three men and nine women) found the use of *routines* very useful, particularly for practice motivation: "I'd [practise] every day, I'd do a technical routine, I've done it today and erm, that's the only thing that keeps me going really. I just play it because that's what you do" (L8). Some mid-career participants were surprised to find themselves enjoying a new weekly routine: "…suddenly having this real structure of you have a weekend, every week you will get the weekend, I'm just not used to that!" (M2). Listening to music was vital to three late-career participants: "I still connect with the music […] I just feel that love inside of me Susanna, that love of music inside me and that gets me through it" (L11). By contrast, a mid-career participant felt she had to distance herself from it: "It's very hard to listen to music when you can't play, when you haven't got a hope of getting anywhere near because nothing's happening […] it's a bit depressing when you just feel that you might not do it again" (M2).

Two-thirds of participants ($M = 7$, $L = 7$, five men and nine women) had consciously engaged in regular physical *exercise*, such as yoga, Feldenkrais, walking, cycling, gardening, and lifting weights, to maintain their *physical fitness.* As in the general population (Khubchandani et al., 2022), a third of the participants reported having gained weight during the pandemic. Nevertheless six ($M = 2$, $L = 4$, three men and three women) had improved their eating and drinking habits because they were working less and spending more time at home: "I'm much fitter, I'm eating at home, I'm eating decent food, I'm not eating takeaways, I'm not drinking anything like as much beer as I usually do" (L8). Others were drinking more, however: "It's like well 'fuck it, I need a treat and I want a glass of wine, I'm going to have a glass of wine,' stuff it, you know, I've got to do something nice for myself" (L6). Three ($M = 2$, $L = 1$) tried to limit their drinking: "I'm susceptible to depression anyway, so made a sort of an almost a rule for myself at the beginning of lockdown that I would, I wouldn't just drink on my own at home" (M8). Pre-pandemic evidence that alcohol abuse is higher among musicians than in the general population (Crosby and McKenzie, 2021) suggests that it would be worth training music students to develop healthy lifestyles (Matei et al., 2018).

The use of social media might be considered a coping strategy. While a third of participants found it useful for publicizing projects, most felt ambivalent about it, and three mid-career participants described it as increasing their anxiety: "Actually a big factor that affected anxiety levels was social media last year with me, I had to come off it for a while" (M3). This reflects the findings of recent research (Gao et al., 2020) that social media can have both positive and negative influences on affect.

Growth

Despite the challenges of the previous year, many participants reported experiences of *Growth.* These were grouped into three sub-themes: *New opportunities and skills, Resourcefulness,* and *New insights*; in addition, a further set of sub-themes associated with early signs of *Post-traumatic growth (PTG)* was identified.

More than two-thirds of participants ($M = 10$, $L = 5$, six men and nine women) had developed *new opportunities and skills* in the past year. Three mid-career participants had started businesses. One had become a distiller of fine gins and vodkas: "We've taken a lease on a little industrial unit […] we've now got our, our rectifiers and compounders' licence […] it's been quite a steep learning curve […] we're sort of, we're now distillers" (M7). The second was selling their landscape paintings, and the third had completed an online TEFL course, moved to a European country, and set up a new business combining English teaching with musical activities for young children. Among the other mid-career participants, one had started working as a writer and editor for a music magazine, one was a regular volunteer at a vaccination center, and one had learned to play the saxophone so that they could accept a doubling job in a West End show: "I ended up learning the tenor sax in lockdown in November just for this show […] in the past I would have said 'no, I can't do that'" (M3).

Eight participants ($M = 5$, $L = 3$, three men and five women) described acquiring new online music production skills: "learning to use Logic, you know the recording software, that's all been positive professional development that I wouldn't have bothered to do otherwise" (M10).

The lockdowns had given four late-career participants in their mid-50s the opportunity to pursue music-related interests they had been considering for a number of years but previously not had a chance to develop. One had enrolled in a two-year course to retrain as a counselor in creative arts therapies, the second had started to focus on music making with children and adults with disabilities, the third had begun training to become a mindfulness teacher, and the fourth had worked as a museum curator and developed research into music and science. One late-career participant had also worked on developing their public speaking and presentation skills through attending toastmasters' public speaking courses, and another participant in their mid-60s described composing music for the first time. While all the mid-career participants hoped that they would be able to combine their new non-performing interests with performing in future, some of the late-career participants said that their new skills might ultimately enable a transition out of professional performing: "I love music, but I actually even more than that, I love the creative process […] do I want to continue to try and make my whole living as a player, or not? […] it's that connecting with other people deeply is really what makes me tick" (L4).

Resourcefulness is defined as the ability to find quick and clever ways to overcome difficulties (Oxford English Dictionary, 2022). It was evident in the interviews with most of the mid-career and some of the late-career participants ($M = 11$, $L = 4$, six men and nine women): "I've learned that when the chips are really down […] I am resourceful and so one career or one method of paying for everything, for life, just ceased, and I was resourceful enough to find another thing to make it work" (M8); "I did the Uber-Eats delivery because you know, it's quite an ego-crushing thing to do to go and get a […] like a crap job essentially […] but I feel good that I did that because you know it's a positive thing to do, to show that you can, you can adapt" (M10). While the older late-career participants in the first study had shown emotional as well as financial resilience, three of the four older late-career participants in the present study now seemed anxious, confused, and lacking direction, by comparison with the mid-career group: "I feel like I've done so little it's […] like there's so much I can do, could do" (L3).

Most participants ($M = 10$, $L = 8$, eight men and 10 women) described discovering *new insights and self-knowledge* during this period. Those of the mid-career participants focused mainly on their future careers and their desires to fulfill their aspirations as professional performers: "You know, my heart was full, I realized you know, even if I was being paid what was a pretty derisory sum, I felt 'yeah, this is what I'm supposed to be doing, you know, I can do this really well, and I make a great contribution'" (M12). The late-career participants' insights, by contrast, were centered more on teaching and helping others: "I've got experience and actually it's really valuable to teach at this point you know" (L11). Such comments support lifespan models of musicians' careers proposing a shifting focus, from the individual's own performing achievements in mid-career to teaching and taking social responsibility later on in their careers (Manturzewska, 1990; López-Íñiguez and Bennett, 2020). Some of the older late-career participants were ready, in theory, to make way for younger players: "People like me really should be stepping back to make way for younger players now […] I've had the luck of playing for 40 years, of doing all sorts of fantastic, interesting work. I don't think I should be grabbing work that I don't actually totally need" (L2). Yet none were prepared to say they were no longer professional performers: "A lot of musicians I know wouldn't even think of retiring, they wouldn't dream of it, most of them who have gone into retirement, the work just petered out gradually for one reason or another, they aren't employed much anymore. I've never wanted that to happen, I'd rather make the decision myself, from a professional point of view […] I just don't feel ready to do that, but then I'm not sure I feel ready to play […] it's sort of funny, it's a kind of twist in the saga, isn't it?" (L3). This illustrates the confusion musicians may feel when they face the dilemma of how to retire from performing life and the need for help and guidance in the decision-making process.

Several mid-career participants described the attainment of new self-knowledge: "I've learned a lot about myself. I've learned a lot about what makes me happy […] I've also learned who my friends are" (M1). They also had a new appreciation of the importance of achieving a better work-life balance: "I will be putting myself and my family higher up that order […] not to put work first all the time" (M10).

Post-traumatic Growth (PTG)

Tedeschi and Calhoun (2004) define intensely negative and unexpected events that severely challenge the individual's fundamental assumptions about the world as *traumatic*. They propose that the struggle with great adversity can, however, be transformative in producing post-traumatic growth (PTG) in one or more of five domains: (1) *appreciation of life*, (2) *openness to new possibilities*, (3) *personal strength*, (4) *relating to others,* and (5) *spiritual change*, and that growth in even one or two domains can be profoundly influential. In the first study, a third of the participants ($M = 6$, $L = 2$) had experienced the sudden loss of their much-loved careers as traumatic. Although the present study was carried out only a year later, there were already some indications of PTG. For example, 10 mid-career participants had a renewed *appreciation* for aspects of their professional and their personal lives: "I just thought, now I'm just going to go home to a really amazing family, you know, my wife still loves me (laughs), I've got a son who is actually pretty spectacular" (M12).

Many mid-career participants who had previously been very distressed at the devastation of the careers for which they had worked so long and so hard were now *open to new possibilities*: "English teaching was a route, an avenue, a way of getting here [abroad] and you know, having an income […] I removed every single thing that was sort of stable, and I changed everything" (M9); "I set up an art business which […] without

COVID I don't think, well I wouldn't have had time to build a website, start selling art you know, doing commissions" (M11).

Several participants reported discovering *personal strength*: "I am definitely much more resilient than I thought I was. And that's, that's a quite nice thing to be aware of you know" (M8). Some felt they *related to others* differently: "Before the pandemic I was still in a relationship which I was wanting out of, couldn't find a way out, and I was just going from pillar to post […] it's definitely made me clearer about what's right for me" (L7). Others felt they had undergone *spiritual change*: "I no longer feel like it's a good thing to be just fine flying around being busy […] looking like you are sort of coping with life well, because life's not like that" (L4).

It is important to note that, after only a year, it was still early to be looking for signs of PTG. However, from the generally lower levels of distress among participants in the present study, and the number of new career developments and opportunities being explored, and the new insights attained, it would appear that many participants may already have taken the first steps on their path towards PTG.

Latent Themes

Three additional latent themes were also identified: *awareness and concern for others*, *being an intrinsically motivated self-learner,* and *feeling fortunate*.

As in the first study, *awareness and concern for others* was evident in all interviews, with participants expressing particular concern for musicians at earlier stages of their careers: "It's the 20-somethings who've been so fucked over […] I think our generation should be looking out for them constantly […] and giving them the breaks and giving them the support" (L9). Some ($M = 4$, $L = 1$, three men and two women) experienced "survivor's guilt" about musicians who might have had even less playing work: "I'm quite lucky that I've had bits of work, you know, you almost feel bad about it, you know, for the people that don't" (M2). Participants' sensitivity toward others might be a reflection of the acute listening and communicating skills that are essential qualities for freelance musicians to be able to carry out their everyday work of playing together (Myers and White, 2012).

A second latent theme identified was *Being a self-motivated learner.* This was evident in the motivation of both groups of participants to continue practicing, despite the absence of performing opportunities, and also in their motivation to develop new skills and interests in novel areas. Interestingly, the participant who had become a distiller during the pandemic described trying to improve the taste of a new gin in the same way as he practiced his instrument: "I thought alright, what can I do to do it better? […] maybe it's that musicians' mind […] I need to have one particular thing to aim for […] wanting to make it better, and wanting to sort of find a way" (M7). A recent study found that being an independent, intrinsically self-motivated self-regulated learner is a common characteristic of successful classical musicians (López-Íñiguez and McPherson, 2020), suggesting the need to encourage students to develop this trait during training (López-Íñiguez et al., 2022).

Given the distress experienced by participants in the first study, we were surprised to find that all 21 participants in the present study reported feeling "fortunate" or "lucky": "I've, I've made [having to take a job in a café] work, but I've been incredibly, I count myself incredibly lucky" (M8). This might reflect participants' gratitude for having been able to work for so long in their hitherto successful and highly satisfying careers in a competitive field (Gembris et al., 2018), or perhaps, the pandemic raised their awareness of and sensitivity towards the struggles of others who were worse off. It could even be that those who achieve careers as classical musicians are inherently more optimistic; all three possibilities merit further investigation. Feeling fortunate in the face of challenging circumstances is a form of "tragic optimism" (Wong, 2019), which emphasizes hope and, like dispositional gratitude, has been found to be a significant predictor of wellbeing during the COVID-19 pandemic (Mead et al., 2021).

Thoughts for Music Colleges, Musicians' Support Organizations, and Employers

At the end of each interview, participants were asked—in the light of the impact of the pandemic on their lives—how music colleges could equip music students more effectively for the future, and what contribution could be made by musicians' support organizations and employers. All the participants emphasized the need for training in versatility and resourcefulness, for musicians to "have [their] fingers in a lot of different pies" (M11), and not to think that it would be enough simply to excel on their instrument(s). Music students should acquire decent instrumental teaching skills and not see teaching as a lower aspiration than performing (Bennett, 2009); after all, teaching had provided many of the participants with their only regular, reliable source of income during the pandemic. They should develop technological and home-recording studio skills and be able to carry out basic maintenance, especially on wind and brass instruments. In terms of financial management, they should be able to do their own accounts and have a savings plan, no matter how variable their earnings: "Obviously a lot of people have been hit by this, and possibly had no savings at all" (L3). Several participants suggested that music colleges needed to do far more to help musicians develop skills for psychological and physical wellbeing, which had been lacking even before the pandemic: "[music colleges] need trained coaches that can give the kind of guidance to musicians that professional sports people have. We don't have that, and I think that's a failing" (L6).

When asked about the contribution of employers, several participants mentioned their appreciation of being kept informed by companies they had previously worked for, even if they were currently unable to offer them any work. Others complained about lack of reciprocity (see *Cancelations*, above): musicians are expected to be flexible but not orchestral managements. Many felt that the MU was not doing enough to protect its members: "I wish the Musicians' Union were somewhere that I could turn to for help, but I don't feel that they would help me" (M1).

Pre-pandemic, more than half the participants ($M = 8$, $L = 3$) had used a diary service—an independent service through which orchestral fixers can book players for work. Unable to justify the expense when there was no work coming in, two participants had given up their diary services during the pandemic: "I'm really sorry I just can't afford that any more […] I'd rather feed the kids" (M7). Other participants, however, praised diary service managers who had waived their fees, offered free help with CV-writing, and were available to chat on the phone: "They were and they are incredibly supportive […] it felt like we really were part of the same community […] I can't speak highly enough of them, they've been absolutely fantastic" (M8). Petriglieri et al. (2019) describe self-employed workers as lacking a "holding environment" (p.132), a space in which work anxieties and tensions can be processed and employees can maintain their sense of identity. They suggest that the provision of holding environments could transform self-employed workers' "precariousness into a tolerable and even generative predicament" (Petriglieri et al., 2019, p. 132). It appears that diary services served as holding environments during this period.

DISCUSSION

Our first study explored the impact of the pandemic on the lives of 12 established mid-career and 12 late-career ("seasoned") freelance self-employed orchestral musicians in a series of interviews conducted in May and June 2020. The present study followed up all the mid-career and nine of the late-career participants in a second series of interviews conducted between June and August 2021. The main finding of the first study was that, although all the participants were anxious about their futures, having experienced the sudden loss of their much-loved and successful careers, the late-career group demonstrated emotional and financial resilience while the mid-career group was in crisis, anxious, and confused about their identity as musicians. The main finding of the present study is that, although freelance performing work was still scarce, the positions of the two groups had changed. All the mid-career participants remained committed to their performing careers. By contrast, four younger late-career participants, aged 54–59, had developed interests and acquired skills in aspects of music that didn't necessarily involve performing and that might ultimately lead them to leave the profession as they had known it. Meanwhile the four older late-career participants, aged 66 and over, feared that the break from performing enforced by the pandemic meant that they might already, *de facto*, have retired. We now discuss the findings with reference to the precarity of working as a freelance orchestral musician (Bartleet et al., 2019; Willis et al., 2019; Caza, 2020), lifespan models of musicians' careers (Manturzewska, 1990; Bennett and Hennekam, 2018; López-Íñiguez and Bennett, 2020), self-determination theory (Ryan and Deci, 2000), and the concepts of resilience (Bonanno et al., 2011), resourcefulness (Rosenbaum, 1983) and PTG (Tedeschi et al., 2018), and their implications.

Even before the pandemic, self-employed freelance orchestral musicians experienced precarity and insecurity (Teague and Smith, 2015; De Witte et al., 2016; Bartleet et al., 2019; Willis et al., 2019; Gross and Musgrave, 2020). The sudden loss of work at the beginning of the pandemic left many in an extremely vulnerable position both financially and emotionally, unable to earn a living and missing their careers (Cohen and Ginsborg, 2021; Spiro et al., 2021). Pre-pandemic, the authors of several studies had recommended music colleges to ensure that students enter the music profession with realistic expectations, emphasizing that salaried positions as a member of an orchestra are few and far between, and that it is very difficult to earn a living solely from performing; musicians should, rather, be prepared for varied portfolio careers, working as part of the gig economy (Bennett, 2009; Bartleet et al., 2019; Caza, 2020; López-Íñiguez and Bennett, 2020). Participants' inability to support themselves and their families at the outset of the pandemic suggests that their portfolios of skills were not sufficiently varied, and points to the need for music colleges to train students not only for performing but also for teaching, recording, community music making, entrepreneurship, financial management, and running small businesses, so that the next generation of freelance musicians will be better able to cope with future challenges on a similar scale to those presented by the pandemic (Bennett and Bridgstock, 2015; López-Íñiguez and Bennett, 2020). In the past, music colleges have privileged the training of performers over teachers (Bennett, 2009), but teaching—the only reliable source of income for many of our participants—has a vital place in the freelance musician's portfolio. As so many of our participants had little or no savings or pension provision, it would be worth musicians' support organizations providing not only crisis referrals and help, as they have done throughout the pandemic, but also in-house financial management advice services, with details of flexible savings and pension schemes appropriate to the needs of a population whose earnings are often erratic.

Participants' reports of last-minute cancelations of work without recompense, reduced fees, and lack of reciprocity with respect to musicians' and managements' flexibility suggest that freelance musicians need more effective representation to protect their working conditions. Discussions between representatives of both parties should take place as soon as possible to draw up an agreement on what constitutes reasonable and appropriate behavior, on both sides, in exceptional circumstances.

Although music listening and the use of music to maintain wellbeing all increased during the pandemic (Carlson et al., 2021; Granot et al., 2021; Hennessy et al., 2021), neither government nor the general public appear to understand what it means to earn a living working in the music industry. A third of the participants in our first study were ineligible for a SEISS grant (Musicians' Union, MU, 2020), for example, and the public remains unwilling to pay for online music consumption. In addition to calling for the government to provide financial aid for musicians through the MU's #InvestInMusicians, #FixStreaming, and #WorkingInTheEU campaigns, musicians' organizations should also aim to educate the general public to have a greater appreciation and understanding of the expertise

that is required to create the music they love but are reluctant to buy.

The continued commitment of our mid-career participants to pursue their performing careers supports lifespan models of musicians' careers whereby musicians focus on their performing achievements in mid-career (Manturzewska, 1990; Bennett and Hennekam, 2018; López-Íñiguez and Bennett, 2020). Participants' commitment to performing even though they could not play with others, live, in public, during the pandemic, illustrates the high level of classical musicians' internal motivation shown in other studies (Appelgren et al., 2019; López-Íñiguez et al., 2022). Lifespan models also propose that musicians' priorities change in late career, from their own achievements to passing on their skills and an increased sense of social responsibility. We saw this change in our late-career participants' dedication to teaching and willingness to provide students with emotional support as well as extra lessons. Manturzewska (1990) describes a later stage in her lifespan model in which musicians "slowly but systematically retreat from professional activity. Musicians who are teaching or playing in orchestras retire" (p.137). She provides no information, however, as to how this process is or should be managed, suggesting that this is an area warranting further research.

In our first study, we examined the differences between the experiences of mid- and late-career participants through the lens of the PERMA model of wellbeing (Seligman, 2012). In the present study, we have chosen Self-Determination Theory (SDT) to explain the signs of growth we identified in our mid-career and younger late-career participants after a year, and the confusion we observed in the accounts of our older late-career participants. SDT posits "three basic innate psychological needs—competence, relatedness and autonomy—which when satisfied yield enhanced self-motivation and mental health and when thwarted lead to diminished motivation and wellbeing" (Ryan and Deci, 2000, p. 1). *Competence* is the need to gain mastery of tasks and to learn different skills; *relatedness* is the need to experience a sense of attachment and belonging to other people, and *autonomy* is the need to feel in control of one's own behaviors and goals (Krause et al., 2019). Mid-career participants' success in generating alternative sources of income and enjoying rare performing opportunities can be understood as satisfying the need for competence. They satisfied their need for relatedness by identifying themselves clearly as performing musicians, still part of the workforce despite the lack of performing work, and they satisfied their need for autonomy by forging ahead and exploring new opportunities despite the challenges posed by the pandemic. By contrast, the four older late-career participants were receiving state pensions and had no need to find alternative ways of earning money. Their need for competence was not satisfied, as two participants were injured and unable to perform and three were anxious as to whether they would be able to play again after taking such a long break. Their need for relatedness was not satisfied either, since most had not engaged very much in playing or teaching and were not sure if they still considered themselves performing musicians. Finally, they faced a dilemma: they had loved their careers as performers but were anxious about their competence; they didn't feel they could retire or that they could return to performing. Accordingly, they tried to manage the situation by adopting a "wait and see" attitude but at the cost of not being in charge of their own goals or behaviors and thus failing to satisfy their need for autonomy. This finding underlines the need for older musicians to be provided with specialist careers advice and coaching to help them prepare for their departure from performing and plan the next stages of their lives.

In the first study, we found that our late-career participants demonstrated emotional and financial *resilience*, defined as the ability to maintain relatively stable, healthy levels of psychological and physical functioning when exposed to a potentially highly disruptive and adverse event (Bonanno et al., 2011). This finding confirmed those of other recent studies showing an association between older age and greater resilience at the start of the pandemic (Finstad et al., 2021). By contrast, we identified many examples of *resourcefulness* in the present study, especially among mid-career participants who appeared distressed and confused in the first study, as well as early signs of PTG. According to Tedeschi et al. (2018), "the struggle that leads to post-traumatic growth is not usually at first a struggle to grow or change, but rather to survive or cope. The growth tends to be unplanned and unexpected" (p. 5). We found evidence of PTG in both the intense anxiety and distress expressed by mid-career participants in the first study, and the novel, unexpected areas in which growth and new opportunities developed in the present study. Tedeschi et al. stress the difference between resilience and PTG in their conceptualization: resilience is the ability to bounce back and return to baseline functioning while PTG is transformative. There were few signs of transformative change in our older late-career players, however. Given recent reports of "the great resignation" (BBC, 2021b)—the phenomenon of retiring early in the light of insights attained during the pandemic (which itself may be an example of PTG)—the absence of transformative change among the older late-career participants in the study seems unlikely to be related to chronological age. While the resilience demonstrated by the older late-career participants in the first study appeared to be the product of their greater financial resources (they owned their own homes, had savings and regular income from state pensions), and their greater cumulative life experience which, according to the strength and vulnerability integration model (SAVI; Charles, 2010), enabled them to "navigate their worlds more successfully than younger adults" (Charles, 2010, p.1073), this initial financial and emotional resilience might have also been responsible for the absence of a sense of urgency in the need to create an alternative, meaningful work-life balance, which resulted in the feelings of confusion and lack of control expressed in the follow-up study. This supports existing evidence that failure to satisfy basic psychological needs in times of uncertainty such as the pandemic can produce confusion and distress (Vermote et al., 2022).

Maitlis (2020) argues that PTG can be facilitated by *sensemaking*, "a meaning-making process through which people work to understand unexpected or confusing events" (p. 405). Sensemaking takes place through the sharing of narratives with *attentive companions*, who have the "patience, empathy and the capacity to listen well" (Maitlis, 2020, p. 407). Given that we identified

participants' empathy and awareness of others in both our first study and the present study, and that the ability to build rapport and collegiality are essential parts of the freelance orchestral musician's skillset, we recommend that musicians' support organizations train suitable interested musicians to be "attentive others" and establish mentoring schemes in which they can facilitate PTG in those affected by crises such as the pandemic.

To create and sustain a successful career in music it is important to be a self-motivated learner (López-Íñiguez and Bennett, 2020); this also helped musicians maintain their motivation to practice during the pandemic (López-Íñiguez et al., 2022). Music colleges should therefore consider providing courses that help students to cultivate their capacity for self-motivated learning and self-efficacy—"the belief in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura, 1997, p. 3)—particularly as self-efficacy has been found to be positively associated with music students' performance (González et al., 2018), more effective practice (Mornell et al., 2018) and health-promoting behaviors (Cohen and Panebianco, 2022). Feeling fortunate, the third latent theme, was a surprising finding, given the challenging circumstances in which the participants found themselves. Although existing examinations of the personality characteristics of classical orchestral musicians have consistently found that musicians exhibit higher levels of openness than non-musicians (Butkovic and Rancic, 2017; Vaag et al., 2017), there are no studies investigating trait optimism among freelance orchestral musicians, so far as we are aware, so this is an area meriting further research.

Study Limitations and Conclusion

The first limitation of the present study is that it provided a snapshot of musicians' experiences during a period when the number of COVID-19 cases was decreasing and a return to live performance appeared to be imminent. The situation changed, however, in the final months of 2021 with the emergence of the highly infectious Omicron variant resulting in more last-minute cancelations (The Strad, 2021). Although—at the time of writing—the government is behaving as though COVID-19 has become endemic, other variants may yet appear. If the disruption to participants' lives and livelihoods in late 2021 and early 2022 is to be explored, a further follow-up study is required. The second limitation is that we didn't investigate the experiences of early-career musicians, who were particularly badly affected by the pandemic (Spiro et al., 2021; UK Music, 2021), as we were more interested, initially, in its impact on musicians with already established, successful freelance careers. We now wish to interview a sample of these musicians. The third limitation is that the participants in both the first and the present study were self-selected musicians choosing to respond to invitations on social media to participate. This suggests that they are proactive and highly motivated, and as such, their experiences of the pandemic and its impact on their lives may not reflect those of other players.

In conclusion, the findings of the present study show that, a year on, the COVID-19 pandemic is continuing to have a huge impact on the lives of self-employed freelance orchestral musicians in the United Kingdom. This examination of the participants' experiences over the longer term has served to shine a spotlight on the precarity of their working lives; on the need for music colleges to train future generations of musicians for more varied and robust portfolio careers; and on the need for greater support from the government and the general public. On the basis of our finding that the older late-career participants were no longer so emotionally resilient but, a year on, troubled and confused about their future, we recommend further research to inform the development of guidelines addressing both musicians' and managements' expectations as to when and how retirement should take place, and support for musicians in the later stages of their late career. We already knew that freelance orchestral musicians had to be determined, dedicated, organized, creative, and socially skilled team players. The latent themes we have identified from our participants' accounts of developing new interests and the early signs of PTG that we have observed suggest that successful freelance orchestral musicians are also self-motivated learners, aware of others, and able to assume a positive, optimistic attitude in the face of challenges. Taken together, these attributes suggest that they possess an extremely powerful and transferable set of skills likely to be valuable in a huge array of working situations, whatever the future may bring.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee, Royal Northern College of Music, Manchester, UK. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SC and JG designed the study and procedures and analyzed the data. SC carried out the interviews and drafted the manuscript with support from JG in all sections. Both authors contributed to the article and approved the submitted version.

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APPENDIX A

Interview Guidelines for Semi-Structured Interview (follow-up)

Could we start with an overview of how this past year has been for you, since we last spoke?

Prompts:

1. Are you working in music at the moment? How is that?
2. What do you have in your diary for the future? Are you (still) using a diary service?
3. Are you currently practising at all? If so, what? How is that?
4. What (if any) preparations are you doing for getting back to work?
5. How have you been managing financially?
6. When do you think you might be able to return to your pre-covid earnings from music?
7. How are you dealing with all the uncertainty?
8. What are your hopes/fears about continuing to work in the music profession?
9. How have your moods been?
10. What helps you to cope during this time?
11. Are there any positive things that have come out of this time for you?
12. What (if anything) have you learned/plan to take forward from this time?
13. In what way has Brexit influenced your professional life?
14. Are you vaccinated?
15. What do you think music colleges should be thinking when training young players?
16. What do you think employers should be thinking of?
17. Is there anything else you'd like to add or anything you think I've left out?

Thank you!

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ORIGINAL RESEARCH
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An Examination of Trunk and Right-Hand Coordination in Piano Performance: A Case Comparison of Three Pianists

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Playing the piano at expert levels typically involves significant levels of trial-and-error learning since the majority of practice occurs in isolation. To better optimize musical outcomes, pianists might be well served by emulating some of the practices found in sports, where motor learning strategies are grounded in biomechanics and ergonomics in order to improve performance and reduce risk of performance-related injuries. The purpose of the current study is to examine trunk-hand coordination and preparatory movement strategization in piano performance, while considering the influence of anthropometry, skill level of the performer, and musical context. Using a ten-camera motion capture system, movement of C7 and right-hand distal phalanges was tracked at three different playing speeds during performance of an excerpt from Beethoven's "Appassionata" Sonata. There were three participants: two males and one female of differing anthropometric characteristics and skill levels. Motor strategization was examined. Expertise influenced starting trunk position: Initiation intervals and trunk range of motion (ROM) both suggested anthropometry to be a performance factor. For the shortest performer, trunk movement appeared to be used as an efficiency measure to compensate for a shorter arm reach. Skill level was revealed by examining right-hand velocity at the fastest tempo. The current study hypothesizes that an examination of proximal-to-distal preparatory strategies in terms of anthropometry and skill level can help to optimize motor learning for pianists. To realize piano performance as a whole-body skill and encourage healthy practice, pedagogy needs to educate learners regarding fundamental biomechanical and ergonomic principles, movement optimization, and movement strategization in the service of artful performance.

Keywords: piano performance, movement coordination, anthropometric kinematics, skilled behavior, motion capture, motor learning and control

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INTRODUCTION

It is estimated that 17 million people worldwide play the piano at an advanced level (Harris, 2017). Attaining an advanced level of piano performance skills requires years of training. In western pedagogical traditions, music learning occurs in a one-on-one student–teacher setting. Typically, students receive only one instructional session per week and the majority

of time spent learning involves individually motivated practice. For piano students enrolled at university, weekly practice hours can be as high as 39 h per week (Kaufman-Cohen et al., 2018). For professional pianists, average practice hours can range from 3.30–3.83 h per day (Jabusch et al., 2009; Moñino et al., 2017) or 13.70–27.00 h per week (Ericsson et al., 1993; Krampe and Ericsson, 1996; Allsop and Ackland, 2010). Given the long hours of necessary self-directed practice, the learner must be equipped with both cognitive and motor-based learning strategies that are grounded in deliberate and directed practice.

Motor learning research has shown that engaging in deliberate practice improves skill acquisition (Ericsson et al., 1993; Baker et al., 2020). With regard to the biomechanics of music performance and the ergonomics of interacting with a piano, deliberate practice can be a challenge because (a) most music teachers are not trained in the fundamentals of movement science, and (b) the majority of music biomechanics pedagogy is based in empirical methodologies—the subjective experience of the teacher (Visentin et al., 2008; Shan et al., 2013). Since there is a strong reliance on teachers' abilities to communicate personal perceptions of their own experiences, this model of pedagogy has limitations (Turner et al., 2021a). Specifically, learning will tend to include a significant amount of trial-and-error practice. This can result in the acquisition of "bad practice habits" or the development of idiosyncratic playing styles, which has implications for increased risk of playing-related injuries (Fry, 1987; Guptill and Zaza, 2010; Moraes and Antunes, 2012; Turner et al., 2021b). To better optimize learning, students of piano need to be provided with motor learning strategies that are grounded in biomechanics and ergonomics. Unfortunately, in existing research, there is sparse discussion of meaningful motor learning strategies devoted to optimizing piano performance (Turner et al., 2021a).

In piano performance, a performer is required to physically move. A piano keyboard has 88 keys that are fixed in location and span a distance of 1.22 m. Since the keyboard is stationary, performers must adjust their position to the piano, coordinating trunk and upper limb movement according to the demands of the musical score. For high-level performers, movement seems autonomous. However, it is the product of long-term practicing involving deliberate decision-making and mental planning in the pursuit of specific musical goals (Bangert et al., 2014). From a biomechanical standpoint, utilization of the trunk during coordinated movement provides a more efficient means of executing motor skills (Turner et al., 2021a). In sports, the use of proximal musculature to facilitate distal movement is well documented (Shan and Westerhoff, 2005; Zhang and Shan, 2014; Zhang et al., 2016). In music, proximal-to-distal movement sequencing has been examined for drumming (Altenmüller et al., 2020) and piano keystrokes involving a "struck touch" (Furuya and Kinoshita, 2007; Verdugo et al., 2020). Pappa et al. (2020) reported that adolescent novice pianists exhibited more trunk and hand movement while playing scales at fast tempos compared to more experienced adolescent pianists. By analyzing the timing of shifts in balance during performance of a virtuosic piano composition, Turner et al. (2021a) concluded that movement coordination is dependent on timely preparation; when and how a pianist prepares for movement greatly affects performance. These findings support Godoy et al. (2010) and Godøy (2013) who identify the importance of movement preparation for musical co-articulation in terms of motor chunking and sound-producing actions. Given the complexity of both cognitive and biomechanical preparation, study of individualized factors helps us understand how and why preparatory strategies are executed during piano performance.

Optimizing performance strategies requires consideration of a pianist's anthropometry and skill level in terms of the musical demands of the composition being performed. Anthropometrical characteristics dictate how a motor skill is learned (Ballreich, 1996). Because anthropometry differs among individuals, this suggests that most motor learning must be individualized. In music performance, motor behavior can vary greatly depending on the music being performed and the skill level of the performer. Advanced performers strategize and manipulate gross and fine motor skills in order to achieve artistic and interpretive musical outcomes (Shan et al., 2013). Mere repeatability is not the goal. This complexity makes the study of music performance and the application of motor learning methodologies very challenging.

In the current case study, two expert pianists and one intermediate pianist performed the last 9 measures of the 3rd movement in Beethoven's Sonata in F Minor Op. 57 ("Appassionata") at three different playing speeds. Preparatory movements involving timely coordination of the trunk and right hand (RH) were analyzed. The purpose of the current study is to examine trunk-hand coordination and preparatory movement strategization in piano performance, while considering the influence of anthropometry, skill level of the performer, and musical context.

MATERIALS AND METHODS

Participants

Three pianists (two males and one female) of differing anthropometric characteristics and skill levels were recruited for the study (**Table 1**). Participants 1 (P1) and 2 (P2) were professionals with completed Doctorate degrees. Participant 3 (P3) was an intermediate-level pianist with 11 years of piano study. All participants were right-hand dominant and, according to the Beighton Hypermobility protocol, exhibited no signs of hypermobility. Participants gave written informed consent after a briefing on the research protocol and procedures, all of which were approved by the University of Lethbridge Human Subject Research Committee [approval #2018–098].

Musical Excerpt

Participants performed the last 9 measures (mm. 363 to 371) from the 3rd movement of Beethoven's Piano Sonata in F Minor Op. 57 ("Appassionata"; **Figure 1**), an excerpt exemplary of the virtuosic literature from the early Romantic period.

TABLE 1 | Sex, select anthropometric measures, handedness, and experience level of each participant in the study.

Participants	Sex	Body height (m)	Hand span (m)	Hand length (m)	Forearm length (m)	Upper arm length (m)	Handedness	Experience level
P1	Female	1.645	0.178	0.172	0.253	0.289	Right	Expert
P2	Male	1.900	0.203	0.219	0.270	0.331	Right	Expert
P3	Male	1.735	0.193	0.192	0.258	0.326	Right	Intermediate

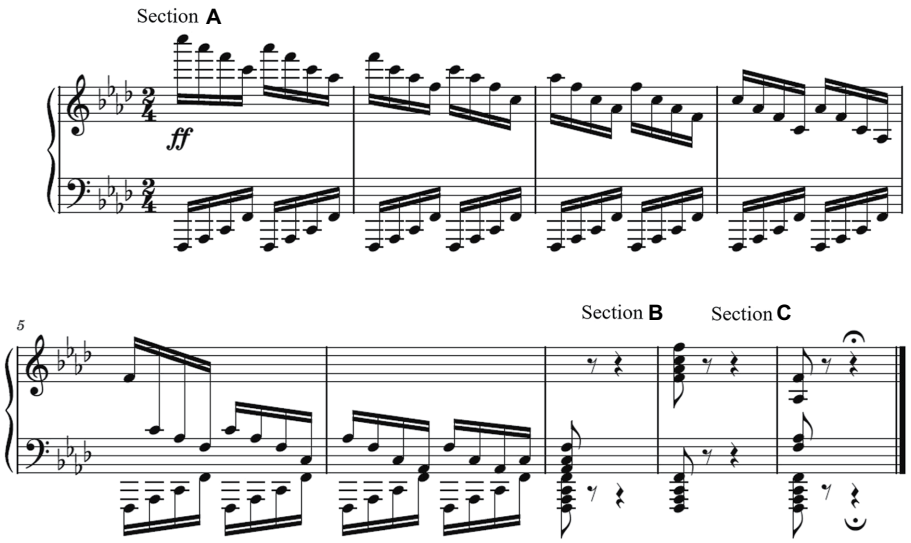


FIGURE 1 | The last 9 measures (mm. 363–371) from the 3rd movement of Beethoven's Sonata in F Minor Op. 57 ("Appassionata") with three identified motor behavior phases: gradual RH descent (Section **A**), 2-octave medial-to-lateral RH jump (Section **B**), and 1 octave lateral-to-medial RH jump (Section **C**).

Three playing speeds were examined: 6, 8, and 10 notes/s (N/s). Performing at the fastest tempo (10 N/s) is an expert task. By examining three different tempos, it was possible to evaluate motor strategization differences that might be due to tempo. Participants were instructed to perform in accordance with Beethoven's instructions in the score but without using the pedals. Excluding the pedals permitted focus on upper body movement without the confounding variable of right-foot pedaling. Participants were given the music two weeks prior to data collection. Notwithstanding that there was no requirement to memorize the excerpt, based on visual observation, none of the participants read from the score during performance.

The musical excerpt divides into three sections (A, B, and C) based on distinct motor demands for the RH: A) a gradual, descending series of "broken" 4-note chords covering a lateral-to-medial distance of 57 cm (3.5 octaves), (B) a medial-to-lateral jump using "blocked" chords and covering a distance of 32.5 cm (2 octaves), and (C) a lateral-to-medial jump using "blocked" chords and covering a distance of 16.25 cm (1 octave). Throughout the excerpt, the LH was stable in terms of medial/lateral position, playing a repetitive 4-note pattern for the first six measures, and the same four notes in "blocked" chords for the last three measures. These kinds of motor behavior demands are common in western musical tradition. Many pedagogical sources, such as "Essential Finger Exercises for Obtaining a Sure Piano Technique" by Dohnányi (1929), deliberately cultivate medial–lateral motor behaviors using chordal patterns.

Data Collection Procedure and Analysis

To quantify movement during performance, reflective markers were placed on six key anatomical landmarks and a ten-camera motion capture system (VICON MX40, Oxford, England) recorded positional and kinematic data. Capture frequency was 200 Hz (calibration error < 0.6 mm). One marker was placed on C7 and five were placed on the distal phalanges of the RH. The C7 marker provided a reference for trunk position while the RH position was determined using the five markers on the RH. 88 markers were placed on the keys of the piano to identify keystroke timing and accuracy.

To simulate a realistic performance setting, participants performed on a 9-foot New York Steinway grand piano in a concert hall (**Figure 2**). A metronome was used to regulate tempo (playing speed), which made possible comparison between participants. Otherwise, participants were permitted interpretive latitude according to their own artistic understanding of the musical passage. Additionally, each pianist was permitted to adjust the piano bench height and position according to personal preference. By employing this kind of observational methodology, where movements are minimally controlled by experimental design (Anguera et al., 2017), unrealistic motor behavior strategies



FIGURE 2 | The experimental set-up of the motion capture system in the concert hall.

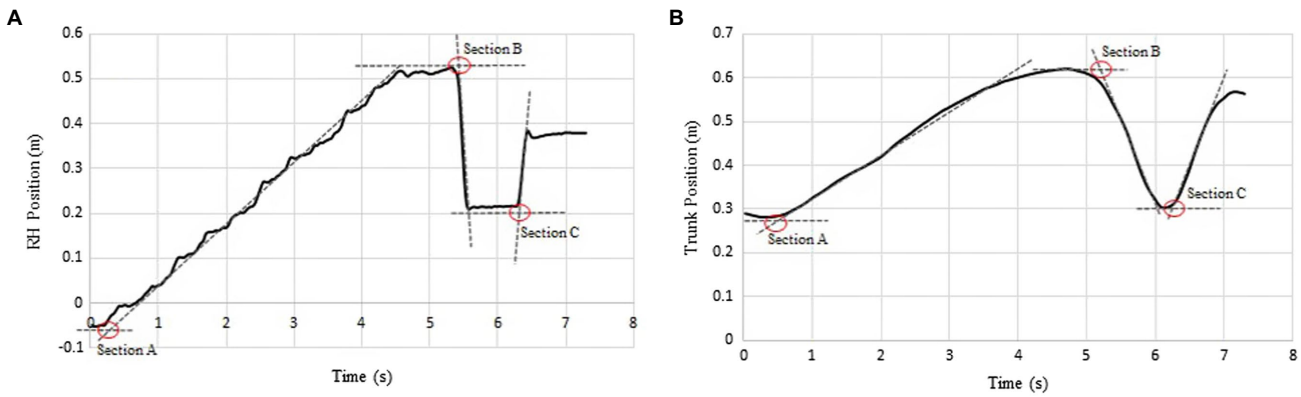


FIGURE 3 | (A,B) An example of the method used to calculate initiation time points. The intersection points between the initial position and positional slope (red circles) indicate the initiation time for the RH and trunk in each section of the musical excerpt.

arising from the control of performance parameters were avoided (Turner et al., 2021a). To establish timing of motor control, medial/lateral movement for the RH and trunk was analyzed using a global center point for the RH and the C7 marker. The positional data of the five RH markers were averaged to determine a global center point for the RH. RH position is plotted in **Figure 3**. Medial/lateral movement of the trunk (C7) is plotted in **Figure 3B**. "Best fit" slopes for each of the graphs were determined (dotted lines—**Figures 3A,B**). The intersection of these slopes establishes time points where changes in motor control occur. Control changes coinciding with the beginnings of A, B, and C are identified using red circles (**Figures 3A,B**). Initiation intervals were defined as the difference in time between trunk and RH time points. Positive values indicate that the trunk starts moving before the RH and negative values indicate the converse. Since the LH remained in a constant register, playing the same four notes throughout the excerpt, it can be viewed as a stable biomechanical factor. For the current research, the RH was analyzed because of its greater activity.

RESULTS

Medial–lateral starting position of the trunk differed among participants. The two expert performers began with a C7 starting position that favored the RH. For P1, C7 was, on average, 65.9 mm closer to the RH than to the LH and for P2, this distance was 33.9 mm. For the intermediate performer, C7 starting position favored the LH by 7.2 mm.

Initiation intervals for each participant are shown in **Table 2**. During the first section of music (A), interval values are negative, indicating that all participants initiated with the RH. As tempo increased, initiation times for P1 decreased while, for P2 and P3, initiation times increased from 6 N/s to 8 N/s and decreased at 10 N/s (**Table 2**). Average initiation times were distinctly different for each subject, −0.450 s, −0.927 s, and −0.668 s for P1, P2, and P3, respectively. During section B, trunk movement preceded RH movement. For the expert pianists, P1's initiation intervals were remarkably consistent across all tempos (0.205 s, 0.215 s, 0.185 s) while P2's were more variable (0.350 s, 0.490 s, 0.260 s). For P3, the intermediate-level

TABLE 2 | The initiation intervals between the trunk and RH for all three sections of the music across the three tempos. Trunk initiations are in bold print.

Participants	Tempo (N/s)	Music Sections					
		A (s)	Average of A (s)	B (s)	Average of B (s)	C (s)	Average of C (s)
P1	6	−0.885	−0.450 ± 0.385	**0.205**	0.202 ± 0.015	−0.050	−0.013 ± 0.033
	8	−0.330		**0.215**		0.015	
	10	−0.145		**0.185**		−0.005	
P2	6	−1.080	−0.927 ± 0.522	**0.350**	0.367 ± 0.116	**0.695**	0.253 ± 0.426
	8	−1.355		**0.490**		**0.220**	
	10	−0.345		**0.260**		−0.155	
P3	6	−0.465	−0.668 ± 0.179	**0.355**	0.205 ± 0.153	**0.445**	0.265 ± 0.157
	8	−0.800		**0.210**		**0.155**	
	10	−0.740		0.050		**0.195**	

pianist, initiation intervals steadily decreased as tempo increased (0.355 s, 0.210 s, 0.050 s). During section C, P1's initiation intervals were consistently close to zero (−0.050 s, 0.015 s, −0.005 s), with an average of −0.013 s across all tempos. For P2 and P3, initiation intervals decreased as tempo increased (0.695 s, 0.220 s, −0.155 s) and (0.445 s, 0.155 s, 0.195 s) for P2 and P3, respectively.

Trunk range of motion (ROM) across all tempos are shown in **Table 3**. For each musical section (A, B, and C), P1 had the largest trunk ROM, P2 had the smallest trunk ROM, and P3's ROM was somewhere in between. Across musical sections A, B, and C, each of the participants had highest trunk ROM in section A and lowest in section C, with section B ROM falling in between. Looking at the extreme speeds, slowest and fastest tempos only: in section A, ROM for P2 increased while it decreased for P1 and P3; in section B; ROM increased for P1 and P2 while it decreased for P3; and, in section C, ROM increased for P1 while it decreased for P2 and P3.

In **Figure 4**, medial–lateral RH velocity of the two expert pianists (P1 and P2) showed similar motor behaviors while the intermediate performer (P3) had a markedly different motor behavior. Maximum RH velocities achieved by P1 and P2 were 1.6 m/s and 1.4 m/s. For P3, maximum RH velocity was 0.8 m/s. Velocity curve contours showed similar differences. For P1 and P2, velocity curve contours were smooth and continuous with medial–lateral movement completion requiring ~0.22 s while, for P3, the curve contour was irregular and movement completion required more than 0.5 s.

DISCUSSION

When performing compositions, such as Beethoven's Appassionata Sonata, both proximal (trunk) and distal (hands) body structures must move; the distances between the notes are simply too big for the trunk to be static. When coordinating body segments for complex movements, relevant questions for musicians could be "what should move first?" and "how should it move?" By examining musical demands, ranges of motion in the trunk and the hands, initiation intervals, anthropometry, and expertise levels, the current study provides a means to examine these questions in a way that can be meaningful to musicians.

Starting Position

Whether consciously rationalized or not, a pianist's starting position is the first preparatory decision they must make. Position influences the availability of movement options for the performer, and consequently can be considered in terms of both expertise and anthropometry (Ackermann and Adams, 2003; Vantorre et al., 2014; James, 2018). In the current study, medial–lateral motor demands placed on the RH were considerably greater than those for the LH. Expert performers positioned themselves closer to the RH than the LH, effectively adjusting skeletal alignment to provide better proximal support for the RH. In contrast, the intermediate performer's starting position, equidistant between his hands, fails to recognize the demands imposed upon the RH, a finding that is likely linked to his lower skill level. Given that there is a relationship between preparatory movements and sound production, the intermediate performer's lack of preparation may be a consequence of a still developing perceptual schema of body awareness (Godøy, 2011). The two expert players, because of greater body awareness developed through long-term training, "naturally" positioned themselves asymmetrically to favor the hand executing the more difficult passage work.

In addition to expertise, anthropometry underpins data regarding starting position. P1, the shortest performer, started 65.9 mm closer to the RH than to the LH. For P2, the tallest performer, this positional asymmetry was only 33.9 mm. Simply, P1's shorter reach required greater compensation from the trunk as a means of supporting fine motor execution in the RH. For P3, given his stature, it seems reasonable to expect that playing optimization would have required him to position his trunk somewhere between 33.9 mm and 65.9 mm closer to the RH. The current paper asserts that a learning environment sensitive to biomechanics and the influence of anthropometry could help such a performer improve ease of playing and performance outcomes.

Initiation Intervals

Section A of the music has continuous playing involving movement throughout the right limb. Since the right limb must begin in an extended position, the consistent initiation of movement with the RH by all participants can be understood from a standpoint of effort minimization. The RH has a greater

TABLE 3 | Trunk ROM (mm) across all tempos and sections of the musical excerpt.

	Trunk range of motion (mm)											
	Section A				Section B				Section C			
Participants	6 N/s	8 N/s	10 N/s	Average	6 N/s	8 N/s	10 N/s	Average	6 N/s	8 N/s	10 N/s	Average
P1	313.3	340.0	272.2	308.5	262.1	318.5	270.1	283.6	191.0	265.6	254.2	237.0
P2	147.4	155.7	198.8	167.3	76.3	80.4	94.8	83.8	66.2	55.8	32.3	51.4
P3	188.0	167.7	174.0	176.6	164.5	135.5	107.3	135.8	83.8	89.0	27.3	66.7

medial–lateral mobility than the trunk and, since it has less mass, it is the easier segment to move. This underpins the role of the RH as the initiator of movement in section A of the excerpt. Average initiation intervals were smallest, largest, and in between for P1, P2, and P3, respectively (**Table 2**). The small initiation interval for P1 indicates that she is moving the trunk more closely in tandem with the RH. In using this strategy, proximal-to-distal skeletal support is better maintained throughout the entire passage. For P2, longer upper limbs permitted a greater medial–lateral right arm reach and a correspondingly smaller reliance on trunk movement. His larger initiation interval, nearly double that of P1, indicates that he was less dependent on moving the trunk to optimize skeletal alignment in support of the RH. For P3, initiation times fell in between that of P1 and P2 suggesting his stature, intermediate to P1 and P2, to be a determining factor.

In music section B, the presence of "rests" in the music influences the motor strategization. During rests, a pianist does not play any notes, so the body has greater behavioral freedom in preparation for upcoming playing demands. In spite of this increased freedom, in section B, all participants initiated movement from the trunk. This supports the idea expressed by Furuya and Altenmüller (2013) that proximal-to-distal motor coordination might help optimize motor behavior. This furthers the notion that musical rests may present pianists with opportunity to prepare and optimize motor strategies.

In section B, other musical demands also affect movement; a *fortissimo* ("very loud") "blocked" chord occurred after the RH medial-to-lateral jump of 32.5 cm (two octaves), making trunk movement necessary to support the RH. This substantiates the findings of Verdugo et al. (2020) with regard to the involvement of the trunk during *forte* ("loud") playing. For P1, initiation intervals across all tempos were remarkably consistent (**Table 2**), with less than 3/100ths of a second difference between trials. This consistency suggests P1's expertise to be very high. For P2 and P3, initiation intervals varied somewhat more than for P1 (0.367 s ± 0.116 and 0.205 s ± 0.153 for P2 and P3, respectively). Differences observed for P2 and P3 are small, also showing high levels of expertise.

Section C of the music ends the composition and requires a "very loud" finishing gesture. P1's use of simultaneous trunk and RH movement (initiation intervals across all tempos varied less than 0.065 s), show her to be maximizing trunk support to achieve this effect. For P2 and P3, the RH became more closely synchronized with the trunk at the two faster tempos. While P1 employed this strategy at all tempi, P2 and P3 selectively optimized trunk support for the RH only as the difficulty of playing increased because of increased speed. From this, it appears that Beethoven's "very loud" chordal finishing gesture is enhanced by greater synchronization between trunk and hand movement at faster tempos.

Trunk ROM

In the current study, average trunk ROM was linked to anthropometry. Average ROM was largest for P1 (shortest performer), smallest for P2 (tallest performer), and somewhere in between for P3 (medium-sized performer; **Table 3**). This

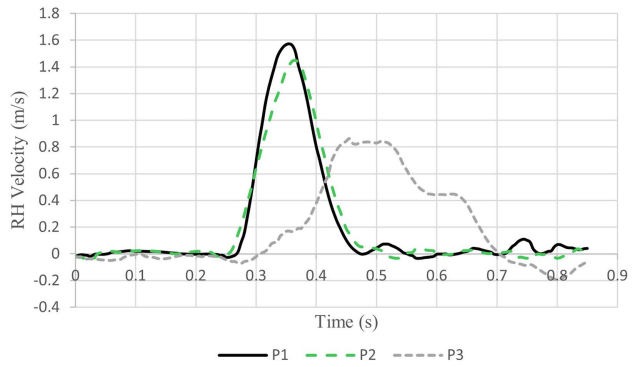


FIGURE 4 | RH velocity for all pianists during section C at 10 N/s.

suggests anthropometry to be an important factor for trunk movement. For P1, the participant with the shortest arm reach, a larger trunk ROM may have served as a compensatory mechanism to optimize RH support. P2's longer upper limbs permitted a greater medial–lateral arm reach and greater leverage when striking the piano keys, so less trunk movement was required in general. For P3, trunk ROM was intermediate to those of P1 and P2, a finding consistent with his physical stature. Comparing sections of music, each participant's average trunk ROM was greatest in A, less in B, and least in C. This phenomena appears to be coupled with RH playing demands; the RH moves furthest in A, less in B, and least in C.

Tempo-dependent trunk ROM is revealing with regard to movement strategization. P1 used much more trunk ROM than either P2 or P3. For P1, reducing proximal movement trunk ROM had utility as an efficiency measure. At faster tempos, since there was less time to move, P1 reduced trunk movement (**Table 3**). For P2 and P3, because they were moving so much less than P1 overall, there was little efficiency gain to be had by employing P1's motor strategy.

Right Limb Coordination

Analyzing RH coordination provides insight on expertise. The complex RH movement patterns of P3 are in stark contrast to those of P1 and P2. This can be clearly seen in **Figure 4**, which compares RH velocities of all participants for section C of the music at 10 N/s. P3 moves in "fits and starts" while P1 and P2 have smooth and continuous RH velocity changes. For P3, trunk movement is nearly frozen in this trial, moving only 27.3 mm, which is evidence of his lesser expertise; his RH must attempt to compensate for reduced trunk movement. This reinforces the assertion of Drake and Palmer (2000) that expert pianists anticipate during performance than less experienced pianists.

In the context of piano performance, movement strategies must be sublimated into artistic intention, and these are expertise-dependent. A further consequence of suboptimal movement behaviors is that they have the potential to increase risk of playing-related injury (Taimela et al., 1990; Turner et al., 2021b). In the case of P3, pedagogical instruction directing his attention toward trunk movement may have improved his coordination.

Limitations and Future Work

The current study asserts that anthropometry, skill-level, and musical context are all necessary considerations when learning to perform the piano. As a case comparison, it only involves three participants, two experts, and one intermediate-level participant. As such, the utility of the current study lies in the rationalized discussion of the data. Because of the relatively stable positioning of the LH, only the RH was examined in the current study. Since piano performance involves an array of musical contexts, more studies are needed to come to a complete understanding of how musical context directs motor strategization; a larger body of work examining practical biomechanical strategies is needed. Lastly, in the current study, the authors were careful to make the experimental process as natural as possible for the performers, so that they would not deliberately manipulate their "normal" playing style to accommodate experimental design. Notwithstanding this, the data gathering process was not a "normal" situation for the performers and the possibility of some subtle playing alterations cannot be eliminated. We propose that a line of research which considers cause and effect of the conscious manipulation of movement strategies in the service of artistic performance could have broad ranging application by employing systematic observational methodology that utilizes polar coordinate or T-pattern analysis to detect movement regularities among pianists.

CONCLUSION

In the current case study, three pianists' timely coordination of the trunk and right-hand (RH) preparatory movements were analyzed during performance of the last 9 measures of the 3rd movement in Beethoven's "Appassionata" Sonata, at three different playing speeds. The musical excerpt had three different sections requiring distinct motor behaviors for the RH, while the LH remained relatively stable. This permitted examination of preparatory strategies for each of the various motor behaviors. Starting position, initiation intervals, trunk ROM, and right limb coordination were analyzed. Despite similar initiation strategies for all pianists (distal-to-proximal in section A and proximal-to-distal in sections B and C), the trunk appeared to 1) move within the RH medial–lateral confines of each musical section (musical context) and 2) be a source of compensation for anthropometry, specifically for P1, the shortest pianist. Evidence of level of expertise was found in the positional preparation relative to the keyboard and RH coordination at the fastest speed.

The current study underpins the utility of recognizing the influence of biomechanics, anthropometry, skill level, and motor learning strategies in piano learning and performance. Comparative analyses, such as those of the current study, provide biomechanical and ergonomic perspectives that have potential to optimize the process of learning to play the piano. Individualization of preparatory strategies should be recognized in terms of the anthropometry of the learner. The generally

accepted concept that proximal body structures initiate movement may not be possible depending on musical context. In this case, expertise and anthropometry need to be considered more carefully. In addition to improving musical outcomes, this has the potential to optimize movement intentionality in the service of injury prevention. Future studies can contribute more effectively to motor learning by focusing on the questions "how does the musical context require that a motor strategy be employed?" and "what motor strategization should be used?" These two questions are eventually faced by every musician and need to underpin the motivation of music biomechanics research that is intended to be cross-disciplinary.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because as a case comparison study, it may make subjects identifiable to third parties. Requests to access the datasets should be directed to g.shan@uleth.ca.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Lethbridge Human Subject Research Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CT, PV, and GS contributed to all facets of the research (concept, design, data collection, analysis, interpretation, and manuscript preparation). DO contributed to the design of the research protocol and data interpretation. SR contributed to the revisions of the manuscript. All authors contributed to the article and approved the submitted version.

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Online Group Music-Making in Community Concert Bands: Perspectives From Conductors and Older Amateur Musicians

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At the beginning of the pandemic, many music ensembles had to stop their activities due to the confinement. While some found creative ways to start making music again with the help of technologies, the transition from "real" rehearsals to "online" rehearsals was challenging, especially among older amateur musicians. The aim of this case study was to examine the effects of this transition on three community band conductors and three older amateur musicians. Specific objectives were to explore (1) intergenerational relationships to support online group music-making; (2) digital literacy and access in later life; and (3) online music-making in a COVID-19 context. Semi-structured interviews were conducted and theoretical thematic analysis was undertaken (Braun and Clarke, 2006). Results were analyzed from the conductors' and older musicians' perspectives, and common trends were combined to facilitate interpretation. The first theme showed that being part of an intergenerational ensemble contributed positively to the learning experience online. The second theme demonstrated that because both conductors and musicians were new to the online rehearsals, it contributed to attenuate the age-related digital divide that may have been observed in other studies. Regarding access in later-life, older musicians reported benefits associated with rehearsing online, specifically in terms of distance/commute, time, energy, and cost. However, for those who did not already have internet and electronic devices, the cost of acquiring all the necessary equipment to make music online could have been too high. Finally, the third theme revealed that musicians appreciated the opportunity to make music online and indicated that it was definitely better than having nothing, especially for its social aspects. In conclusion, while participants noted several challenges associated with online music-making (e.g., zoom fatigue and technological issues), they were also appreciative of the opportunity to continue making music at a time when in-person rehearsals were not possible. Pedagogical implications are discussed, specifically the importance of the support network, of meeting people where they are, of learning to adapt, and of collaborative teaching.

Keywords: group music-making, community music, older amateur musicians, pandemic (COVID-19), online music

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INTRODUCTION

In March 2020, owing to the onset of the global COVID-19 pandemic, many music ensembles had to stop their in-person activities (Camlin and Lisboa, 2021, p. 129). Despite tumultuous circumstances, some found creative ways to start making music again with the help of digital technology. That said, the transition from in-person rehearsals to virtual ones was not an easy step, especially among older amateur musicians.

There exists a well-documented generational divide regarding the use of technology, with older adults being less likely to engage with technology than what is observed among younger generations (Charness and Boot, 2009, p. 253; Poushter, 2016, p. 6–23). That said, one study has shown that older adults are more compelled to engage with new forms of technologies when the perceived benefits outweigh the challenges associated with their technical use (Heinz, 2013, p. 69–70). In other words, despite feelings of frustration or inadequacy, older adults may be willing to learn to use new technologies if they perceive that these may be useful and contribute to their independence or quality of life (QoL). Additionally, for many older adults, music is suggested to be a significant resource in supporting their QoL, with some studies reporting benefits associated with the social and collaborative nature of group music-making (Coffman, 2002, p. 85; Creech et al., 2013, p. 96–98; Varvarigou et al., 2012, p. 183). Therefore, within the context of the pandemic, it became clear that to continue having access to this resource, one had to learn to make music within an online space (Camlin and Lisboa, 2021, p. 129). However, particularly during the earlier months of the pandemic, overcoming one's fears or reservations about technology became a necessity in order to maintain participation and access to these group music-making activities.

For musicians whose music-making centered on chamber ensembles, wind bands, orchestras or choirs, continuing to pursue musical goals within those group contexts required a willingness to transition from practicing music weekly with others in a place-based rehearsal space to participating virtually within an online space. While the changes and restrictions introduced by the pandemic affected all musicians, as they limited (or even totally prevented) in-person collaborations and synchronous music-making (Fram et al., 2021, p. 2; Rosset et al., 2021, p. 9–10), these shifts came with multiple challenges and barriers that may have particularly affected older musicians (regardless of level). Examples include technological challenges (i.e., highly complex technology), technical challenges (i.e., unstable internet connection), and musical challenges (i.e., not being able to hear bandmates while playing). In an earlier study, Vaportzis et al. (2017, p. 1) had identified barriers to using technology among older adults, particularly when interacting with tablets. The authors concluded that most participants "were eager to adopt new technology and willing to learn" (2017, p. 1) but voiced some concerns about specific barriers (for instance, cost, lack of support or knowledge, feelings of inadequacy).

During the pandemic, older musicians were not alone in their struggle: all generations were forced to adapt to the new reality of COVID-19, from students and music teachers in elementary and high schools (Cheng and Lam, 2021; Boucher et al., 2022) to amateur musicians in community music schools (Salvador et al., 2021) as well as professional musicians (Coletto, 2020). As a result, musicians—regardless of age or background—pulled together to ensure that music would prevail during these trying times. That said, many music teachers felt they were not adequately prepared to make the shift, which generated stress and anxiety (Cheng and Lam, 2021, p. 211). The authors reported that music teachers were concerned about issues such as technological integration and the ability of students to adapt to online teaching. Fortunately, as Thornton (2020) reflected, there were ways in which the pandemic influenced music teachers and artists to respond to these new challenges, translating to an increase in creativity, a stronger sense of community and a responsiveness to students' needs through empathy, patience and thoughtfulness. One particular example comes from Rowan (2021), who reported trying multiple methods (e.g., Skype, email, and Jamulus) in order to continue to provide music despite the fact that everything was online, illustrating the resiliency of conductors in such a challenging context.

The aim of this research was to examine the effects, in a pandemic context, of transitioning band rehearsals from in-person to an online environment on community band conductors and older amateur musicians. Specific objectives were to explore :

- Intergenerational relationships to support online group music-making.
- Digital literacy and access in later life.
- Online music-making in a COVID-19 context.

METHODS

Design

This was a qualitative intrinsic case study (Creswell and Poth, 2018), bounded by the unique and unexpected circumstance that arose from the pandemic, whereby an adult community music activity (MNHB) had to transfer from an in-person to an online environment.

Participants

This research project was approved by the ethics board of the Université du Québec à Montréal and the informed consent of participants was acquired by email prior to the start of the data collection process. Musicians were recruited within the Montreal New Horizons Band (MNHB), a bilingual and intergenerational community concert band for amateur musicians. Founded in 2014, the MNHB is a non-profit organization composed of three groups that are based on levels of musical proficiency: Initiation (for people who never played music before), Adagio (for beginner/intermediate musicians) and Allegro (for intermediate/advanced musicians). Three main conductors are usually involved with the organization (one for each group). Team-teaching is common practice among the conductors as all groups meet on the same evening (for instance, the main conductor of the Initiation band also acts as assistant

conductor in the Allegro band). When not on the podium, all conductors play with the ensemble to support musicians. Music specialists are also hired as needed to lead sectionals. In addition, guest conductors are frequently invited (mostly students in Music Education who are following conducting classes at McGill University).

Before the pandemic, 86 musicians were registered to at least one group in the MNHB. In March 2020, all activities were suspended. Starting in Fall 2020, online activities were offered to Adagio and Allegro members. No Initiation band was offered as it was deemed too complex to introduce music to novices playing multiple (and different) wind instruments within an online context.

Online activities included two virtual bands (Adagio and Allegro levels, rehearsing weekly for 60–75 min between September and June), chamber music coaching (small ensembles rehearsing with a private coach for six 60-min sessions) and jazz workshops (a 10-week interactive course offered virtually between February and May 2021). All activities were provided by the regular MNHB conductors through Zoom Video Communications Inc (2022). Some of these conductors also offered private instruction online.

In the Fall semester, 20 musicians registered to one or more activities online. In the winter semester, 23 musicians registered and in the spring semester, 21 musicians. **Table 1** describes the number of musicians registered in the virtual bands and chamber music coaching each semester as well as the number of people who abandoned their activities during the year. Participants in the jazz workshops are not included in this table due to the fact that the activity was offered for free to all members registered in one or more online activities. Therefore, the attendance was not taken and as a result, the attrition rate could not be reported (data are missing).

It is worth noting that participation across two or three semesters was more stable for members of the Allegro band than the Adagio band. Some reasons for dropping rehearsals included health concerns, time conflicts with work, perceived difficulty of participating, and not appreciating the online format for rehearsals.

To recruit MNHB participants for the study, a convenience sampling method was used. Participants consisted of all the conductors teaching online in 2020–2021 (three female adults aged under 30 years) and three amateur musicians having participated in at least one online activity throughout the 2020–2021 season.

Conductors A and B were in charge of the virtual bands (intermediate and advanced levels). Conductor B was also responsible for all the online chamber music ensembles. Conductor C provided the jazz workshops for members. Conductor B and C also offered individual instrumental lessons online. All of them had completed at least a Bachelor's of Music in their primary instrument and had taken undergraduate-level conducting classes sometime prior to the pandemic. Conductor A also had a Master's in sound recording and was a Ph.D. candidate (Music Education) at the time of the study. Conductor C had a Master's in instrumental conducting and was a music teacher in schools. Conductor B owned a music studio and was a full-time music instructor. They have been teaching and conducting within the MNHB for at least 4 years.

The musicians (two females and one male, aged between 67 and 79 years old) have been part of the MNHB for 5–7 years and were considered to be at intermediate levels on their main instruments. Additional demographic information appears on **Table 2**.

It is important to mention that Conductor A, once the interviews were completed, joined the research team to contribute to the data analysis. While she was unaware (during the time she was conducting one of the virtual bands) that the transition from in-person rehearsals to virtual ones would become a specific focus for research within this context, her contribution to the analysis provided a valuable insider perspective and significantly enriched the credibility and trustworthiness of the analysis.

Virtual Band Structure of Rehearsals

The virtual bands' rehearsals were recorded and made available to ensemble members during the semester. Permission to record was asked at the beginning of each semester and participants who felt uncomfortable being recorded were suggested to keep their camera off. Unlike regular in-person rehearsals, the majority of the online band rehearsals were held in a sectional format, with musicians being split into their instrument families (woodwinds; Brass and percussion). Full band rehearsals were held three times during the semester—one at the beginning, one approximately in the middle, and one at the end of the term. Typical rehearsals usually started with announcements (if needed) or a question period, which was followed by a brief warm-up done with the full band. While most of the time all musicians had to be muted to adequately hear the conductor's sound source, for warm-ups and slower chorale-like pieces, it was possible to have everyone

TABLE 1 | Registration and attrition per online semester.

	Fall 2020		Winter 2021		Spring 2021	
	Registration	**Attrition**	**Registration**	**Attrition**	**Registration**	**Attrition**
Adagio	12	3	15	5	9[a]	1
Allegro	15	0	21	3	17[a]	0
Chamber music coaching	7	Not available	16	1	6[b]	0

[a] *These musicians continued on from Winter 2021.*

[b] *Participants rehearsed together outside following social distancing measures.*

unmute and play together. The ensemble was then separated into break-out rooms for sectionals or stayed together during full band rehearsals to work on pieces. Repertoire chosen for online music instruction were mostly flex band[1] arrangements to allow more freedom regarding parts assignments. The rehearsal ended with a run-through of a piece (time permitting) or a question period. During rehearsals, musicians played along with either the conductor on keyboards or with recordings of the repertoire. Recordings were manipulated to be slower tempi using AudioTrimmer. Occasionally, musicians also received music theory and music history lessons during rehearsals. Both bands concluded their semesters with members individually recording themselves playing a selected piece to be put together for a "virtual concert" video (for more details on rehearsal structure, please refer to **Supplementary Appendix 1**).

Data Collection and Analysis

Semi-structured interviews were conducted in French or English, based on the mother tongue of participants, and lasted approximately 45 min. All interviews occurred in July 2021, during summer break, after the end of all online activities. Interviews were transcribed in their original language. French quotes that were selected for analysis were translated to facilitate interpretation using DeepL, checked for clarity by a researcher fluent in French, and validated by the research team. Quotes that were selected to be included in the analysis were then sent back to each participant individually, to ensure that the written transcriptions were a representative depiction of his/her thoughts and experience.

The format of the interview consisted of 13 open-ended questions (**Supplementary Appendix 2**) that addressed three themes: (1) intergenerational relationships, (2) digital literacy and access in later-life, and (3) online music-making in a pandemic context. The intent was to seek participants' perspectives in relation to these themes, with questions such as: "You participated in a virtual ensemble that was intergenerational. Do you feel that this intergenerational context may have improved your learning experience? If so, how? " (Theme 1); " How can virtual music-making maximize equitable access in later-life to creative musical expression, engagement in learning, digital literacy and quality of life amongst older citizens?" (Theme 2); or "What implications has the shift to an online environment had for you as a musician (or teacher)? What new skills or resources have you had to develop, in response to opportunities or challenges raised by the pandemic?" (Theme 3).

Following the guidelines set out by Braun and Clarke (2006, p. 83–85), theoretical thematic analysis was undertaken, meaning that data analysis was based on the researchers' specific areas of interest and focused on specific aspects of the data rather than the entire dataset. Analysis was undertaken primarily at the "semantic" (or explicit) level, establishing patterns between extracts, and then attempting to understand their significance and establish their broader meanings in an iterative process. A research assistant, in charge of coding the data, was supervised by the main researcher through the first stage of analysis. Afterward, a second researcher checked the coding process and contributed to its improvement. Codes were reorganized as needed, based on a deductive approach. Participants' perceptions of transitioning from in-person rehearsals to online rehearsals was examined from two perspectives: those of the teachers (adult band conductors) and those of the students (older adult band members). Results were combined to facilitate interpretation when trends were observed.

[1]Arrangements that divided musical parts into "voices," similar to soprano-alto-tenor-bass (SATB) choir music, instead of via instrument. Flex band pieces typically ranged from 4 to 6 parts with percussion/keyboards or auxiliary instruments.

RESULTS

Theme 1: Intergenerational Relationships to Support Online Group Music-Making

Intergenerational Interactions

The first question participants answered was associated with how they thought the intergenerational context of the virtual ensemble (namely, having teachers that were younger than them) contributed to their learning experience. From the band members' standpoint, two main perspectives appeared—one in which the intergenerational relationship was helpful and one in which it did not have an impact on the learning experience. None indicated that having younger conductors was detrimental for their learning experience.

Among the participants who considered that the intergenerational context contributed to the learning experience, one musician thought about intergenerationality in relation to technology and problem-solving. The fact that people came from multiple technological backgrounds meant that there was a great deal of collaboration between participants:

> [When there were] things that were not clear, there were always people in the group who were a little more competent in technology than others and then we don't all get stuck in the same place. The things that I find super easy, others will find difficult and vice versa. So, the fact of being intergenerational, with technology evolving at a crazy speed, I think it's really an advantage (Musician A).

For others, intergenerationality was not necessarily relevant to participants' experience. For example, a musician indicated that they did not really focus on the intergenerational aspect when rehearsing, saying "to be honest, when you're all together, you don't see the intergeneration[ality] for all the group" (Musician C).

From the teacher's standpoint, one conductor explained during the interview that being younger and still experiencing technological issues contributed to destigmatizing problems: "I think it helps that it was intergenerational 'cause they saw that [Conductor B] and I would mess up sometimes too and if we could laugh about it, so could they" (Conductor A).

Explorations

Conductors and musicians were pushed to undergo exploratory phases at the beginning of the semester in order to problem-solve effective ways in which to do community band online.

TABLE 2 | Demographic information of study participants.

	Age as of Summer 2021 (years)	Involvement in MNHB (years)	Years spent playing primary instrument/conducting	Participation in other online musical activities
Conductor A	28	6	7	Yes[d]
Conductor B	28	7	7	Yes[e]
Conductor C	27	4	6	Yes[e]
Musician A	67	7	8[a,b]	No
Musician B	79	5	4[a,c]	Yes
Musician C	72	7	8[a,b]	Yes[e]

[a] *Took private lessons on their main instrument before joining MNHB.*
[b] *Novice: Started learning music later in life.*
[c] *Had played a variety of instruments before throughout their life.*
[d] *Took online private music lessons.*
[e] *Taught online private music lessons.*

When asked to reflect on this, participants reported elements that worked particularly well and elements that did not.

Positive comments were made about the fact that commuting to rehearsals was not an issue anymore: Participants appreciated that tasks such as driving or commuting to and from rehearsals and carrying large instruments were absent for online rehearsals. Additionally, within the Montreal New Horizons Band, participants wishing for more playing time on their instruments had the opportunity to participate in the two bands that rehearsed back-to-back on Tuesday evenings (one intermediate band and one advanced band). With the virtual band, people kept this opportunity not only to play with both bands, but also to play different instruments in each band (for instance, alto saxophone in one, and tenor saxophone in the other). They could even switch instruments between pieces during the same band rehearsal. Therefore, because they did not have to physically carry multiple instruments to rehearsal, there was no space issue to keep both instruments beside them, and they had time to switch between one and the other as needed, they considered the experience as a positive. The online environment also offered a safe space to make mistakes, as no one (including the conductors) could hear when they made an error: "When we play, if our playing is not good or we're not doing the right scale, there's nobody who knows! [laugh]" (Musician A). In addition, some challenges associated with in-person playing were alleviated in the context of online music-making. For instance, Musician A explained that "for all the little 5 feet people, to be able to see the teacher who is conducting, when she is conducting and I have my tablet, I will say that it's 50% of my pleasure." She continued on to explain that while it was a big disadvantage to be small in life in general, it was worse in an orchestra because one constantly had to move to the right or left to see the conductor, and there is a limit to asking the people in front of you to settle down (Musician A).

As for the negative aspects, both musicians and teachers experienced technical difficulties that were out of their control (internet connection; problematic issues with the Zoom platform; etc.). In addition, being seated for long periods (working on a computer during the day, then sitting in front of a computer for rehearsal) created some discomfort. Teachers also reported that initially it was challenging to find strategies to engage learners during rehearsals, leading them to a solution whereby musicians were encouraged to unmute and speak whenever they had a question. In terms of motivation, Musician B pointed out that, unsurprisingly, it was more motivating to meet in person than online, but that the latter was better than having nothing at all.

Facilitating the Online Transfer

When exploring the impact of young conductors supporting band members through the transfer of in-person to virtual rehearsals, one element that stood out was the musicians' level of appreciation for their teachers in accompanying them through the experience of making music online. For instance, Musician A shared the following about the teachers' humanity, as they showed kindness and compassion, used humor and were able to respond to individuals' needs within the group setting:

> I think we really got the best of the best teachers. Not only are they competent, knowledgeable, but they're also human, kind and honestly, I really enjoyed getting to know [Conductor B] differently than how I saw her when we were face to face. She's a lot funnier in person and she's very, very human, really. [Conductor A] is the same. It's true that we were in a group, but at the same time we were like individuals, so there are human aspects to this that are very valuable to me (Musician A).

Another element reported by both musicians and teachers was the importance of support and feedback, be it through written tutorials or immediate technical help during rehearsals. Conductor B explained: "Most of it was, either one of two things : [1] the tech side of it (making things work so that they can hear and they can participate); And then [2] the technical difficulties of trying to figure out the music on their own." They added that musicians did not have a recording of their individual parts, which made it difficult for them to isolate their melodic line when playing with the recording and to ensure that they were performing it correctly. Because musicians were not able to receive feedback while playing, conductors later started to provide personalized feedback, which took the form of written comments to musicians who sent individual recordings of themselves playing by email.

In summary, intergenerational relationships were mostly considered positively, especially relating to helping with technological troubleshooting. While a perspective emerged stating that intergenerationality was not a focal point of the

learning experience in the virtual environment, participants did not mention negative aspects of having a mixed age range within the group.

Theme 2: Digital Literacy and Access in Later Life

Fostering Digital Literacy and Mitigating the Generational Divide Through Music Technologies

By participating in weekly online rehearsals, musicians explored different technological tools. For instance, the conductors shared a list of online resources that musicians could use in their spare time (e.g., musictheory.net), prepared videos on musical topics for asynchronous learning (e.g., identify major keys and their relative minors), and created various written tutorials using a checklist format (step-by-step guides on how to set-up Zoom and how to record yourself for virtual concerts). As such, the nature of conductor support changed from a sole focus on musical matters to encompassing how to use the technology to mediate the learning. Consequently, we explored whether music technology could allow band members to develop skills that would be transferable to their daily lives and contribute, then, to attenuate the generational digital divide that has been observed by some researchers (Charness and Boot, 2009, p. 256; Poushter, 2016, p. 10). When interviewing the musicians, they perceived that using technology should not necessarily be associated with being young or old, but rather with the level of interest (or fear) one may have:

> I think it's a bit of a stereotype to say that older people are not good in technology, because I'm better at it than quite a few people in my family and other people. So, it more depends on what your interest is and what your familiarity is, and how afraid you are of it. I think a lot of it is overcoming fear (Musician B).

Here, Musicians B described her use of technology in comparison with those of family members, whereas Musician A focused on the fact that levels of expertise did not have to be associated with age: "In life, you deal with all kinds of levels, with people of all ages, and for me, it doesn't matter at all." The latter continued by explaining that she would want more intergenerational initiatives but that our society still has a tendency to categorize the population by strata, which results in dividing and polarizing people:

> I've seen it even more lately, our society divides people. And I would like to encourage activities like those in the Montréal New Horizons Band so that people stop using this age barrier, and stop placing people in packs or classify them. I know that each one of us can learn from someone else (Musician A).

All musicians also commented on the fact that they received a lot of support from their teachers, which contributed to making their experience positive.

> We are lucky to have leaders who are competent and generous and kind [...]. It's really comforting to see that there are young people who are interested in that [i.e., intergenerational learning] because we don't often hear about it, unfortunately (Musician A).

As for the conductors, they reported that to make musicians feel comfortable in the virtual format of the rehearsal required a great deal of preparation on their side. They chose to assume that everybody was novice in using technology and prepared accordingly by creating tutorials and written guidelines:

> Making those types of things... not assuming that everyone knows [technology]: Having tutorials, walkthroughs, try to make everything intuitive but not just for people who know how to use a smartphone. Making sure not to rely too much on those assumptions (Conductor B).

In terms of mitigating the generational divide, Conductor A emphasized that because the situation was new to everybody, including the teachers, it contributed to decreasing the digital chasm:

> I think it helped close that gap a little bit because, we were navigating it with them too: I had never done that before, teaching them in that way, in an online format, so I think it made them a lot more comfortable, and me too, to be fine with things that didn't work or if we made mistakes. . . and even to celebrate the little things that go right (Conductor A).

Maximizing Equitable Access in Later-Life

Could virtual rehearsals have the potential to foster equitable access to music? Responses were mixed among participants. For instance, while Musician B indicated that "it really overcomes the barrier of distance and cost for people," Conductors B and C were more cautious with their answers. Conductor C indicated: "Tricky, because not everyone has the same set up, not everyone has the same access to technology, and that's been super apparent with what went on at the beginning of the pandemic." She also added that "using technology requires technology," which is aligned with Conductor B who indicated that it "requires a lot of investment in the hardware, a good internet connection, and things like that." That said, Conductor B also mentioned that it made it easier for people to engage in activities: "the online stuff has actually made it in some ways more accessible to people 'cause it's less work than to have to go somewhere else to do it, you could just do it from home in your pajamas [laugh]."

In order to maximize access, musicians and conductors indicated that using the Zoom platform to hold the rehearsal was a good choice as it was quite user-friendly and did not require an account for attendees to join. It is worth noting that in addition to the weekly virtual rehearsals, most participants had used that platform on other occasions as well. For instance, Musician B used Zoom to communicate with her family as well as to sing in a choir online: "I belong to this Mandarin choir and we would be meeting on Zoom every other Saturday."

Theme 3: Online Music-Making in a COVID-19 Context

The third theme addressed online music-making during the pandemic and members' perception about their experience. Our first question was: What implications has the shift to an online environment had for you?

From the teacher's perspective, Conductor C commented on the importance of being able to adapt, to be flexible, to try new

things and to be okay if it did not work because at least, you tried. She also emphasized the difference between in-person teaching and online teaching, even for a person as exuberant as herself:

> I think it has allowed me to be adaptable of teaching in person and teaching a full classroom—whether it's a band scenario, whether it's a classroom of kids for example, vs. lecturing online, it's made me be able to adapt and flip between two completely different styles of teaching because even though I have an excitable personality and I'm very out there, I actually find it way more exhausting to do that online than to do that in person (Conductor C).

From the musician's perspective, having access to online rehearsals was definitely better than having nothing at all. Musician B explained that missing rehearsals for a year would have made it very easy to abandon playing music: "I was really glad that you decided to do it online, because missing that year and some... It would've been really easy to drop out of it all together, and stop practicing, and then not feel like coming back, and losing touch with all the learnings and the teachers and the other group members."

Musician A said that because she could continue to do music, she did not feel as if she had given up all aspects of her life to the pandemic: "I didn't feel like I'd lost everything when the pandemic struck. I would have missed it a lot if I did not have these rehearsals."

Another element that she (Musician A) and others mentioned was that unfortunately, the shift to online rehearsals caused a drop in the number of members. Musician A indicated that she knew some individuals who did not register because they lived in apartments and could not play their instrument in the evening, out of respect for their neighbors. Others also felt they were just not familiar enough with technology to participate, or simply did not have the equipment to do so.

Teachers and musicians had to develop new skills or resources during their year of doing music online. Conductor A commented on how nice it was to see participants evolve and become more comfortable over time, especially when comparing the very first rehearsal to where they were at the end of the year.

> Thinking about where they were in the very first online rehearsal and then seeing them where they are now, is just like a big source of pride. Because I knew it was gonna be hard for them and I knew that we would end up losing people [along] the way because it was gonna be frustrating. [But] seeing them evolve from [thinking], "I don't really know what we're doing" to laughing because they can't turn off the bunny filter [on Zoom], [and also] being able to feel comfortable unmuting to ask a question or to make a joke was really nice (Conductor A).

Additionally, when asked about the pandemic and how music may have helped people go through it, that same conductor told the following story:

> [At] the end of our last rehearsal in the spring, [the] cohort seemed to [feel] closer to each other [...]. [There] was one point during [Advanced Band] where I had a sectional and they were feeling pretty confident and I felt pretty confident [about] them and we all just checked on each other. [It] had nothing to do with music, we were just asking [each other], "how are you doing? How's work? How's school?" "Are you okay?" "What's going on?" and we just talked for more than half of the sectional, getting to know each other, and that was really really nice 'cause I would've never been able to do that [during in-person rehearsals] (Conductor A).

One may wonder whether this is solely the product of the online environment or whether the circumstances surrounding the pandemic allowed these types of interactions to happen. That said, this quote highlights how social relationships progressively strengthened, suggesting that interpersonal aspects may flourish through online music-making.

Lastly, participants were asked what they felt they would need for a satisfying experience if they were to continue music-making online. From the responses, three requirements were emphasized by both students and teachers: (1) personalized feedback, (2) taking ownership of one's learning, and (3) support.

Personalized Feedback

The majority of rehearsals were held in a sectional style, with musicians separated between instrument families to receive more specific instruction relating to their instruments. Full ensemble rehearsals were held approximately three times per semester. Before these rehearsals, conductors asked musicians to submit individual recordings of themselves performing a run through of the pieces in order to better assess problematic areas and challenges that were not always evident during full ensemble rehearsals (e.g., incorrect rhythms, wrong notes, etc.). Personalized feedback was then sent via email to each musician who submitted a recording, which participants felt was helpful and even an advantage over their previous in-person rehearsals: "Our conductors analyze our recordings, and I think that is so wonderful. That's an improvement over in-person: you get individual feedback on your performance" (Musician C).

Musician B further underlined the importance of this personalized feedback, saying: "That's an excellent idea, because otherwise [the teachers don't] really know if we're doing anything." The following anecdote also illustrates how conductors may have been unaware of different issues (technological or otherwise) that could have affected musicians' ability to follow them:

> A couple of times, I couldn't get the music, it was on my tablet and because of my issues with my technology, I couldn't get to do it fast enough so I wasn't even doing it... and [the conductor] didn't know I wasn't doing it! [laugh] And one other member was asked to do a little part and I think he wasn't even looking at the right music at the time... and it didn't show! [Laugh] If he hadn't been asked, nobody would've known so, I think it puts more of an onus on ourselves to actively participate. But I think most of us are, really, actively participating. I think it's pretty good considering (Musician B).

While this provided humorous examples of musicians not getting their materials fast enough to play when prompted during ensemble rehearsals, it also meant that conductors were limited in terms of diagnosing the challenges musicians faced when playing together online. This often made it difficult for conductors to gauge what to work on during full band rehearsals.

Taking Ownership of One's Learning

As mentioned by Musician B above, it became the learners' responsibility to actively participate in order to fully benefit from the virtual music-making experience. This suggests a fundamental change of facilitator style from largely hierarchical to much more cooperative. Taking ownership represented a significant departure from the teaching approach used previously during in-person rehearsals, where conductors tended to take the lead in choosing what to work on based on hearing the ensemble as a whole. Here, in virtual band, conductors indicated that musicians' ownership of their learning was paramount for lesson planning and rehearsing. For example, they heavily encouraged musicians to ask questions—via Zoom or email—on aspects they were having issues with, or regarding passages they wished to work on more. Conductor B commented on the importance of dialogue:

> I think that the engagement, the feedback, and having people talk—having it be more of a conversation—for the people on the other side to take more ownership of that and to come with questions, or to be prepared to stop things and [say]: "I need you to do this, can you explain this again?" (Conductor B)

While some musicians initially felt hesitant to un-mute themselves to ask questions, conductors tried to support the group by saying it was okay to make mistakes, to not know things, and gave resources they may find helpful outside of rehearsal time.

Providing Support

Many participants noted that the shift from in-person to online rehearsals was indeed challenging. However, both musicians and conductors supported one another during this process by being open, welcoming, understanding, and by sharing resources.

For example, proper technological set-up (both for equipment and Zoom settings) were required from musicians and conductors. Musician B states: "I think the teachers gave a lot of online resources. And that was helpful. Like how to get online, how to record, and also links to exercises online done by other people. Those were very useful."

DISCUSSION

This study addressed three themes: (1) intergenerational relationships to support online group music-making; (2) digital literacy and access in later life; and (3) online music-making in a COVID-19 context. The first theme showed that being part of an intergenerational ensemble composed of younger conductors and older adult musicians contributed positively to the learning experience online. The second theme demonstrated that the generational digital divide reported in research (Charness and Boot, 2009, p. 253; Poushter, 2016, p. 6–23) was not particularly apparent in the context of the Montréal New Horizons Band. In fact, all participants, be they young or old, conductors or musicians, were new to the online format of rehearsals, which contributed to attenuate the age-related differences that may have been observed in other studies. Regarding access in later-life, online rehearsing was beneficial for older musicians in terms of distance/commute, time, energy, and cost. However, for those who did not already have internet and electronic devices, the cost of acquiring all the necessary equipment to make music online could have been too high. Finally, the third theme revealed that musicians appreciated the opportunity to make music online and indicated that it was definitely better than having nothing, especially for its social aspects.

It is worth noting that throughout these themes, several challenges and opportunities were noted by the musicians and conductors.

Challenges

Overall fatigue was said to be a major challenge for all those involved in the online rehearsals. Musicians and conductors stated that sitting for long periods of time in front of a screen could be especially taxing—particularly since some participants had desk jobs, were already teaching online, or were taking university classes online. As a result, conductors felt they had to "dial up" (Conductor A) their personalities when teaching online, further adding to their overall fatigue due to a perceived need to "fill the void/space" (Conductors A and B) in a virtual environment. Conductors A and B, who were teaching the online bands, both related this to difficulty gauging levels of engagement and the lack of immediate feedback from participants, factors noted in other studies looking at music learning during COVID-19 (Salvador et al., 2021, p. 195; Schiavio et al., 2021, p. 174). Conductor B mentioned feeling the need to talk much more during online rehearsals, which took more energy. This was also paralleled by Conductor C who stated that though she perceived herself to have a more "excitable" personality, it was exhausting to maintain this in an online space. In a paper by Gibson (2021), the author mentions that even those considered to be great educators and mentors may struggle in the virtual environment, as they may feel that talking to a screen is less inspiring than to a room with people (p. 160). Likewise, Thorgersen and Mars (2021, p. 235–237) mention that online teaching can be especially time consuming. Moreover, fatigue often affected musicians' motivations to practice repertoire, with participants saying that they felt less driven to practice for online rehearsals than for in-person, perhaps due to having to play on mute during rehearsals. This finding is aligned with Akyürek (2020, p. 1804) who also noticed lower motivation to complete homework by undergraduate students in music education in the context of distance learning.

Additionally, online rehearsals require a certain level of equipment, such as a decent internet connection and a functioning computer—things that unfortunately may not be accessible to all people, whether educator or student (Gibson, 2021, p. 159–160; Rowan, 2021, p. 3; Thorgersen and Mars, 2021, p. 226). Oftentimes, the quality of an individual's technological equipment may serve to propel or hinder the virtual learning experience (Gibson, 2021, p. 161). For example, Schiavio et al. (2021) write that technological tools may play an important part in building "reciprocal presence" among teachers and students, which can help promote student learning and acquisition of skills

(p. 172), or create frustrating situations for learners and educators if technological quality is poor (p. 174). Furthermore, scheduling or the availability of home space could get in the way of rehearsals, as participants needed to be mindful of their work hours or their neighbors.

Lastly, the chance that technical issues would emerge was always present in the online format. Unsatisfactory internet connection or equipment simply not working were often sources of frustration for participants and were not always within their control to fix, a finding also reported by Rowan (2021) and Salvador et al. (2021, p. 201). Approaches that were used extensively during in-person rehearsals may not have always translated well into the online environment as well, such as ensemble tuning, isolating parts, or listening for balance.

Opportunities

Despite these challenges, online music-making also provided participants with several opportunities that perhaps had not been available to them during in-person rehearsals. As was mentioned above, personalized feedback was highly valued by musicians and was an aspect of online rehearsals that many felt was an advantage over in-person rehearsal structure. Though time consuming, both musicians and conductors noted the benefits of this approach, which seemed similar to what one may get from private music instruction.

Surprisingly, many participants had noted that they were able to get to know each other far better online than when they were in-person. Conductors were able to always see participants' names in the Zoom window, and musicians were not limited to just speaking to their section mates. For example, while clarinets and trombones were situated on opposite sides of the stage during in-person rehearsals, this was a non-issue for virtual rehearsals. This is similar to an observation made by Cheng and Lam (2021), who stated that though student-teacher interactions decreased during the pandemic, when they were able to chat, students appreciated seeing their teachers' faces and teachers observed more focus or excitement toward learning music (p. 219). Additionally, the virtual environment was a way for individuals to stay in contact with others *and* continue making music, stating that it was beneficial to their lives during the pandemic.

Similar to the way that physical proximity within the group could inhibit social contact within place-based rehearsal but ceased to be a barrier within the online environment, geographic location, weather, and instrument weight were no longer issues. Musicians could freely attend rehearsal regardless of extreme weather or public transit malfunction—both of which Montréal is well-known. Prior to the pandemic, in-person rehearsals were held at a building located near the top of a steep hill. For those playing larger instruments like tuba or tenor sax, the transport of their instruments or walking up a potentially icy hill during wintertime was no longer a barrier for participation. These convenient factors were also noted by Salvador et al. (2021), who stated that no commuting, being comfortable at home, and not carrying heavy equipment were appreciated by young and adult students, as well as parents of students (p. 199). Additionally, some participants had expressed interest in picking up new instruments for the intermediate band while remaining on their main instrument for the advanced band. Virtual rehearsals made it easier for them to switch between instruments without having to worry about transporting two instruments or having their cases being cumbersome for fellow bandmates to sit next to. It also made it easier to see the conductor when playing. Interestingly, the online environment played a role in mitigating some "structural barriers" associated with active music-making that have been identified by Creech and colleagues (2014, p. 138), such as location and transport issues. They also identified finance as a structural issue, which, in this case, was taken into account by offering the virtual band at half the price of the regular in-person activities.

Lastly, some musicians had mentioned they were more able to move at their own pace. Rehearsals and sectionals were recorded and made available to ensemble members, providing them a way to catch up if they were absent during a rehearsal, or to simply go back and watch segments whenever they wished. This showcases the potential for online music-making in helping to support an individual's own practice (Gibson, 2021, p. 153).

Virtual Rehearsals: Some Ambiguities

There were some aspects of virtual rehearsals, however, that did not entirely fit under a challenge or opportunity, and instead provided both. Perhaps the most obvious change between online and in-person rehearsals was the ability to play synchronously while hearing one's peers and experiencing the sense of being part of an ensemble. While virtual rehearsing did not lend itself well to exploring issues such as group intonation or balance, many musicians felt more at ease when playing because no one but themselves could hear their mistakes. Additionally, though conductors admitted that it was challenging to learn to adopt a more flexible or adaptive teaching style, it was also a valuable learning experience. Conductors noted that they were able to think "on their feet" better (Conductor A and C) and were more open to creative solutions and approaches in teaching. Lastly, while asking musicians to take more ownership over their learning could be a challenge, it was also an opportunity for them to practice critical self-reflection on what they did well and what they needed to improve. Some musicians become noticeably more comfortable over time pausing rehearsals to ask questions or clarify things with which they were uncertain.

Despite the ease with which we dichotomize in-person and online learning, the ambiguities listed above may help to emphasize that each approach has pros and cons that should be considered when building music learning environments, particularly in a post-pandemic world (Camlin and Lisboa, 2021, p. 137).

Pedagogical Implications

From these findings, we propose the following pedagogical implications for future online music environments.

Support Network

Many interviewees noted that they were able to get to know other members better online than even in-person. Here, the

online music environment provided a support network for those involved, no matter their age. Musicians were not only able to learn more about their bandmates, but they were able to get to know the conductors better as well—reducing the "space," both physical and psychological, between musician and conductor, and allowing meaningful intergenerational relations. This support has been echoed in other papers examining musical activities through the pandemic. In an editorial by Camlin and Lisboa (2021), the authors note a common theme among their received papers, stating that though there existed several disruptions, many people turned toward each other for "practical, psychological, familiar, peer, and/or collegiate support" (p. 135). Additionally, online music helped members stay in contact with each other despite the pandemic's social distancing rules. Members were able to have a weekly event where they could share interests, chat, and check in on each other. This contributed to the overall "welcoming" feeling of the online music ensemble, with one musician stating that perhaps being welcomed was something everyone needed during the pandemic. Schiavio et al. (2021) note that the shift to online may have helped people realize how important having a community was to them particularly when experiencing challenges, providing a source of encouragement and advice (p. 173). This also aligns with Thornton's (2020) reflection about how, in response to the pandemic, a stronger sense of community was developed among music teachers and artists.

While providing a welcoming space was also emphasized during the Montreal New Horizons Band's in-person rehearsals before the pandemic (through common coffee breaks, for instance), most people tended to speak with musicians they already knew and to defer to the conductors to make most decisions, which created, although involuntarily, some form of hierarchy. Because the online environment took away that physical space factor that can so often reinforce power relationships, it placed people on a level playing field as all, musicians and conductors alike, were new to virtual music-making. There is thus a strong case to be made for in-person ensembles to consider encouraging a support network by incorporating some kinds of online elements (for instance, online meet-and-greets or get-togethers, virtual jams) to reproduce this sense of community with equal status.

Meet People Where They Are

Providing a welcoming environment, aligned with the "meet people where they are" mentality the conductors adopted, meant that they made no assumptions about anyone's ability with technology. For example, though the young conductors may have been more accustomed to using technology in their daily lives, they did not assume that their older amateur musicians had the same level of comfort they did. In an effort to improve technological fluency and to help band members to feel at ease, a set-up checklist with instructions on how to position one's computer, music stand, and instructions for Zoom settings was provided to all musicians. This is in line with a conclusion from Vaportzis et al. (2017, p. 1), who state that providing help in the earlier learning process in order to facilitate the adoption of technology for independent living was just as important as understanding older adults' perceptions on using technology.

Conductors underlined that it was fine to make mistakes—especially as not everything in an online environment could be controlled. Often, even conductors experienced internet problems, bugs, or technological mistakes that the whole ensemble could laugh about together, while also teaching them to be flexible in an online teaching environment. In his experience with the New Horizons Band Guelph, Rowan also commented on the fact that "each trial presented a different challenge" and that his capacity to "adapt to technical troubleshooting" became his "most important skill as a facilitator" (2021, p. 2). Conductors and teachers should consider providing a safe space to interact with technology, as it has been suggested to encourage technology adoption among older adults (Heinz, 2013, p. 69–70). Importantly, it has been mentioned that while learners need support and resources in order to benefit from the online environment, that educators must also feel well-supported in their endeavors to ensure that the teaching experience they give is not adversely compromised (Camlin and Lisboa, 2021, p. 137). This highlights the importance of reciprocal support between both educator and learner (Gibson, 2021, p. 154), particularly as how, when the pandemic began, many music educators felt they were not ready to make the "shift," which in turn affected their wellbeing (Cheng and Lam, 2021, p. 211). As mentioned above, organizing online events could be a solution to facilitate access and increase digital literacy while providing some form of social support.

Learning to Adapt

Teaching online was often found to be more exhausting for the conductors compared to in-person teaching, perhaps due to more of a "lecture-style" approach. Because of this, conductors heavily encouraged musicians to be more proactive in what and how they wanted to learn, reflect honestly on what they did well or needed to work on, and ask questions during the rehearsal or via email. In some cases, raising one's hand in an in-person classroom setting may have been easier than unmuting on Zoom, but interestingly, Musician A noted that they felt themselves grow braver in asking questions because of their online experience.

Musicians unanimously stated that the idea of personalized feedback was an advantage to online music, especially as it was difficult to play synchronously and therefore not always possible for the conductor to gauge problematic areas in pieces. It is important to note that musicians perceived this as an advantage over in-person rehearsals, as they would not have necessarily received this level of personalization unless they were taking private lessons on the side. This approach not only helped the musicians but also the conductors in noticing common mistakes among the recordings, signaling to them that this was an area to work on during full band rehearsals. However, it is worth noting that this approach may not be sustainable in the long-term as it was time-consuming for teachers and may not have been, in fact, what group music-making really aims to achieve. This perhaps is a real indicator of the limitations of the online environment—i.e., that the context may have propelled conductors toward using

personalized feedback and encouraged participants to seek it, but in truth, it was not a traditional form of group music-making. Even if conductors could be properly resourced to do this, personalized feedback does not replace the situated peer learning and support that can be achieved in an in-person environment.

Additionally, during in-person rehearsals, the conductor was often in charge of lesson planning based on past rehearsals. However, the online music environment pushed conductors to be flexible in their teaching approach, using pre-planned content, adapting to the needs of the learners, improvising, trying new methods, or any combination of these. Being responsive to students' needs is a characteristic that has been identified by Thornton (2020) as a consequence of the pandemic. Moreover, while in-person rehearsals had the conductor for the most part choosing what to work on, online music teaching became more of a team effort between teachers and musicians. For instance, the idea of trying to play chorale-like pieces unmuted was something both musicians and teachers decided to explore together. This democratic approach should be worth replicating, even with in-person teaching, as it contributes to musicians' ownership of learning, a key component of musical engagement (Creech et al., 2014). In addition, a willingness among music teachers to creatively adapt and be flexible may also reflect an openness to transition from being instructors to becoming facilitators of their students' learning, which could promote the latter's autonomy, even beyond the pandemic crisis (Camlin and Lisboa, 2021, p. 137).

Collaborative Teaching

For this online ensemble, teaching became less of a solo endeavor and more of a team effort in order to find new and effective ways of delivering quality musical experiences to the ensemble. Even during full band rehearsals, where one conductor took the lead, the other often stayed on in the background to provide technological support, answering the Zoom chat, helping the main conductor answer questions, etc. Conductors often met in their free time to discuss their approaches—what they felt worked, didn't work, solutions, and other areas of note.

As a humorous example, Conductors A and B recalled an instance where Conductor B's (the main conductor for this particular session) internet was not stable enough for video, and therefore she couldn't conduct. Both conductors ended up working together so that Conductor B would play audio and give instructions to the ensemble, while Conductor A directed on video. Though both conductors were initially convinced this approach would fail, it ended up being surprisingly successful. The evidence seems to suggest that team teaching should be strongly encouraged in the context of online music-making, to reduce the cognitive load of the conductors as one can focus on the music and the other on technological issues.

Limitations

Some limitations must be acknowledged. The aim of our study was to document a situation where music practices were transformed to adapt to the constraint of the pandemic and to report it through first hand experience of participants. In that sense, this study does not have results that are generalizable. While our sample was made of culturally diverse individuals, they all came from higher socio-economic backgrounds, meaning that they had the financial means to access technology. As such, we missed the voices of those with lower incomes, who could have provided a different perspective about equitable access. All participants who agreed to be interviewed for this study were already familiar with technology, which may not be representative of all musicians within the Montreal New Horizons Band. Furthermore, they already knew how to play their instrument. During the months that this project took place, no novices were offered the opportunity to start learning an instrument online with the band, because it was deemed too complex to provide an introduction to music on multiple instruments to a group of beginners online. Therefore, novice musicians were outside our study parameters.

Another limitation of the current study is that participants only included those who stayed active within the ensemble during the pandemic (i.e., less than 30 musicians out of 86). This means that those who did not participate or those who did not participate throughout the three semesters (fall 2020, winter and spring 2021) may have viewed certain challenges and opportunities differently than those who stayed consistently active throughout the pandemic. For example, musicians in the Allegro band, who were more comfortable on their instruments, seemed to have been more likely to continue participating in online activities for two or three semesters, whereas fewer musicians in the Adagio band continued their participation in two or three consecutive semesters. This could perhaps be due to advanced band members being more comfortable on their instruments, while intermediate band members may have had to deal with more musical challenges in addition to the technological ones. This could also be due to the fact that they may not have been part of the MNHB for as long as the more advanced musicians, which means that their sense of belonging may have been weaker. Another hypothesis is that the more advanced musicians had experienced the benefits of in-person music-making for longer, so they may have been more motivated to persevere until the situation could come back to normal.

In terms of study design, we chose to complete interviews after 9 months of participation rather than do pre/post interviews, which would have allowed us to explore how perceptions evolved over time. This choice originated from the fact that one of the authors was also one the conductors of the virtual bands. At the time, she was not aware that the study would take place, so she focused fully on her conductor role before joining the research team to analyze results.

CONCLUSION

> "*Among all the conversations about logistics, there has been a constant call for empathy, patience, and thoughtfulness for student needs. Educators were leading voices in reminding society that we have to think about everyone as in need of care.*" (Thornton, 2020, p. 4)

The aim of this paper was to examine the effects of online group music-making on community band conductors and older

amateur musicians who had to stop in-person rehearsals because of COVID-19. Intergenerational relationships were explored, as well as participants' perceptions about digital literacy, access in later life, and online music-making in a COVID-19 context. Risks and opportunities were discussed, and results showed that despite the multiple technological and musical challenges reported, participating in online musical activities also offered new opportunities, like a greater flexibility in the learning experience and a renewed sense of community among band members.

The pandemic has been an incredibly trying situation, with many of us struggling with feelings of increased isolation and anxiety. Group music making—which many use as a source of wellbeing and comfort—faced challenges from the shift of traditionally in-person rehearsals to virtual rehearsals. COVID-19 also had an impact on quality of life, and older adults had to find creative avenues to sustain wellbeing during this period. For musicians, it meant having to engage with technology to pursue their artistic goals and to continue benefiting from the social aspect of collaborative music-making. In the end, participants were grateful to have had the opportunity to keep music in their lives while everything else had stopped.

Ultimately, this situation has allowed teachers and students to explore and identify strategies that, not only were effective in the pandemic context, but will also be transferable to the post-pandemic musical context. While the use of online tools or technology for music participation and education was in use pre-pandemic, the actions of musicians, students, and educators have showcased their creativity and resilience in learning to adapt and innovate to these emerging challenges and opportunities.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because some information contains identifiable data. Requests to access the datasets should be directed to A-KB, barbeau.audrey_kristel@uqam.ca.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Comité Institutionnel d'Éthique de la Recherche avec des Êtres Humains de l'Université du Québec à Montréal. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

A-KB designed the research project, collected the data, and wrote the article. MG contributed to the data analysis, the redaction of the article, and the formatting of the manuscript. AC contributed to the review of the literature, acted as an adviser for qualitative analyses, and contributed to the review of the article. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Effect of Hearing Protection Use on Pianists' Performance and Experience: Comparing Foam and Musician Earplugs

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Professional musicians are often exposed to high noise levels and thus face the risk of noise-induced hearing loss. Yet, adoption rates for hearing protection among musicians are low. Previous surveys indicate that the chief concern is the effect of hearing protection use on performance. However, few studies have investigated actual changes in performance when wearing hearing protection. We report an experiment investigating differences in pianists' performance and experience with and without hearing protection. We compare the effect of foam earplugs and musician earplugs, designed to preserve sound quality with a flat frequency response. The analysis revealed that participants performed overall more loudly with the foam earplugs than with the musician earplugs, and in turn performances with the musician earplugs were louder than the open condition, indicating a compensatory effect. However, this effect was stronger for novel excerpts than for familiar excerpts. No effect was observed on dynamic range. Furthermore, we observed an acclimatization effect, whereby the effect of hearing protection use, observed on the first performance, decreased on the second performance. In terms of experience, participants reported changes in coloration, difficulties gauging dynamics and articulation, and increased effort required when performing with hearing protection. These effects were more pronounced when wearing the foam earplugs, and the participants reported finding the musician earplugs more comfortable to wear and play with. In conclusion, hearing protection use affects pianists' performance particularly in terms of dynamics and their experience more so in terms of coloration. But the effects are less marked for familiar pieces and after repetition, suggesting that pianists can quickly adjust their playing when playing familiar pieces with hearing protection.

Keywords: hearing protection, music performance, auditory health, musical practice, piano, MIDI, flange earplugs, musician wellbeing

INTRODUCTION

Professional musicians are often exposed to noise levels that exceed occupational exposure limits and thus face the risk of noise-induced hearing loss (Thom et al., 2005). While there is some disagreement in the literature as to whether the incidence of noise-induced hearing loss is in fact higher among musicians than among the general population, there is no debate that the risk of hearing loss can be reduced by use of hearing protection. While standard foam earplugs tend to distort the spectral content reaching the wearer, a variety of specialized musician earplugs have been designed with the aim of providing a flatter frequency response to preserve sound quality — an obvious concern for the professional musician. Despite advances in hearing protection technology, however, various studies have found use of hearing protection devices among professional musicians to be low and inconsistent.

LITERATURE REVIEW

Musicians' Use of Hearing Protection

Laitinen (2005) found that only 6% of participants from orchestras in Finland reported consistent use of hearing protection devices, and 35% reported seldom use. A similar study of Danish orchestra musicians (Laitinen and Poulsen, 2008) found consistent use in 15% of participants while 49% used earplugs in both ears only occasionally. A survey of German orchestra musicians (Zander et al., 2008) found occasional use among 38% of participants and of them, 6–15% use custom-molded earplugs. Jansen et al. (2009) found that 36–85% of participants from professional orchestras use some form of hearing protection and of those who do, most report using disposable protectors. A study from Australia (O'Brien et al., 2014) found higher rates of use (64%) than those found in European studies and the authors attribute this finding to what they consider to be a more robust hearing conservation program in Australia. While this does seem to suggest that education programs can play a role in increasing use of hearing protection, it should be noted that O'Brien et al. (2014) compared results to European studies from five to 10 years prior, and that rate of use could now be higher in Europe as well. While these studies indicate a range in rates of use, the results nevertheless confirm low rates of hearing protection use among professional musicians.

Factors Influencing Use- Perceived Changes in Performance With Hearing Protection

In addition to rate, the questionnaire studies cited above also investigate musicians' perspectives with regard to the advantages and challenges of hearing protection use. The main barrier to adoption is the potential effect of wearing hearing protection on musical performance. Among instrumentalists, the chief complaint was the inability to assess the sound of their own instrument, followed by difficulties hearing others, leading to problems of balance and intonation in ensemble settings (Laitinen, 2005; Laitinen and Poulsen, 2008; Zander et al., 2008; Jansen et al., 2009; O'Brien et al., 2014; Beach and O'Brien, 2017). In one study of choral singers—who are also exposed to high noise levels—singers report greater difficulty hearing others than hearing themselves when using hearing protection (Cook-Cunningham, 2019).

More specifically, musicians report distortions of timbre and dynamics (Huttunen et al., 2011). These concerns create hesitancy among musicians, who feel that wearing protection could put them at a disadvantage in a highly competitive professional environment. Some users of hearing protection report removing hearing protection for particularly complex passages (Laitinen and Poulsen, 2008) or using hearing protection in one ear only (Laitinen and Poulsen, 2008). The degree of difficulty in playing with hearing protection varies across instruments, where brass (and specifically trumpet) players report the greatest difficulty (see Mead (2012) for an in-depth discussion of trumpet players' use of hearing protection). Likewise, the rate of use of hearing protection in orchestras is lowest among brass players (Zander et al., 2008).

Other Factors Influencing Hearing Protection Use

While these studies indicate that the chief barrier is concern over the effect of hearing protection on performance, the fact remains that some musicians do choose to wear hearing protection—and consistently so. What factors compel certain musicians to wear hearing protection despite concerns over performance?

One common finding among these studies is higher rate of hearing protection use among musicians with existing hearing complaints (Laitinen, 2005; Laitinen and Poulsen, 2008; Zander et al., 2008). While it is possible that not all of these hearing complaints are noise-induced, this suggests a lack of preventive use and that musicians are more likely to use hearing protection after a certain degree of damage has already been done. While disheartening on the one hand, this also suggests that musicians are receptive to wearing hearing protection after they have experienced some damage, which can aid in stabilizing their condition and preventing further hearing loss.

Different rates of use are consistently noted among players of different instruments (Laitinen and Poulsen, 2008; Zander et al., 2008; Chesky et al., 2009; Jansen et al., 2009; O'Brien et al., 2014; Beach and O'Brien, 2017). This in large part seems to be related to the fact that some instruments are more difficult to play than others when wearing hearing protection (see discussion above). Additionally, however, Zander et al. (2008) found a positive correlation between use of hearing protection and perception of loudness of one's own instrument as well as loudness of neighboring instruments (Zander et al., 2008). Highlighting the subjective nature of loudness, Rawool and Buñag (2019) suggest that perception of loudness among musicians—and thus willingness to use hearing protection—may be influenced by cultural background (comparing here Caucasian and Filipino musicians, but playing different instruments). In a series of in-depth interviews with

various musicians, Beach and O'Brien (2017) found that student participants expressed more advantages related to the use of earplugs compared to professional and amateur musicians. These findings indicate a possible interaction between individual factors and instrument type in the decision to use hearing protection and warrant further exploration.

Measured Effects of Changes in Performance With Hearing Protection

While qualitative studies are an important aspect in incorporating musician perspectives into education initiatives and development of technology, another complementary approach is to investigate measurable changes in performance with and without earplugs through acoustic analysis. This approach has been taken in an industry setting when studying the effect of earplugs on speech production but few studies have done so with musician performance.

In the context of speech production, two main effects have been documented: the Lombard effect and the occlusion effect. The Lombard effect is a well-documented phenomenon whereby speakers increase their level of speech relative to increased environmental noise. The occlusion effect is another phenomenon whereby self-generated sounds (speech, chewing, swallowing) are perceived to be of increased loudness when the ears are covered. The ability to adjust speech levels to noise has been shown to be affected by use of hearing protectors whereby the level of speech produced in noise while wearing hearing protectors is lower compared to speech in noise without hearing protection (Howell and Martin, 1975; Tufts and Frank, 2003; Bouserhal et al., 2016). However, this decrease is not observed in speakers wearing hearing protection in quiet conditions (Tufts and Frank, 2003) and Howell and Martin (1975) actually found an increase in level in quiet conditions while wearing hearing protection.

Turning to the effect of hearing protection use on musician performance, a finding analogous to the Lombard effect was reported in choral singers (Cook-Cunningham, 2019) with a 1.30–5.29 dB decrease when singing in a choir with earplugs versus without earplugs. In the same study, recordings of soloist singers were not significantly affected by use of earplugs (< 1 dB change).

With instrumentalists, spectral analyses of musicians' performances with and without earplugs with various instruments were conducted in solo and ensemble settings (Kozłowski et al., 2011). Specific differences in 1/3-octave bands were observed for different groups of instruments. The greatest change was observed for the trumpeter with a 5–15 dB drop in the high frequency range. By contrast, the spectrum of the clarinetist's and violinist's performances were not significantly affected by use of earplugs and the vocalist's performance changed less than 5 dB. The effect of instrument type as seen in acoustic analysis reaffirms the self-reported findings in the qualitative studies cited above wherein brass players report the most difficulty playing with hearing protection. This effect of instrument type could be explained by the occlusion effect, whereby instrumentalists who produce self-generated sounds, such as singers or brass players, might be susceptible to an increase in loudness perception of their own sounds while wearing earplugs. Consequently, they are likely to sing or play more softly to compensate for the perceived increased loudness. Conversely, instrumentalists whose means of sound production rests outside of the body, such as pianists or string players, should be immune to this effect and might actually play more loudly to compensate for the level attenuation of the sound they produce as it reaches their ear while wearing earplugs.

A third study (Rawool and Buñag, 2019) compared solo performances of musicians playing a wide variety of instruments with and without earplugs in terms of average sound level and dynamic range. The authors cite musicians' complaint that earplugs hinder their ability to differentiate loud and quiet sounds as a reason to investigate changes in dynamic range. In solo performances, the majority of participants did not significantly alter overall level with earplugs; however, 8–31% of participants played more loudly while wearing earplugs. Differences in dynamic range with and without earplugs were observed in some players, although the degree of change was affected by trial number indicating the possibility of acclimatization. While previous studies support the need for caution when making generalizations across instrument type (e.g., Kozłowski et al., 2011), this finding warrants the investigation of possible acclimatization to hearing protection.

A fourth recent study (MacLeod et al., 2021) investigated the effect of foam earplugs and musician earplugs on pitch perception, using a pitch matching task with music students. Small but significant differences were observed for specific intervals only. Participants' pitch matching was most accurate in the absence of hearing protection, followed by the musician earplugs condition, and they were least accurate when wearing foam earplugs. The results suggest that musician earplugs may provide valuable protection while minimally affecting pitch perception.

While few in number, the above studies lay the foundation for further research into the measurable changes in musical performance with and without hearing protection. This is not to say that quantitative measures are somehow more valid than subjective experience of performance. For example, if acoustic analysis reveals no difference but musicians report greater effort required to perform with hearing protection, this increased effort could present a barrier to consistent use. Thus, both qualitative and quantitative aspects are needed to better understand the effect of hearing protection on performance.

Research Questions

With the aim of better understanding the effect of hearing protection use on musical performance, this study has four objectives. First, we investigate pianists' attitudes toward hearing protection, with a detailed questionnaire on auditory health practices and attitude toward hearing protection. Second, we explore changes in performance with and without hearing protection while controlling for instrument (piano) and performance context (solo). Specifically, we compare the loudness and dynamic range of solo performances recorded by the same pianists under three conditions: without hearing

protection, while wearing musician earplugs and while wearing foam earplugs. Third, we investigate acclimatization to hearing protection by comparing first-time and second-time performances. Fourth, we investigate pianists' experience while performing with and without hearing protection with a short questionnaire administered after each trial.

MATERIALS AND METHODS

Recruitment

Seventeen pianists with more than 10 years of musical training were recruited through the mailing lists of the McGill University Schulich School of Music and the Centre for Interdisciplinary Music, Media and Technology. They received $15 CAD for their participation and took home both pairs of hearing protectors tested.

Procedure

Participants were first asked to fill out a questionnaire on their auditory health practices. Then, the participants were instructed to play three excerpts under three different hearing conditions: namely, an open condition without hearing protection, while wearing foam earplugs, and while wearing musician earplugs, for a total of 9 trials per participant . Participants performed on a Yamaha upright Disklavier Mark III, which recorded their performance as MIDI data. The order of the hearing conditions was counterbalanced across participants. The order of presentation for the 3 excerpts was fixed, starting with the most familiar, played from memory, to the least familiar, in a sight-reading task (see details below). After each trial, participants filled out a short post-trial questionnaire on their experience. The entire session lasted about an hour.

The excerpts were selected as follows:

- E_0: Participants were instructed to prepare a short excerpt of their choice, under 2 minutes, before the study. They played this first excerpt from memory. This was designed to provide the participants with maximum familiarity with this excerpt. Selections included pieces by Bach, Mozart, Haydn, Schumann, Schubert, Gershwin, Scriabin, Einaudi and Veloso.
- E_1: Participants were instructed to sight-read the first 24 bars from the Prelude No. 15, opus 38 by Frederic Chopin. This excerpt was chosen as a common excerpt of medium difficulty from the standard repertoire, and participants were expected to have heard or played it before. This was designed to provide the participants with an intermediate level of familiarity with this excerpt.
- E_2: The participants were instructed to sight-read the first 17 bars from the Nocturne No. 3 by Francis Poulenc. This excerpt, also of medium difficulty, was chosen because it is a lot less common. This was designed to provide the participants with a low level of familiarity with this excerpt.

Furthermore, a subset of 11 participants was asked to repeat each performance of the familiar E_0 excerpt under each of the three protection conditions. This was done to investigate a potential acclimatization whereby participants might be less affected by the hearing protection on their second try. The experimental design is represented in **Figure 1**.

Hearing Protection

We tested two types of earplugs, namely foam earplugs and musician earplugs. The foam earplugs were standard roll-down slow-recovery foam 3 M 1,100, widely available at a cost of around 1$ per pair, with an advertised Noise Reduction Rating (NRR) of 29 dB (when properly inserted). The musician earplugs used were flange Etymotic ER-20 earplugs, at a cost of $20 per pair, with an advertised attenuation of 20 dB but an official NRR of 12 dB. Frequency-specific attenuation, as provided by the manufacturers, as shown in **Table 1**. It should be noted that there might be substantial differences between the attenuation advertised and measured on individual users, particular in lower frequencies, because of leakage due to suboptimal placement. For foam earplugs specifically, previous studies measured NRRs around 25 dB (instead of 29) for unsupervised use and observed large inter-individual differences (Berger, 2013; Copelli et al., 2021). Given the stronger and non-uniform sound level attenuation of the foam earplugs, we hypothesized a stronger effect on performance with foam earplugs than with musician earplugs.

Questionnaires

A general auditory health questionnaire was administered when participants first arrived. The questionnaire consisted of 31 Likert scales and 3 open-ended questions. It was adapted to the musical setting from a previous survey with industry workers (Bockstael et al., 2013) and translated from Dutch. The questionnaire was structured into four sections related to (1) Attitudes towards hearing protection, (2) Auditory health issues, (3) Use of hearing protection, (4) Demographics and musical training. In addition, after completing each condition involving the use of hearing protection, participants filled out a post-trial questionnaire related to their experience performing. The questionnaire consisted of an open-ended question about the perceived sound quality followed by 12 Likert scales on their experience in terms of perceived benefits and disadvantages of hearing protectors, intention to use when practicing and preferences. The full questionnaires are available in the **Supplementary Material**.

RESULTS

Participants

Seventeen music students (4 women, 12 men and 1 other), all currently enrolled at the Schulich School of Music of McGill University, participated in the experiment. They were aged 18 to 37 (mean age 24). Twelve studied piano performance (mostly at the graduate level), either classical or jazz, while the remaining 5 played piano as their secondary instrument. They reported an average of 17 years of musical training and 3.4 hours of daily practice. All participants had prepared a short excerpt to play from memory (E_0), all reported being somewhat familiar with E_1 and all reported never having played E_2 before.

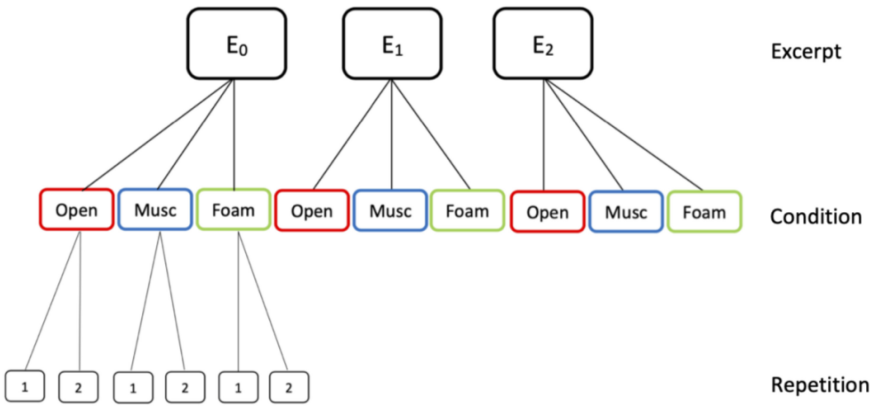


FIGURE 1 | Experimental design. E0 was a highly familiar excerpt played from memory, while E1 (of medium familiarity) and E2 (of low familiarity) were sight-read. All excerpts are performed by all 17 participants in three hearing conditions, namely Open without earplugs, Music while wearing musician earplugs, Foam while wearing foam earplugs. Eleven participants further repeated E0 in all three hearing conditions to investigate acclimatization effects.

TABLE 1 | Frequency-specific attenuation and Noise Reduction Rating of the foam and musician earplugs as advertised by the manufacturers.

Frequency (Hz)		125	1,000	4,000	8,000	NRR
Attenuation (dB)	Musician earplug	19.2	21.2	20.7	23.6	12
	Foam earplug	20.3	26.5	32.3	41.1	29

Auditory Health Questionnaire

All participants reported some concern over their auditory health, and 12 participants (out of 17) reported taking measures to protect their auditory health, such as moving away from loud sounds, avoiding loud live music, and limiting headphone volume. Seven participants reported auditory health issues, specifically tinnitus (N = 4), hypersensitivity to loud sounds (N = 3), pain related to noise exposure (N = 1), and some form of hearing loss (N = 1). Yet only 9 (out of 17) participants reported using hearing protection, but only very occasionally and mostly when studying (N = 6), attending events or parties with amplified music (N = 6), being exposed to loud noises (e.g., construction) (N = 6), or sleeping (N = 1). Four participants reported using hearing protection in the context of group rehearsals while one other participant reported using it for individual practices but not for group practices. While most participants (14 out of 17) reported that both their own instrument and others' instruments were loud, they also reported that most musicians did not wear hearing protection, and that playing music with hearing protection was less fun. Furthermore, 13 found hearing protection uncomfortable, and five participants reported being worried that wearing hearing protection would make them look unprofessional.

Performance Data Analysis

From each participant's MIDI data, we extracted individual note velocity, used as a measure of loudness in previous studies (Lazarov et al., 2019 *inter alios*), for each of the three excerpts in each of three conditions. We represented velocity over time over the entire duration of each excerpt for each trial. An example of this representation is shown in **Figure 2**. The following analyses rely on the mean velocity per excerpt and condition, collapsing over all participants.

Effect of Hearing Protection on Loudness

To investigate the effect of hearing protection, we only considered the first performance of each excerpt in each condition (N = 68,008 notes), excluding repeated excerpts. A two-way repeated measures ANOVA was performed to evaluate the effect of the hearing protection condition on loudness over three different excerpts. There were significant effects of condition [$F(2,32) = 130.83$, $p < 0.001$] and excerpt [$F(2,32) = 39.33$, $p < 0.001$] as well as a statistically significant interaction between condition and excerpt on velocity [$F(4,64) = 49.98$, $p < 0.05$]. Therefore, the effect of the hearing protection condition was analyzed separately for each of the three excerpts using one-way repeated ANOVAs for each excerpt with condition as a factor. The effect of condition was significant for all three excerpts [$F(2,32) = 27.91$, $p < 0.001$ for E_0, $F(2,32) = 36.96$, $p < 0.001$ for E_1, and $F(2,32) = 95.43$, $p < 0.001$ for E_2. Post-hoc tests (Tukey HSD with adjusted p-values) revealed significant differences between all pairwise combinations of the three conditions, for each of the three excerpts ($p < 0.001$).

The results shown in **Figure 3** indicate that participants performed more loudly while wearing earplugs; that is, they compensated for the sound attenuation of the hearing protection by playing more loudly. As hypothesized, the differences were more marked with the foam earplugs than with the musician earplugs. Specifically, participants played at the softest level in the open condition, followed by the musician earplugs condition, and at the loudest level in the foam earplugs condition. These differences across conditions were significant for all three excerpts, but were less marked for the familiar excerpt E_0 than for novel excerpts E_1 and E_2. The differences in mean MIDI velocities across conditions were 1.46 for E_0, 2.59 for E_1 and 4.13 for E_2 for

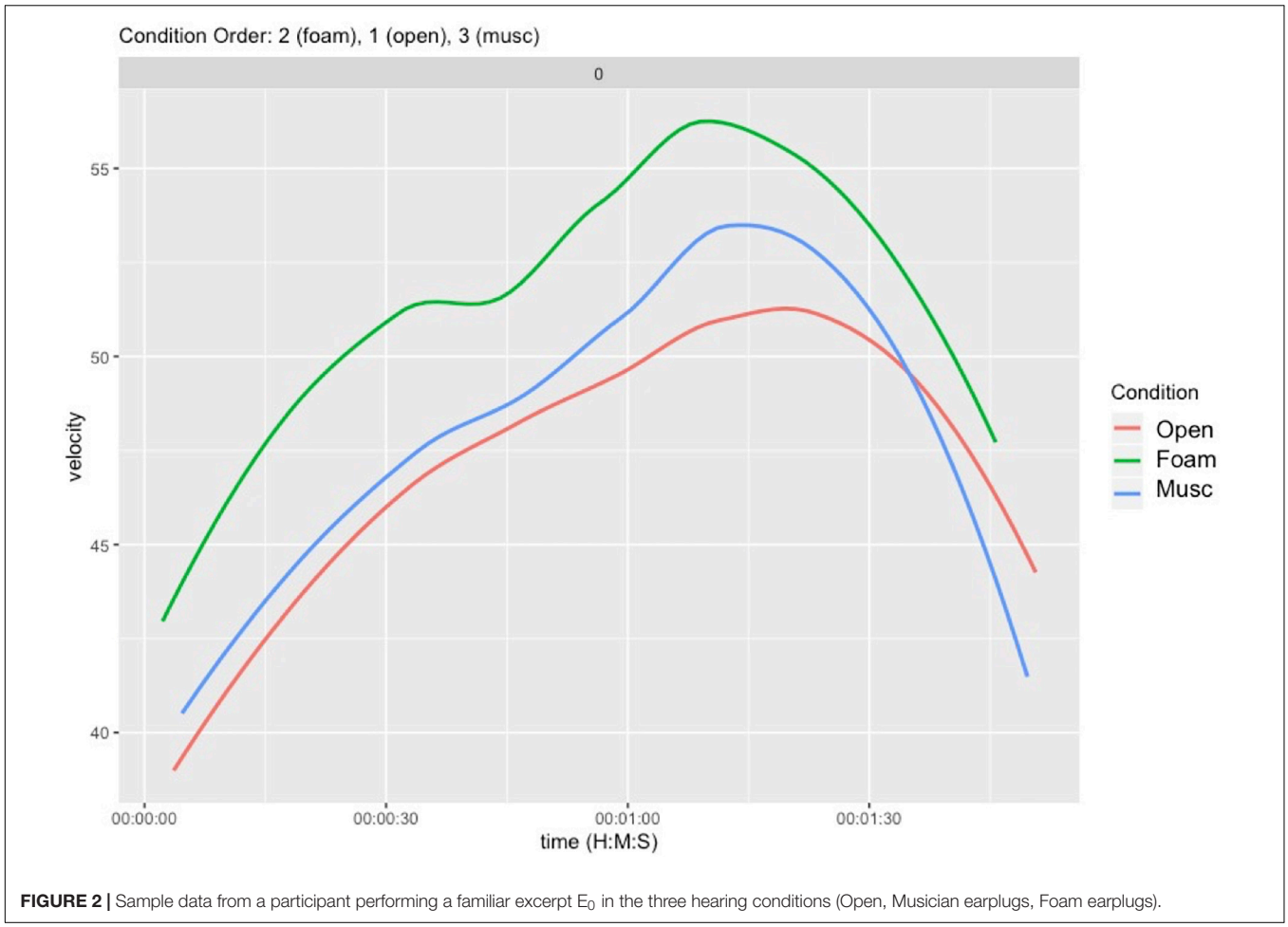


FIGURE 2 | Sample data from a participant performing a familiar excerpt E_0 in the three hearing conditions (Open, Musician earplugs, Foam earplugs).

MIDI velocities in the medium to low range (47 to 55). According to relationships between MIDI velocity (ranging from 20 to 100) and sound level (measured at 3 ft) established by Repp (1997)[1], these mean level difference across conditions can be estimated under 1 dB for E_0 (which would not be perceptible), and around 1 dB for E_1 (which would be just perceptible) and above 1 dB for E_2 (which should be perceptible).

Effect of Hearing Protection on Dynamic Range

To further investigate the effect of hearing protection on performance, we evaluated the effect on dynamic range, defined as the difference between the loudest and softest note for each trial. A two-way repeated measures ANOVA was performed to evaluate the effect of hearing protection condition on dynamic range over three different excerpts. A significant main effect of excerpt was observed [$F(2,32) = 15.58$, $p < 0.001$] but no other effects were observed. The results, shown in **Figure 4**, indicate that dynamic ranges do not vary significantly across hearing condition. A previous study by Rawool and Buñag (2019) operationalized 2 different measures of dynamic range, namely (max-min) and (max-mean). We therefore replicated the analysis for the second measure of dynamic range and obtained similar results; that is, no effect of hearing condition on either measure of dynamic range was observed.

Effect of Acclimatization

To investigate acclimatization, we only considered the familiar excerpt (E0) which was performed twice in each condition by 11 participants (N = 40,045 notes). A two-way repeated measure ANOVA revealed significant effects of condition [$F(2,32) = 110.56$, $p < 0.001$] and repetition [$F(2,32) = 1{,}109.78$, $p < 0.001$] as well as an interaction effect of condition × repetition on note velocity [$F(4,64) = 22.61$, $p < 0.001$].

Therefore, the effect of the hearing protection condition was analyzed separately using one-way repeated ANOVAs for each repetition with condition as a factor. The effect of condition was significant for both repetition conditions [$F(2,32) = 27.91$, $p < 0.001$ for first time, $F(2,32) = 21.4$, $p < 0.001$ for the second time]. Further analyzing differences for the first-time performance, post-hoc tests (Tukey HSD with adjusted p-values) revealed significant differences between Open and Foam

[1] Using a Yamaha Disklavier Mark II grand piano recorded at 3 feet from the curved rim of the frame.

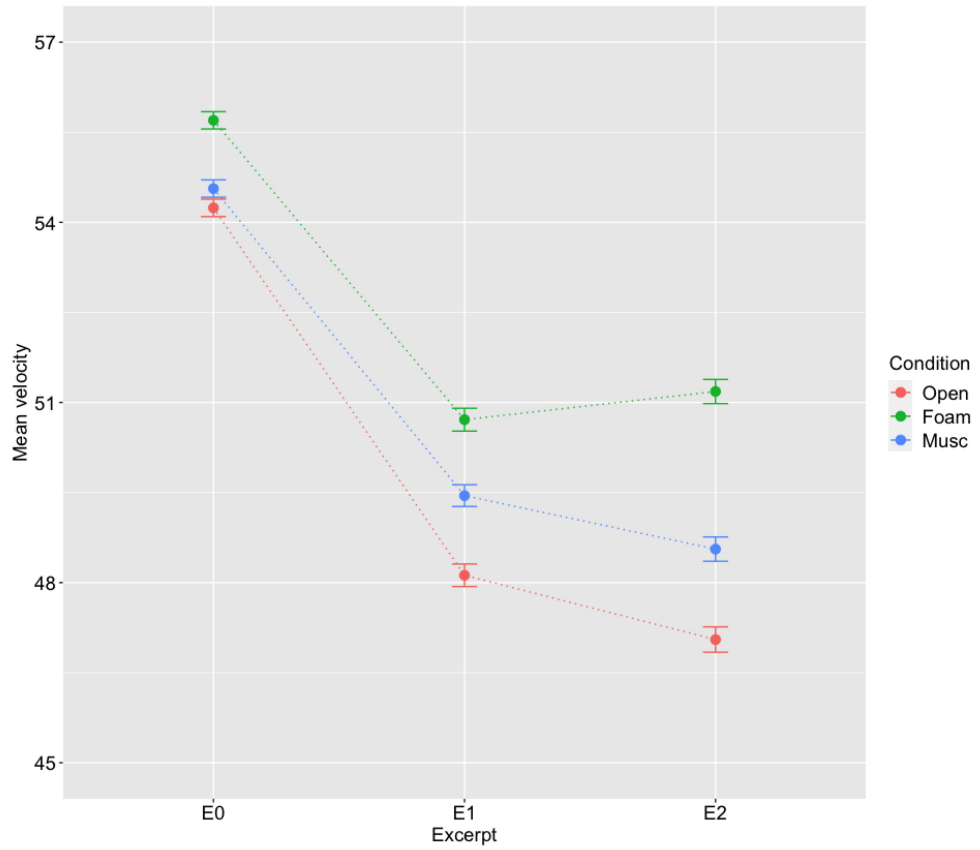


FIGURE 3 | Mean velocity and standard error by excerpt and hearing condition (all 17 participants). Significant differences across hearing conditions (Open, Musician earplugs, Foam earplugs) were observed for each of the three excerpts.

conditions as well as between Foam and Musician conditions (both $p < 0.001$) but no significant difference between Open and Musician conditions ($p = 0.25$). For the second performance, post-hoc tests revealed a significant difference between Foam and Musician conditions ($p = 0.004$) but no significant differences between Open and Musician ($p = 0.8$) or between Foam and Open conditions ($p = 0.06$). In other words, on the second performance, no significant differences were observed between the open condition and the two hearing protection conditions. Indeed, as shown in **Figure 5**, the differences across hearing conditions are less marked for the second time than for the first time. This indicates an acclimatization effect over only a few minutes. While velocities remain unchanged in the Foam condition, we observed an increase in velocity after repetition in the Open and Musician conditions, which could be attributed to increased confidence and familiarity with the instrument.

Effect of Hearing Protection on Experience

The effect on experience was investigated through the post-trial questionnaire analysis. The free-form answers to the sound quality question were grouped into four broad themes using an inductive content analysis. Specifically, the first and last author first segmented free-format responses into individual mentions and independently categorized them into themes emerging from the constant comparison method (Glaser and Strauss, 1967). They then discussed their categorization and harmonized the themes accordingly. The themes were related to Coloration (106 mentions), Comfort (41 mentions), dynamics (40 mentions), and articulation (24 mentions). Each mention was categorized as either positive or negative based on the connotation inferred from the free-form answers. The distribution of positive and negative mentions for each of the 4 themes is represented in **Figure 6**. The majority of mentions were related to coloration, with participants most often reporting a dull and muffled quality of sound when wearing earplugs, with more negative mentions for foam earplugs than for musician earplugs. Comfort description referred to how comfortable participants felt while playing with earplugs, as well as difficulties encountered, such as spatial disorientation and additional effort needed. In terms of dynamics, participants reported that their playing felt quiet. They further expressed difficulties gauging dynamics and trouble hearing certain ranges (both piano and forte). In terms of articulation, they reported the need to articulate more, issues with attacks, difficulties gauging the amount of pedal needed.

Overall, the difficulties and discomfort level were higher when wearing foam earplugs than musician earplugs, as

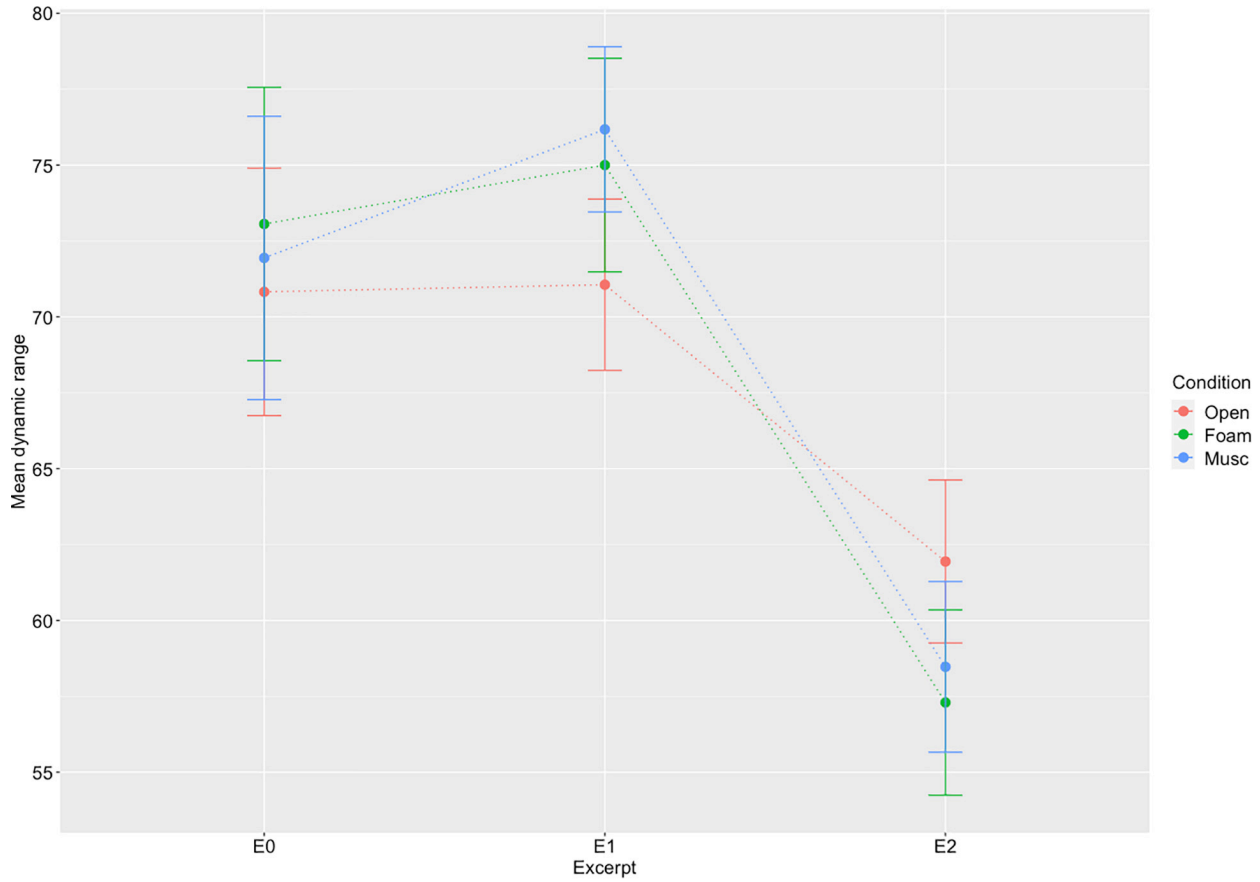


FIGURE 4 | Mean dynamic range (max-min velocity) and standard error by excerpt and hearing condition (Open, Musician earplugs, Foam earplugs) (all 17 participants). No effect of hearing condition was observed.

can be seen from the distribution of negative and positive mentions.

The analysis of the Likert scales was in line with the qualitative results. Indeed, the overall satisfaction level was significantly lower for foam earplugs (2.6 out of 5) than musician earplugs (3.4 out of 5) ($p < 0.0001$). Similarly, the sound was perceived as significantly boomier (2.6 out of 5) with foam earplugs than with musician earplugs (1.9 out of 5) ($p < 0.001$). In terms of overall experience, participants reported a strong preference for the open conditions (4.5. out of 5) and their intention to use or buy either type of hearing protection was low (2.1 out of 5).

DISCUSSION

Attitudes and Experience

While all participants expressed concerns over their auditory health, only half of them reported using hearing protection, and mostly did so outside of a musical context. Possible explanations for limited use of hearing protection include the reported discomfort and decreased enjoyment when practicing with hearing protection, as well as the perceived low adoption rates of hearing protection among colleagues.

In terms of actual experience while playing with earplugs, pianists reported changes in coloration (more muffled sound), difficulties gauging dynamics and articulation, and additional effort required. These disadvantages could be even more problematic in an ensemble context, particularly to hear subtle cues (e.g., breathing cues) and finer adjustments needed to achieve ensemble blend.

Although our participants generally disliked playing with earplugs, they were more comfortable with the musician earplugs than with the foam earplugs. Being aware that one type of protection was designed for musicians might have affected their perception. It is understandable that unacclimatized musicians would feel discomfort when first playing with earplugs, but it is encouraging that their experience was more positive when wearing musician earplugs. This provides support for the use of musician earplugs and encourages further technological initiatives aimed at preserving musicians' auditory health.

Compared with previous studies on hearing protection in industry workplaces (see Bockstael et al., 2013 for a review), our participants were more aware of the potential risks of noise exposure than industry workers. Yet, they did not seem to evaluate the risk as high in the context of musical practice, as most of them only used hearing protection outside of musical

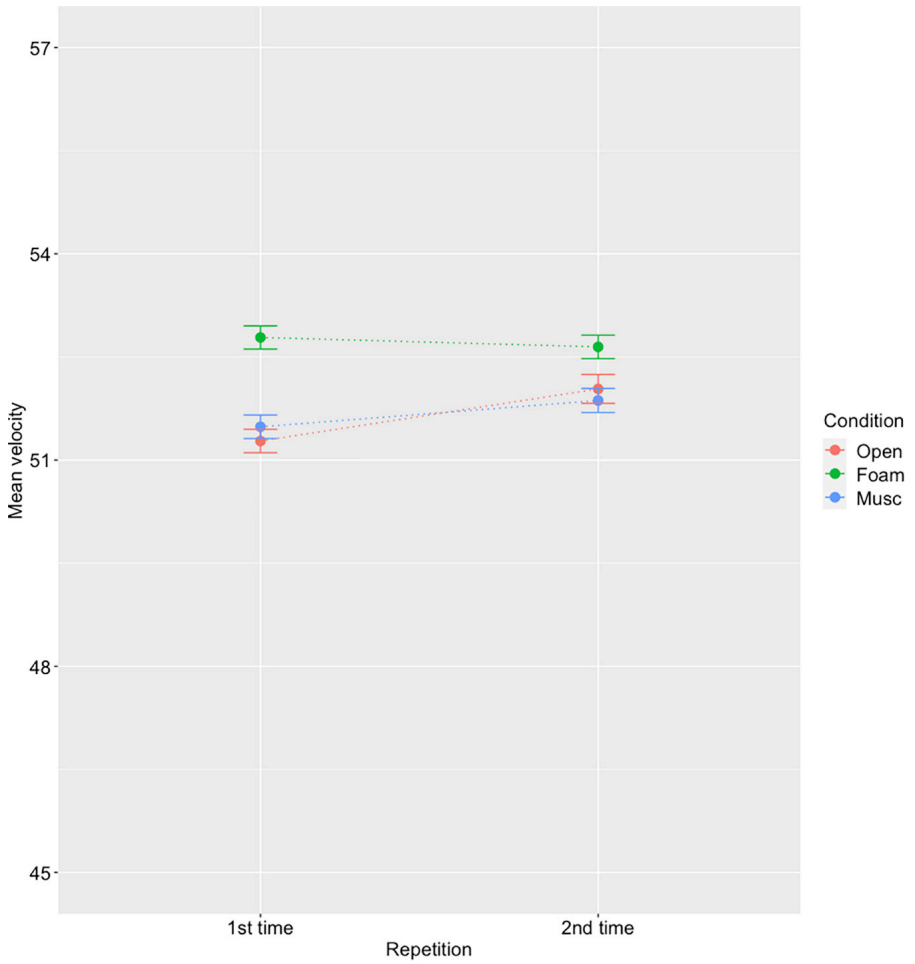


FIGURE 5 | Mean velocity and standard error by repetition and hearing condition for the familiar excerpt E_0 (for 11 participants). While there was a significant effect of condition on the 1^{st}- time performance, no significant differences were observed between the open and hearing protection conditions on the 2^{nd}- time performance, indicating an acclimatization effect.

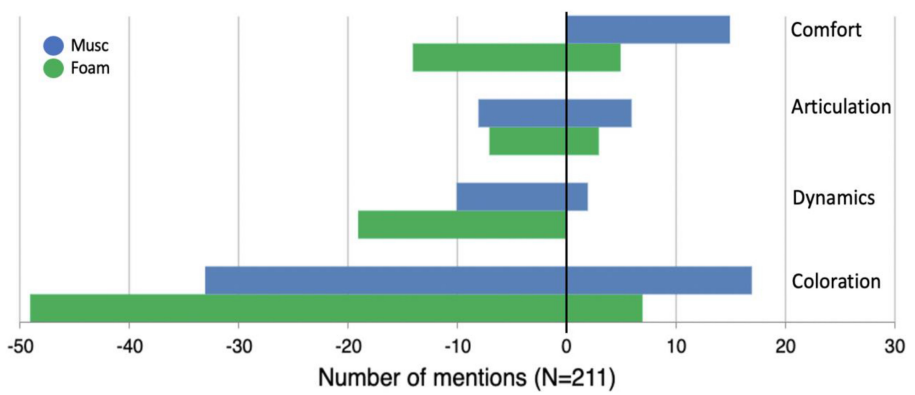


FIGURE 6 | Mentions of sound quality descriptors for the foam and musician earplugs conditions. Mentions with a negative connotation are displayed with negative values; mentions with a positive connotation with positive values. The number of mentions collected is the absolute value.

activities. It should be noted that our participants are pianists, and as such may be less exposed to harmful sound levels than orchestral musicians, given that they are more likely to play alone or in small ensembles. However, studies in industry caution about the underestimation of the risk of noise-induced hearing loss in environments where sound levels are comparatively lower but still potentially harmful. Furthermore, studies on occupational noise highlight the role of the working environment. Specifically, safety policies contribute to higher adoption rates (Bockstael et al., 2013). This suggests that institutional encouragement about hearing conservation for musicians, as part of a curriculum or in professional ensembles, might foster more widespread use of hearing protection .

Performance

Our experiment revealed that participants played more loudly when wearing hearing protection, and this effect was stronger when they wore foam earplugs than musician earplugs. This indicates a compensatory effect whereby participants increased the loudness of their playing to compensate for the level attenuation caused by the earplugs. This is further supported by the fact that participants played at the loudest level with the foam earplugs, which have greater attenuation. However, this is in contradiction with previous studies where musicians, usually singers or brass players, instead played more quietly when wearing hearing protection (Kozłowski et al., 2011). This discrepancy can be explained by the occlusion effect, namely that musicians who produce self-generated sounds perceive an increased level of their own sound when wearing earplugs. This perceived increase in sound level would in turn incite singers and brass players to compensate by playing less loudly. However, the pianists in our study perceived instead a decrease in sound level when wearing protection. This can be attributed to the external sound production on the piano (as opposed to an embodied sound production in speech, singing or brass instruments). The level of the external sound reaching the ear is attenuated by the earplugs, and there is no (or very little) bone-conduction transmission. Consequently, pianists compensate in the opposite direction, playing more loudly to make up for the diminished auditory feedback. These differences highlight the influence of instrument type on the effects of hearing protection on performance. Particularly, singers and wind instrumentalists who produce sounds with their mouths, lips and vocal cords may be more susceptible to being affected by hearing protection. Indeed, these musicians need to adjust not only for the external sound level attenuation caused by the earplugs but also for the occlusion effect, resulting in conflicting cues likely to affect their perception of timbre in addition to loudness. This could explain why previous studies found brass players most reluctant to wear hearing protection, even though they are usually exposed to the highest sound levels in orchestral settings (Zander et al., 2008). Pianists, string players, and other musicians who produce sound externally may indeed have an easier time adjusting to wearing hearing protection because the occlusion effect is less, if at all, prevalent.

As previous research (Rawool and Buñag, 2019) had observed an effect of hearing protection on the dynamic range of music performance, we also investigated this phenomenon but found no effect of hearing condition on dynamic range. This could be attributed to two main differences: (1) the instrument types (strings, winds and piano in Rawool and Bunag as opposed to pianists only in this study), (2) the analysis method (audio recording analysis in Rawool and Bunag versus MIDI velocity data in this study).

Our study further reveals the importance of another factor affecting hearing protection use, namely the degree of familiarity with the music performed and/or the task at hand. Indeed, in our experiment with pianists, the effects of wearing hearing protection were less marked when playing familiar excerpts from memory than when sight-reading novel excerpts. This finding suggests that the compensatory effect that caused the participants to play more loudly with hearing protection was moderated by familiarity with the piece they were playing. This could be attributed to the fact that pianists performing familiar pieces play more confidently, rely less on the auditory feedback and more on muscle memory than when sight-reading. But this also suggests that musicians working on familiar pieces, as in the context of practicing standard repertoire, could be somewhat protected from the negative effects of wearing hearing protection. Since some protection is better than none, this finding could encourage musicians to wear hearing protection in musical contexts where they feel more at ease, even if they remain reluctant to do so in higher stakes environments. Finally, the lesser effect of hearing condition for the familiar excerpt could also be related to the fact that it was played more loudly than less familiar excerpts, at a level at which hearing protection might be less efficient.

Our findings also suggest an acclimatization effect whereby the differences in loudness across hearing protection conditions which were observed during the first performance were no longer significant on the second performance. In other words, the compensatory effect disappeared on the first repetition, after only a few minutes of wearing hearing protection. This suggests that musicians could have the ability to quickly adapt to wearing earplugs, which could lead to a reduction of the negative effects of hearing protection after prolonged use. Furthermore, if musicians can easily adapt their playing when wearing hearing protection after a short training period (as they do when playing with a practice mute), they may be able to use earplugs in certain conditions (e.g., when practicing long hours in small reverberant practice rooms) and opt out for other situations (e.g., when performing in a large concert venue). Alternatively, in ensemble settings where they might be exposed to higher levels, they could practice (alone) with hearing protection ahead of time, in order to prepare for group performances where protection is most needed. Future research is needed to determine the extent to which musicians can learn to adjust to different hearing protection conditions.

Limitations and Future Directions

Our investigation was limited to a particular instrument (piano) and performance context (solo). Given that the effects of hearing protection in performance differ across instrument

types, the results may not generalize to other musical contexts. Furthermore, there are reasons to believe that different instrument types may be affected very differently by hearing protection use, particularly because of the occlusion effect which only applies to embodied sound generation. Conducting similar research with a wide range of instrument types, while accounting for the method of sound production, would allow us to reconcile conflicting research findings across studies with different instruments.

Additionally, performance in an ensemble context is likely to be more affected by hearing protection use. Indeed, the Lombard effect, which predicts that speakers raise their voice in louder environments, could apply to music performance in ensemble contexts. In other words, performers wearing earplugs would play softer because of the sound level attenuation of the surrounding environment. This might counterbalance or at least reduce the compensatory effect observed in this study, where solo musicians played more loudly when wearing earplugs.

Future research is also needed to investigate whether the beneficial effects of familiarity and acclimatization also apply in the context of ensemble playing. Musicians are at a greater risk of noise-induced hearing loss in ensemble contexts, yet they are also more reluctant to use hearing protection in such contexts. Testing these effects of familiarity and acclimatization in ensemble settings could encourage musicians to persevere through the initial challenges encountered when wearing hearing protection. This could contribute to raising the rate of use of hearing protection devices in orchestral contexts.

In their responses, our participants very clearly favored the musician earplugs over the foam ones. It would be important to examine whether musicians would react even more favorably to custom-made earplugs that fit the morphology of their ear with a pre-specified attenuation level. This could encourage hesitant musicians to invest in such devices. Additionally, the attenuation of the earplugs used in this study (in the 20–30 dB range) is perhaps too large for certain musical contexts, particularly for smaller ensembles and quieter instrument types. Certain musicians may get sufficient hearing protection with lower attenuation earplugs while suffering less from the negative effects that come with wearing earplugs. Having a range of attenuation options for musicians to choose from, along with research to inform that choice, could also go a long way to encourage more widespread use.

Another promising path towards the wide-spread adoption of hearing protection devices lies in a new trend of musicians considering earplugs as potential practicing tools. Indeed, a previous study reported on the use of earplugs as a "performance enhancer"; that is, a tool used by performers to distance themselves from their sound in order to mimic the sound environment of larger concert halls in their practice rooms (Beach and O'Brien, 2017). Such approaches could encourage hearing protection use in a variety of contexts and provide musicians with creative ways to experiment and get acclimatized to wearing hearing protection.

Overall, this study contributes to the small yet growing body of literature aiming to increase understanding of the factors influencing hearing protection use among musicians. While we observed a compensatory effect of wearing hearing protection on overall loudness, this effect disappeared after only one repetition, and was less pronounced with familiar excerpts and with musician earplugs. These results suggest that musicians can quickly learn to adjust their playing when wearing earplugs, even if their experience might be negatively affected. Our findings highlight the need for education campaigns about the effects of hearing protection so that musicians can balance the pros and cons to prevent noise-induced hearing loss without compromising the quality of their performance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by McGill Research Ethics Board II. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AB, CG, and SB conceived and planned the experiment. EB analyzed the data under the guidance of CG and AB. EB wrote the manuscript with support from CG, AB, and SB. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.886861/full#supplementary-material

Supplementary Datasheet 1 | Auditory health questionnaire.

Supplementary Datasheet 2 | Post-trial questionnaire.

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Associations Between Ancillary Body Movements and Acoustic Parameters of Pitch, Dynamics and Timbre in Clarinet Playing

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When playing an instrument, there are two main categories of body movements: instrumental movements, which are necessary for the sound production, and ancillary movements, which are associated with individual musical intentions and expressions. In this study, the particular purpose of ancillary movements of clarinet player was investigated especially in respect to how these movements were related to the musical structure of the piece and to specific audio parameters. 3D motion capture data of 19 clarinet players performing the same piece were analyzed regarding common motion patterns during the performance and in accordance with acoustic features related to pitch, dynamics (RMS energy) and timbre (spectral centroid and flux). A focus of the body movements was on the arms and the knees. The results showed that there were certain motion patterns performed by the players depending on specific musical structures. When playing a melodic part, the players often did so by bending their knees. At musical transitions, however, the knees were mainly stretched. Similarly, arm movements were more pronounced during playing melodious parts. At transitions, the arms were put closer to the torso. Considering the connection with the acoustics, a larger range of knee motions was correlated with a larger variation of the timbre. Moreover, at specific moments during the performance, when some players strongly bent their knees or lifted the arms, the RMS energy of the signal was significantly higher. The correlations of the body movements and the acoustic features showed that some players synchronized their movements with particular audio parameters more than others did. In summary, the ancillary movements of the clarinetists pursued both musical expressive intentions and physiologically necessary movements and tended to be performed with individual differences in terms of visual and auditory expression.

Keywords: body movements, motion capture, signal analysis, music information retrieval, expression

INTRODUCTION

Body movements are essential for playing an instrument. Investigating body movements in musicians became a growing research topic in the last few decades (Godøy and Leman, 2010; Gritten and King, 2016; Wöllner, 2017; Jensenius, 2018). Playing a traditional instrument requires physical activities that are inseparable from the sound production (Wanderley and Battier, 2000). However, there are also movements that are not directly involved in the sound production. Hence, the functional aspects of musician's motions can generally be classified into two groups: instrumental movements, which are necessary to produce the sound on the instrument, and body movements, which do not directly generate sound, the so-called ancillary movements (Cadoz and Wanderley, 2000; Jensenius et al., 2010; Nusseck et al., 2018). Where the sound-producing movements are strictly bound to the instrument, ancillary movements are more open and convey individual intentions and expressions as well as personnel characteristics of the musician (Godøy and Leman, 2010). In examining performers' expressive movements, viewers were able to identify which emotions musicians intended to express while playing and the extent of their expressivity by looking at video recordings or point-light displays of musicians (Dahl and Friberg, 2007; Nusseck and Wanderley, 2009; Davidson and Broughton, 2016). Main body areas of ancillary motions are head movements, facial expressions, and side-to-side swaying (Demos et al., 2018). Furthermore, ancillary movements can additionally provide communicative aspects such as giving a cue to other musicians and making eye-contact between musicians or to the audience (Jensenius et al., 2010; Coorevits et al., 2020). In a music ensemble, anterior–posterior body sway has been found to reflect joint emotional expressions (Chang et al., 2019).

The different kinds of body movements usually occur simultaneously during musical performances (Dahl et al., 2010). They serve multiple purposes and form a complex system that changes with respect to the musical performance. For example, the execution of ancillary movements differs when playing with different emotional states and when playing solo compared to playing in an ensemble (Davidson, 2011; Glowinski et al., 2013).

When playing the same piece, instrumental movements are habitually very similar, since the notes have to be played on the instrument. Likewise, ancillary movements also sometimes follow similar patterns and are often aligned with rhythmic patterns and occur at musically important points (Wanderley et al., 2005; Davidson, 2007). For instance, all movements usually stop at the end of a phrase and at a fermata to emphasize the melodic paragraph. This indicates that beside the individual use of ancillary body motion to express certain personal musical intentions there are also common movement patterns related to key musical moments. Considering different expressive performances of the same piano piece, increased movements in an exaggerated performance seemed to take place at similar musical moments (Thompson and Luck, 2012). The authors conclude that the performance of expressive movements is influenced by the musical structure.

For trombone players, it was found that body swaying seemed to be related to certain musical structures and was performed rather similarly by the same performers (Demos et al., 2018). However, it appears that ancillary movements are less consistent across pieces and players, indicating that musicians seem to use different movements in different musical contexts, even within the same performance (Davidson, 2012). As music is produced in the moment, performances of the same piece can differ considerably (Juslin and Timmers, 2010).

For clarinet players, the movement of the bell was used as indicator of music-related body motion and showed certain consistencies between performances of the same piece (Wanderley et al., 2005; Vines et al., 2006). The clarinetists were asked to perform with three different degrees of expression, i.e., immobile, standard and exaggerated, and the movements of the bell were rather similar for each player, but varied between the expressivities with larger motion ranges in the exaggerated performances. In a different study, clarinetists' ancillary movements were quite similar in terms of expressive duration variations for certain melodic phrasings and harmonic transitions (Teixeira et al., 2015). They also showed that recurrent motion patterns of the clarinet bell occurred at specific musical passages, e.g., at the end of the piece. In a solo, however, clarinetists usually stand, which gives them more freedom of movement than just the motion of the bell, i.e., to sway and bend their knees.

In a previous study, ancillary full body movements of clarinetists were analyzed to identify commonalities in movement patterns by using 3D motion capture (Weiss et al., 2018). Angular movements of several body parts of 22 clarinetists playing five different solo pieces were calculated. A cluster analysis on the variances of these angles revealed four different motion types with specific motion characteristics: (1) with predominant knee motions (PkneeM), where players preferably performed with large knee bending, (2) with predominant arm motions (ParmM), where players particularly moved the arms, (3) with no specific prominent motion pattern (NoSMP), where players used both arms and knees to a lesser extent than in case of the first two motion types, and (4) with an overall low motion performance (LowMP), where players performed with lower motion amplitudes in all body regions. **Figure 1** illustrates the different motion types with their main movement areas on a point light display. The motion types distributed across players and performances of 34% the NoSMP, 13% the PkneeM, 14% the ParmM and 39% the LowMP type. In summary, the study identified two main movement areas of clarinetists: the arms in the upper body segment and the knees in the lower body segment. These areas were mainly corresponding to expressive intentions and have also been observed in previous studies (Wanderley et al., 2005; Davidson, 2012).

In multimodal – audio and visual – performances, it has been shown that the observed musician's movements considerably contribute to the perception of the performance (Vines et al., 2006; Nusseck and Wanderley, 2009; Platz and Kopiez, 2012; Tsay, 2013). Those studies highlight the importance of the visual component in musical performances providing a source of information that can change the judgment of the performance. By using the above mentioned motion types of clarinetists in a perceptual experiment, participants were asked to rate the

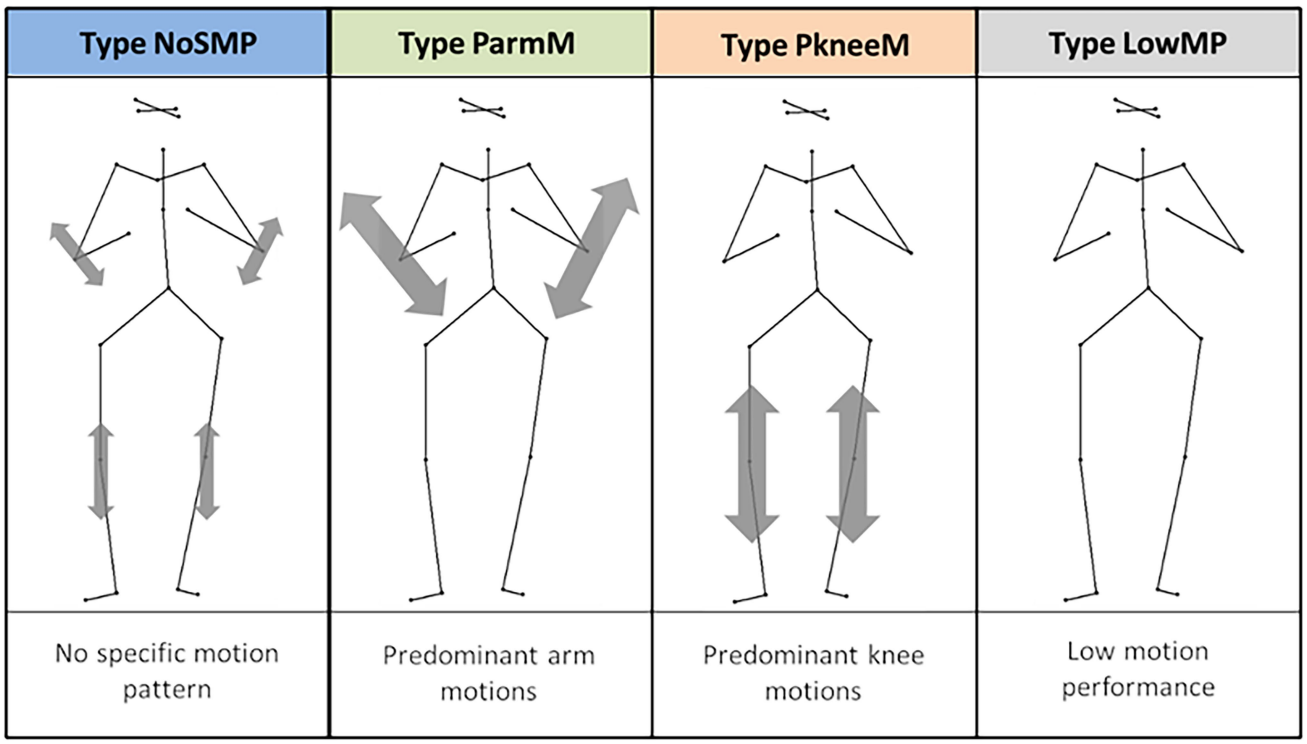


FIGURE 1 | Motion types of clarinetists found in Weiss et al. (2018).

musical performance and expressivity when seeing the motions of the different types but hearing the same audio track (Weiss et al., 2018). The results showed that the motion types with a predominant movement area, i.e., the knees or the arms, were rated higher in their expressivity than the players with no specific motion pattern. The lowest ratings were given to the players with overall low motion performance. In summary, the findings confirmed the influence of visual movements on the perception of the musical performance especially regarding the communication of expressive elements.

Despite visual expressiveness, an important source of expressive intentions in music is provided by the sound. For that, musicians associate changes in acoustic signals, such as dynamics, timing, tempo, loudness, with certain articulations (Gabrielsson and Juslin, 2003; Juslin and Timmers, 2010). However, since body motions are inseparable from the sound, certain acoustic features might be connected with particular movement characteristics (Godøy and Leman, 2010). Musicians' movements contain constitutive elements of the performance, which can also contribute on the acoustic level. In a study examining listeners' responses to static or moving orchestral musicians playing solo, it was found that the moving musicians were easily identifiable (Ackermann et al., 2019).

Ancillary movements of musicians with expressive intentions were also found to be associated with specific acoustic changes. When measuring the acoustic energy (RMS) in piano performances of the same piece played with different levels of expression (immobile, with low expressivity, with normal expressivity, and exaggerated), most dynamic variations were found in the exaggerated condition, while the other conditions remained relatively equal (Thompson and Luck, 2012). By analyzing the movements of the clarinet bell, Teixeira et al. (2018) found similar motion patterns linked with particular acoustic variations in loudness and timbre at specific musical positions such as melodic phrasings and harmonic and dynamic transitions. They concluded that certain musical structures lead to the appearance of specific ancillary movements. Accordingly, those movements seem to be used to support acoustic expressions.

Aside from the clarinet bell, it may be possible that other common motion patterns while playing can be related to the acoustic expression. As a wind instrument, the clarinet is connected to the mouth and limited in its range of motion. Similarly, the hands are fixed to the instrument. Moving the clarinet is therefore dependent on movements in other body areas such as the arms, the torso and more indirectly also the legs. Thus, additional body movements besides the clarinet bell should be focused on in investigations for acoustic correlations. For example, it is possible that the bending of the knees is associated not only with a visual expression, but also with an acoustic change, for instance with an increase in dynamic. Furthermore, it remained unclear how ancillary movements are related with acoustic features in between certain expressive musical positions.

In this study, following the particular motion types of clarinetists described above (Weiss et al., 2018), the use of ancillary movements focusing on the arms and the knees was

examined in more detail in terms of how players moved according to the musical structure of the piece and regarding changes in acoustics features. This leads to two major areas of questions:

1. **Visual aspects:** Do players perform similar ancillary movements following the musical phrasing? For this purpose, the arm and knee angular movements were analyzed for the occurrence of particular common motion patterns across players. Those patterns were then related to musical structural elements, such as transitions and melodic sections.
2. **Acoustic aspects:** Are ancillary movements related to certain acoustic features? Here, acoustic changes were analyzed in conjunction with angular movements in the arms and knees. For that, angular peaks in movement were selected and analyzed for differences in the acoustic parameters. In addition, the overall angular movement variability in the arms and the knees was tested for correlations with the variance of the acoustic parameters. It is expected that due to the relation of ancillary movements with expressive intentions, larger ranges of angular movements may be connected with higher acoustic variations.

Using the motion capture data of the clarinetists, ancillary movements of the arms and the knees were analyzed in relation to their appearance during playing concerning the musical structures of a certain piece and in conjunction with particular acoustic parameters. For that, the analyses were performed on the angle values in the arms and the knees first of all players and secondly separated by motion types. Examining the differences between the motion types is of particular interest because there are players with large ranges of angular motions in either arms or knees and players with very little motion at all. Differences can be discussed in accordance to the motion types and therefore to individual styles of clarinet playing.

The analysis was divided into three parts: first, with a focus on visual movements, i.e., body movements in relation to the musical structure; second, with a focus on acoustic parameters such as dynamics and timbre in relation to the musical structure; and third, with a multimodal focus on the relationships between visual movements and acoustic changes.

MATERIALS AND METHODS

Clarinet Players

The recordings of clarinet players reported in Weiss et al. (2018) have been used. Of the original 22 clarinet players, the data set for this study included 19 players who provided complete sets of both motion and audio data. Nine players were female and ten players were male. The mean age was 32.7 years (SD 12.8 years) and the average duration of playing the clarinet was 22.5 years (SD 12.3 years). Regarding the motion types, five players were in the NoSMP type, four players in the ParmM Type, three players in the PkneeM type and seven in the LowMP type.

The players were originally asked to perform five different solo clarinet pieces lasting about 20 to 60 s. The clarinetists played in standing position and were not allowed to walk around or to take steps. They played each piece once. In case of misplays, the recording was repeated. The sheet music was provided on a music stand about 60 cm in front of them. All players confirmed their written consent to participate in the study.

Recording Setup

An optical 3D motion capture system with four calibrated digital video cameras was used to record the visual movements. The sampling rate was 50 frames per second. Twenty-two reflective markers were placed at central joints and body positions of the players to obtain a whole-body representation (**Figure 1**). There were four markers on the head, two on the shoulders, two on each arm, three on the torso, three on the hip, and three on each leg. The videos were processed with the Templo Software (Contemplas) and the 3D marker positions were digitized by using Peak Motus 10 (Vicon).

Specific body angles were calculated by using particular marker coordinates. The values of the range of angular motions were analyzed to classify the different motion types (see above, **Figure 1**). The method used to characterize the types of motion is presented in more detail in Weiss et al. (2018).

The sound was recorded with a digital audio recorder (Zoom H4N). It was placed on a stand at 1 m height and approximately 2 m in front of the players. A stereo WAV-File with 44.1 kHz sample rate was used. Synchronization between the motion capture and the audio recordings was established by a simultaneous visual and acoustic gesture of the players immediately before each start of the performance. In post-processing, the video and the sound were merged based on this signal.

The Music Piece

In this study, the piece in which the different motion types of clarinettists were most clearly distinguishable was chosen from the recorded pieces. The piece was Mendelssohn's 3rd Symphony ("Scottish Symphony," Op. 56, the first 24 bars of the 2nd movement "Vivace" in A minor). The score of this piece can be found in the **Supplementary Material**. The tempo was given to the players by a metronome (126 bpm) directly before the performance but they did not perform with the metronome. The mean duration of the piece was 24 s.

The melodic structure of the piece consists of six phrases. The first phrase frames the first eight measures (with upbeat) and presents the main melody. The next eight measures repeat the complete previous melody. Unlike the more melodic preceding parts, which contain several sixteenth notes, the next four measures contain a sustained note. The final phrase repeats the previous four measures with a slightly altered harmonic motion.

It is possible to inhale at the transitions of each phrase, i.e., between the main melody parts, before the two final phrases and between the two final phrases, what most of the players did. A schematic representation of the melodic pitch can be seen in the top line of **Figures 2, 3**.

Data Analysis

Visual Movements

The movement analyses included a focus on specific areas of interest for clarinet playing. Weiss et al. (2018) found that the main movements were in the arms and legs. Shoulders, the instrument or side-to-side motions did not show significant common patterns between players. Therefore, the main analyses of the visual movements in this study focused on arm and knee movements, especially angular movements.

The knee angle was calculated from the combination of the foot, the knee and the hip marker. A high value means an extended leg and the lower the angle, the more the knees are bent. Limited by anatomy, the value cannot be higher than 180 degrees and no angle was found below 100 degrees. Both knee angles were highly correlated ($r > 0.9$). Thus, only the right knee angle was used for the analyses.

Since the arm angle was formed from the markers of the elbow, shoulder and neck, a higher value represents a more raised arm with an opening in the armpit. Anatomically, the value ranged from 90 to 180 degrees, with an arm very close to the trunk being about 90 degrees and an arm raised almost horizontally being about 180 degrees. Both arm angles correlated highly with each other ($r > 0.8$). Since the right thumb has a holding function of the instrument, this resulted in a slightly reduced range of motion of the right arm (Weiss et al., 2018). Therefore, only the left arm angle was used for the analyses.

Due to the anatomical differences between the players, the raw data of each player were normalized by dividing the angular values by the mean value of the angle. This procedure yields values around one. Larger angles are above one and smaller angles are below one. The resulting value has no unit.

In addition, the velocity of the angles was calculated for both the arm and knee angles. For that, the difference of two successive angle values was calculated. This therefore corresponds to the angular change over time, i.e., a fiftieth part of a second. The velocities were calculated as absolute values to obtain distinct peak velocities. The value is zero if the movement had stopped at reversal points.

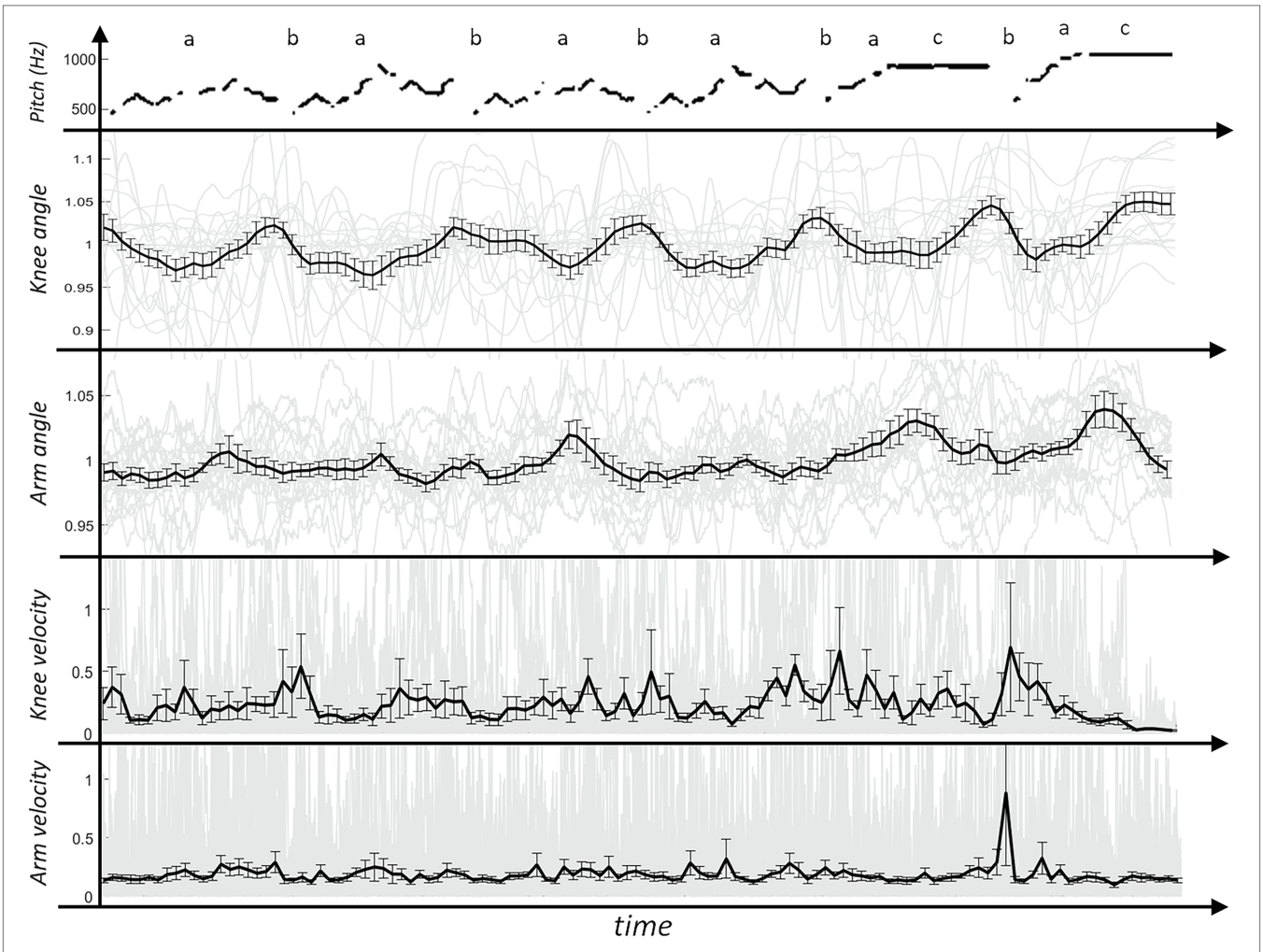


FIGURE 2 | Graphs of the visual movements of the knees and the arms (top row: schematic of the pitch; second and third row: normalized motion of the angle; fourth and fifth row: velocities in 1/50s; gray lines: individual values of the players; thick black line: mean value across all players; error bar: standard error of the mean).

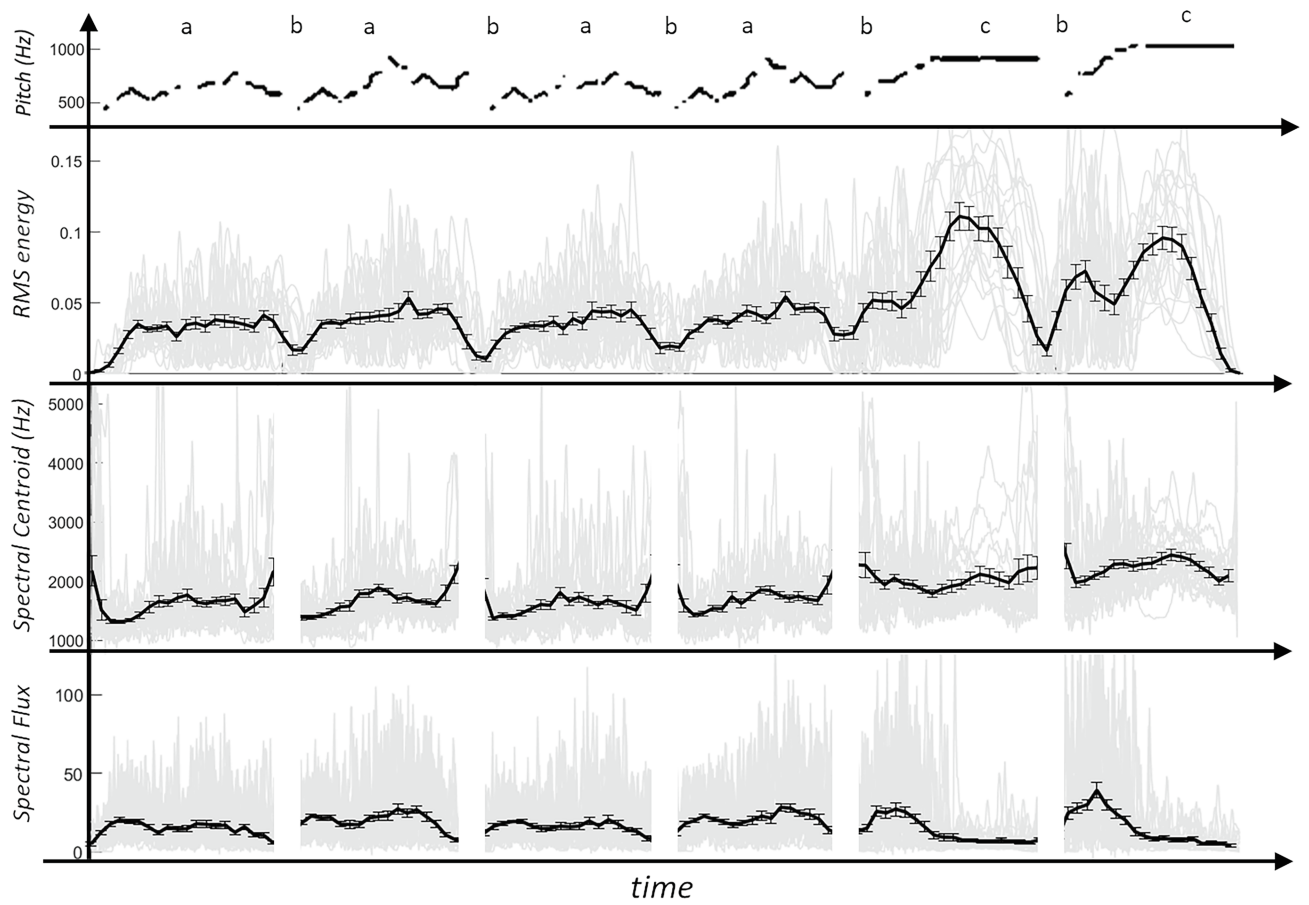


FIGURE 3 | Graphs of the four acoustic parameters (top row: schematic of the pitch; gray lines: individual values of the players; thick black line: mean value across all players; error bar: standard error of the mean).

Acoustic Parameters

Following Teixeira et al. (2018), the sound analyses of the clarinet recordings focused on the musical parameters of dynamics, timbre and additionally the pitch trajectory. Specifically, the pitch represents the acoustic realization of the notes seen in the score (**Supplemental Material**), i.e., the higher the note played, the higher the detected fundamental frequency at a specific time frame. For capturing dynamic changes within the performance, the RMS energy of the audio signal was analyzed over time, which was calculated as the root average of the squared amplitude of the signal. As a descriptor for the timbral brightness, the spectral centroid (i.e., the mean of the spectral distribution in Hz) was included. Additionally, the spectral flux was included in order to quantify timbral change and fluctuations. Similar to the calculation of the angular movements' velocity, the spectral flux determines the distance of the power spectrum between two successive time frames. Its value increases with the amount of spectral fluctuations present.

To extract those audio features, the MIRtoolbox 1.6.1. (Lartillot et al., 2008) for MATLAB (R2020a) was used. Acoustic features were extracted using half-overlapping time frames with a length of 0.05 s. In order to obtain a data set that can be correlated with the visual motion data set, the acoustic data were sampled to match the resolution of the motion capturing data. Both visual and acoustic data were equally reduced to 120 data points for each recording.

Since the spectral parameters were also collected at moments when the clarinetists did not play, i.e., during breathing, the values of these features would measure the background noise causing value artifacts. Therefore, a kind of "noise-gate" was used to exclude those pauses from the analysis. For that, when the RMS energy value was less than 0.02, the values of the collected timbre features at this frame were excluded from the analysis. This setting was also applied when determining the mean values of the timbre features.

Combined Visual and Acoustic Analysis

For the combined analysis of both visual and audio, three different approaches were taken. First, the mean values and variances of the acoustic parameters were compared between the different motion types.

In a second approach of the analysis, the sound parameters were calculated at specific points of interest in the motion of

each player. For that, the motion curves of the angles in the knees and arms were examined for local maxima and minima, i.e., reversal points. A schematic figure of this analysis approach is provided in **Figure 4**. To this end, automatic peak detection was performed in MATLAB (R2020a) using the function "findpeaks" to identify the turning points in the angular movement trajectories of the arms and knees. At those peak points (including the 10 surrounding time frames), the mean values of the acoustic parameters were measured. During the piece, these peaks occurred frequently, but differed in their total number between the players. Since the movements of the angles are normalized, the mean acoustic values at the two extreme points (lowest angle and highest angle) were compared with each other across all players.

In the third approach, for an even more comprehensive player-specific analysis, correlations were calculated between the 3D motion capture data and the synchronized audio features for each player (P1-P19). Thus, certain relations between body movements and audio features could be evaluated in detail for each individual player categorized by the different motion types.

Statistics

For the statistical analyses SPSS (Version 28, Armonk, NY: IBM Corp.) was used. Descriptive statistics were calculated for parametric variables including mean values and standard deviations (SD). Chi-square (χ^2) tests were performed for comparisons of non-parametric variables. Parametric comparisons have been calculated with analysis of variances (ANOVA). When the ANOVA was significant with more than two variables, *post hoc* analyses with Tukey HSD (honestly significant difference) correction were performed. Comparisons between the marker positions within the piece has been performed with a paired sample t-test. Relationships between motion angles and audio features were further investigated for each player individually *via* a correlational analysis. Significant correlations above Pearson's $r = 0.25$ were considered medium, above $r = 0.5$ high correlations (Cohen, 1988). The level of statistical significance was set at $p = 0.05$. However, considering possible multi-testing problems due to the high number of individual combinations, only medium correlations and above (>0.25) were considered for interpretation.

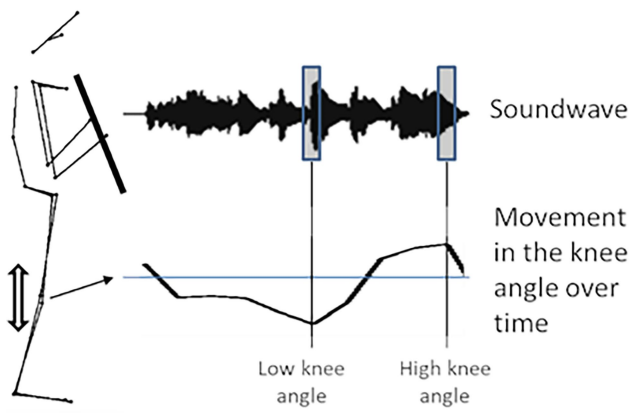


FIGURE 4 | Schematic of the multimodal analysis of motion peaks with sound parameters by the example of the knee movements.

RESULTS

Movement Analysis

Figure 2 shows the mean angular movement values of the knees and arms. For both the movement values and the velocities, the individual values of the players (gray) and the mean value of all players (black) are plotted. To perform a comparative analysis, certain positions were selected and marked. These were the positions during the melody (marked with an "a") and when breathing in ("b"). A third position was chosen during the playing of the prolonged notes in the last two phrases ("c"). For the analysis, the mean values at each marked positions were calculated across players and across the different places in the piece.

In **Figure 2**, it can be seen that the knees were flexed while playing the melody ("a") and at the transitions between the phrases ("b") the legs were stretched to provide a more upright body posture. The comparison between the mean knee angle values at both positions ("a" and "b") showed a significant difference [$t(18) = 3.14$, $p = 0.003$] with lower values at "a."

Similarly, the arms were in a rather neutral and aligned position between the phrases ("b") and during the melody (slightly after each "a"), the arms moved up. The comparison analysis between the mean values at these two positions showed a significant difference [$t(18) = 1.78$, $p = 0.045$] with lower values at "b." In the last two phrases, when playing the prolonged notes ("c"), the arms were lifted to the strongest degree. The analyses between the position "c" with "a" and "b" yielded a significant effect with significantly higher values at "c" [c-a: $t(18) = 3.17$, $p = 0.003$; c-b: $t(18) = 3.39$, $p = 0.002$].

The analysis of variance performed on the mean values of the velocities in the arms and in the knees between the marked positions yielded no significant effects [$t(18) < 1.0$]. This indicates that no systematic pattern was found for the velocities during the performance. The angular movements of the arms and the knees were rather unvarying and showed only some individual peaks.

Acoustic Analysis

For the acoustic analysis, three audio parameters had been selected. The RMS energy was chosen to capture dynamic changes. The spectral centroid as well as the spectral flux were chosen to represent timbral aspects. Similar to the visual movements, comparisons of the mean audio feature values between the marked positions were performed. **Figure 3** shows the acoustic parameters over the course of the performance. The graphs illustrate when the players inhaled (marked with a "b") with low RMS energy at these moments. At the same time, the spectral features would change drastically. Therefore, their values were removed during those positions ("b"). The analysis of the mean RMS energy values between the marked positions showed a significant effect with the lowest values at "b" [a-b: $t(18) = 3.97$, $p < 0.001$, b-c: $t(18) = 11.64$, $p < 0.001$]. While the first four phrases show a very similar pattern

concerning the signal's RMS energy, in the last two phrases, the prolonged notes ("c") were played with significantly higher dynamics than in the previous phrases at "a" [$t(18) = 8.16$, $p < 0.001$].

The spectral centroid and the spectral flux were relatively stable over the piece. However, in the last two phrases ("c"), the mean spectral centroid was significantly higher [$t(18) = 4.42$, $p < 0.001$] than in the previous phrases ("a"). The spectral flux showed two peaks at the beginning of the two last phrases (between "b" and "c") when there were dense note onsets with a significant difference to the previous phrases [$t(18) = 3.99$, $p < 0.001$]. The spectral flux was also significantly lower during the sustained notes in the last two phrases ("c") compared to the previous phrases [$t(18) = 3.87$, $p < 0.001$].

Visual and Acoustic Analysis

Comparisons Between the Motion Types

For analyzing the relations between visual movements and acoustic parameters, statistical comparisons of the acoustic parameters between the motion types were performed. Overall, the analyses of variance showed that there were no significant differences in any of the acoustic parameters [$F(3,15) < 1.0$]. In **Figure 5**, the mean values of the three acoustic parameters, i.e., RMS energy, spectral centroid and spectral flux are shown by motion type.

Movement Peak Analysis

For the analysis of the acoustic parameters at the minima and maxima of the angle curves, the three acoustic parameters of the RMS energy, the spectral centroid and the spectral flux were considered. **Figure 6** shows the mean values of each acoustic parameter for high angular points (maximum) and low angular points (minimum). The multivariate analysis of the three acoustic parameters with types and peaks yielded no significant main effects for the knee movements. However, going into more detail, there was a significant difference in the mean RMS energy value of the PkneeM players between maxima and minima of the knee movements [$F(1,35) = 5.1$, $p = 0.032$] with higher values at points of low knee angles, i.e., when the knees were flexed. For the mean values of the spectral flux, the NoSMP Players performed with significantly higher values when they bent their knees [$F(1,69) = 6.1$, $p = 0.016$].

In case of the arm movements, the multivariate analysis showed a significant main effect of peaks in the RMS energy [$F(3,202) = 4.4$, $p = 0.039$] with higher mean values across all motion types at points of high arm angles (maximum), i.e., when the elbows were lifted. The ParmM players performed with different dynamic intensity depending on the arm position. The RMS energy values were significantly different between the maximum and minimum [$F(1,29) = 9.2$, $p = 0.005$] with higher values at points of higher arms angles (maximum), i.e., with spread arms.

There were significant interaction effects of type and peaks for the spectral centroid [$F(3,202) = 2.8$, $p = 0.038$] and for the spectral flux [$F(3,202) = 4.3$, $p = 0.006$] in the arm movements. Especially the players of the NoSMP type showed significant differences in the spectral centroid [$F(1,58) = 5.6$, $p = 0.021$], with higher values when the arms were lifted, and respectively, in the spectral flux [$F(1,58) = 10.1$, $p = 0.002$], with higher values with arms close to the torso.

Correlations

It was assumed that a greater range of motion might also be accompanied by greater variability in dynamics or timbre. For that, the correlations between the variances of the motions in the arms and knees with the variances in the acoustic parameters were calculated across all players. In this analysis, the pitch was also included. The correlation coefficients are shown in **Table 1**. Only the correlation of the variances in the knee motions and variances in the spectral centroid was found significant ($r = 0.49$, $p < 0.01$), indicating that a larger range of motion in the knees was associated with higher variations in the timbre.

Subsequently, for each player, the correlations between the measured motion angles and the acoustic features were investigated over time (see **Table 2** for the detailed correlation

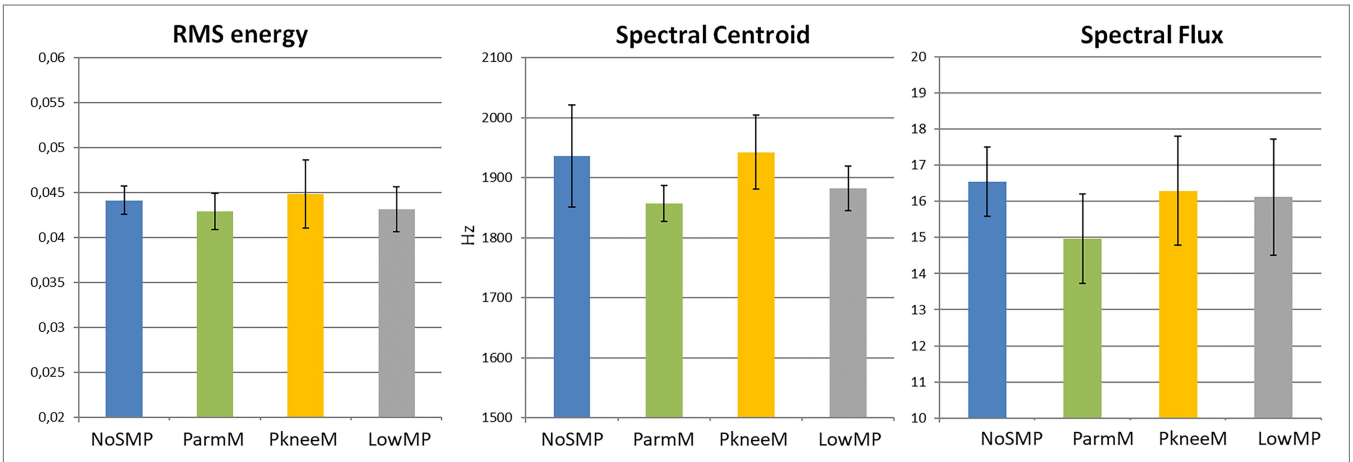


FIGURE 5 | Mean values of the acoustic parameters by motion type (Abbreviations of the motion types see **Figure 1**; error bar: standard error of the mean).

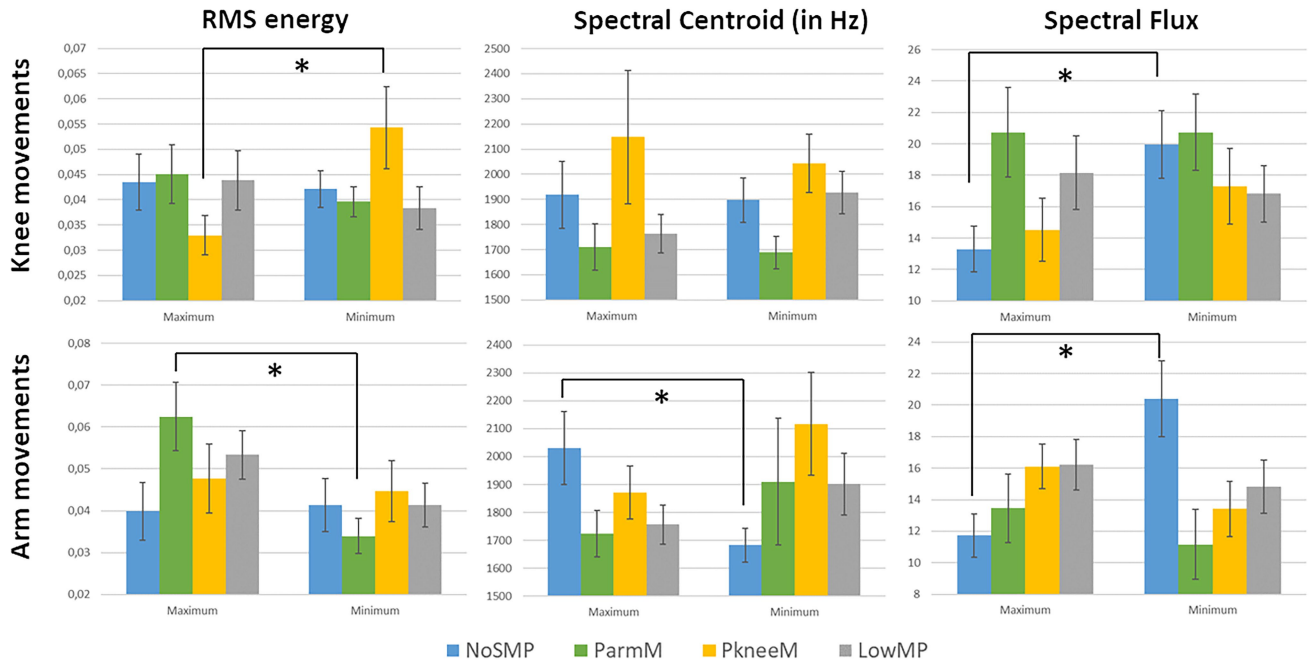


FIGURE 6 | Mean values of the RMS energy, the spectral centroid and the spectral flux by motion type (Abbreviations of the motion types see **Figure 1**) and movement peaks (maximum: high angular peaks; minimum: low angular peaks; error bar: standard error of the mean; $^{*}p < 0.05$).

TABLE 1 | Correlation coefficients with significances between the variances in the motion areas and the acoustic parameters across all players (in bold: significant correlation $p < 0.01$).

	Pitch		RMS energy		Spectral centroid		Spectral flux	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Arm motions	−0.208	0.393	−0.156	0.523	−0.089	0.718	−0.027	0.913
Knee motions	−0.110	0.655	0.141	0.564	**0.486**	0.035	0.001	0.999

coefficients). Positive correlations with the knee motions represent a higher acoustic value when playing with more stretched legs and positive correlations in the arm motions indicate for higher acoustic values when the arms were lifted. As a threshold of interest, only correlation coefficients above Pearson's $r > 0.25$ and below $r < -0.25$ were considered as meaningful. All these correlations were also significant. Some additional correlations below this threshold were also significant, but were not considered for reasons of clarity.

Overall, the pitch and the RMS energy values in many cases showed high positive correlations with the knee and the arm motions. As a pattern, both pitch and RMS energy showed a rather common correlation either in the knees or in the arms. For the NoSMP players, however, it was not consistent which motion region correlated most strongly with these acoustic parameters. While for some players the knees correlated highly with the pitch (P1 and P2), other players showed high correlations in the arm motions (P3 and P5) and one player showed rather low correlations in both body regions with a light preference in the knees (P4). Most of the ParmM players showed pronounced correlations with the arm motions (P6, P7 and P8), while it is noteworthy that one player rather used the knee motions in relation to these acoustic parameters even when performing preferably with large arm motions (P9).

Perhaps counterintuitively, the PkneeM motion type mainly showed rather low correlations between knee motions and the investigated acoustic parameters. Only for one of the players, medium correlations could be observed between this motion region and pitch, RMS energy and spectral centroid values. For the other two players with predominant knee motions, however, the connection between arm motions and acoustics seemed to be more pronounced (P10 and P11).

The correlations of the LowMP players in the knee movements showed a very large variation between 0.7 and −0.64. This seems to be caused by the very low motion ranges in the knees of these players. These correlations are therefore not convincing and have to be considered with caution. The players of this motion type mainly arranged their arm motions with the acoustic parameters pitch and RMS energy. Only one player showed no correlations at all with the arm motions (P15).

Overall, spectral centroid and spectral flux yielded less consistent correlations in all motion types. For only a few

TABLE 2 | Correlation coefficients with significances between the movement trajectories in the motion areas and the acoustic parameters for each player (in bold: $r > 0.25$ or $r < -0.25$).

Players by type		Knee motions								Arm motions							
		Pitch		RMS energy		Spectral centroid		Spectral flux		Pitch		RMS energy		Spectral centroid		Spectral flux	
		r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
NoSMP	*1*	**0.609**	<0.001	**0.373**	<0.001	**0.383**	<0.001	−0.139	<0.001	**−0.289**	<0.001	−0.131	<0.001	**−0.077**	0.025	**0.247**	<0.001
	2	**0.607**	<0.001	**0.357**	<0.001	**0.332**	<0.001	0.076	0.02	**0.400**	<0.001	**0.348**	<0.001	**0.177**	<0.001	**−0.094**	0.004
	3	**0.445**	<0.001	**0.279**	<0.001	0.097	0,006	0.079	0.025	**0.422**	<0.001	0.035	0.501	0.069	0.021	**−0.404**	<0.001
	4	**0.272**	<0.001	0.120	<0.001	0.187	<0.001	−0.248	<0.001	−0.144	<0.001	−0.193	<0.001	−0.110	<0.001	−0.085	0.011
	5	−0.026	0.512	0.113	<0.001	−0.071	0.042	**−0.268**	<0.001	**0.443**	<0.001	**0.529**	<0.001	**0.501**	<0.001	−0.061	0.078
ParmM	*6*	**0.265**	<0.001	0.110	<0.001	**0.278**	<0.001	−0.145	<0.001	**0.506**	<0.001	**0.304**	<0.001	**0.470**	<0.001	−0.078	0.018
	7	0.085	0.018	0.194	<0.001	−0.096	0.006	−0.010	0.775	**0.343**	<0.001	0.246	<0.001	0.165	<0.001	−0.176	<0.001
	8	**0.278**	<0.001	0.124	<0.001	−0.078	0.011	−0.205	<0.001	**0.450**	<0.001	0.181	<0.001	**0.464**	<0.001	−0.057	0.062
	9	**0.486**	<0.001	**0.590**	<0.001	**0.284**	<0.001	−0.178	<0.001	**0.257**	<0.001	**0.405**	<0.001	0.160	<0.001	−0.087	0.013
PkneeM	*10*	0.159	<0.001	0.080	0.016	0.132	<0.001	−0.220	<0.001	**0.319**	<0.001	**0.323**	<0.001	**0.362**	<0.001	0.073	0.027
	11	−0.032	0.387	0.127	<0.001	−0.019	0.579	0.034	0.312	**0.361**	<0.001	0.226	<0.001	**0.295**	<0.001	−0.086	0.011
	12	**0.326**	<0.001	**0.317**	<0.001	**0.310**	<0.001	0.100	0.002	0.098	0.005	**0.309**	<0.001	0.095	0.004	0.184	<0.001
LowMP	*13*	**−0.251**	<0.001	−0.235	<0.001	**−0.294**	<0.001	0.036	0.356	**0.578**	<0.001	**0.596**	<0.001	**0.361**	<0.001	−0.193	<0.001
	14	**−0.641**	<0.001	**−0.447**	<0.001	**−0.463**	<0.001	0.033	0.368	**0.595**	<0.001	**0.421**	<0.001	**0.457**	<0.001	−0.179	<0.001
	15	**0.693**	<0.001	0.149	<0.001	**0.581**	<0.001	−0.222	<0.001	−0.037	0.322	−0.207	<0.001	0.014	0.681	0.043	0.212
	16	−0.206	<0.001	0.026	0.438	−0.222	<0.001	−0.151	<0.001	**0.316**	<0.001	0.046	0.161	0.240	<0.001	**−0.336**	<0.001
	17	**−0.349**	<0.001	**−0.299**	<0.001	−0.085	0.015	0.199	<0.001	**0.563**	<0.001	**0.294**	<0.001	−0.008	0.825	−0.154	<0.001
	18	0.059	0.089	0.088	0.008	−0.118	<0.001	−0.153	<0.001	**0.779**	<0.001	**0.453**	<0.001	**0.480**	<0.001	**−0.323**	<0.001
	19	**0.592**	<0.001	**0.700**	<0.001	**0.281**	<0.001	**−0.332**	<0.001	**0.617**	<0.001	**0.636**	<0.001	**0.581**	<0.001	−0.138	<0.001

players, the correlations reached considerable levels. High correlations with the spectral centroid were found in two players in case of the arm motions (P5 and P19). Additionally, seven players showed medium correlations with the arm motions. For the knee motions, only five players (without the LowMP type) displayed medium correlations.

DISCUSSION

In this study, ancillary movements of clarinet playing were investigated in their relation to acoustic features during playing. For that, a focus was set to the movements in the arms and the knees. A previous study showed that these are the major motion areas of clarinetists during playing (Weiss et al., 2018). The movement angle trajectories were then analyzed in terms of systematic patterns during the playing and in conjunction with specific audio parameters extracted from the recordings of their performance.

Visual Movements

The analysis of the visual movements indicated that the players overall performed with rather similar motion behaviors that followed certain musical structures of the piece. The piece is divided into six phrases in which each phrase contains a distinct melodic theme. Between these phrases, the players could breathe in. The knee motions showed that on average the players bent their knees during the phrases and returned to an upright position at the end of each phrase. Even if some players performed slightly different and the players of the LowMP motion type even with nearly no knee movements at all, this particular motion pattern was found as an overall tendency across players and performances. Following the proposition that ancillary movements are often aligned with musical structures (Wanderley et al., 2005; Davidson, 2007), this finding indicates that the specific melodic composition induced the players to perform with this common knee motion behavior.

The recurrence to an upright position at the end of each phrase might serve the purpose to symbolize the end of the melodic part. However, it might also be performed to bring the body into a better position to breathe in. During rapid and effective inhalation, the diaphragm, with the crus attached to the lumbar region of the spine, is pulled down and flattened. The contraction of the diaphragm is accompanied by a contraction of the iliopsoas muscles in the pelvis, which attach to the femur and are associated with flexion of the hip-knee angle. The physiological movement during inhalation is therefore a bending of the hips and knees (Richter, 2014; Spahn, 2015). The inhalation is physiologically preceded by an exhalation at the end of the musical phrase with stretching in the hips and knees. From this perspective, it is reasonable to assume that the observed movements in the knees at the transitions between musical phrases fulfill both an expressive and a physiological function.

The movements of the arms also showed significant patterns across the players. There was a lifting of the arms in the first four phrases at a relatively fixed position, i.e., after two-third of the phrase. In the last two phrases, the arms moved with larger amplitudes than in the previous phrases and showed a rather smooth movement trajectory when the prolonged notes were played. At the end of each phrase, the arms went back to a more neutral position close to the torso. As the movements of the clarinet bell were shown to be related to specific melodic phrasings (Teixeira et al., 2015), these findings indicate that there is also a common motion behavior of the arms in relation to the musical structure.

The velocities of the body movements were calculated to provide an additional value regarding the motions on top of the angle trajectories. A particular expectation was that besides of angular peaks it might also be possible that velocity peaks play a role in individual motion behaviors. However, the velocity values across the piece showed only low variations indicating rather fluent motion performances without large velocity peaks. Due to the low variance, the velocity values showed no significant correlations with the acoustic parameters and were therefore not considered in more detail in the results section. Hence, despite of large amplitudes of motion in the knees and the arms, the velocities were quite similar. This finding might suggest that the players anticipated their movements and prepared them to avoid fast motion actions.

Acoustic Commonalities

The mean values of the acoustic parameters of all players showed that the first four phrases were played with rather similar dynamics while the last two phrases with the prolonged notes were performed slightly louder. This followed mainly the musical composition of the piece. The last two phrases also show significant differences with regard to the included timbre descriptors, i.e., spectral centroid and spectral flux.

Multimodal Findings

For the combined analysis of the visual movements and the acoustic parameters, different approaches have been addressed. At first, the differences in the mean values of the acoustic features across the whole performance had been compared between the motions types. The results did not find any significant effects. This indicates that there was no fundamental difference between the performances of the different motion types from acoustic perspective and could lead to the assumption that these ancillary movements are mainly visually intended. However, a limitation of this analysis was the small sample size within each of the motion type groups. Therefore, this finding just provides a rough comparison between the motion types.

The closer look at specific peaks in the movement trajectories however indicated some differences between the motion types. Players of the PkneeM type performed significantly louder when reaching the tipping point of the flexed knees than in extended knee positions. Similarly, players of the ParmM type were louder when playing with arms raised compared to positions with arms alongside the torso. It seems that in these two motions types with predominant movement behavior in the knees or in the arms, the strong movements have an

association with the dynamics of the sound. The players may have used these movement peaks to support the acoustic aspects. On the other hand, the acoustic parameter could have been affected by the strong motion action of the knees.

The NoSMP motion type players also showed significant differences in the acoustic features, but only in the timbre characteristics. These acoustic changes were not limited to a single motion area, but were evident in both knee and arm movements. The arm movements were associated with the timbral brightness and higher values were found when the arms were lifted. Therefore, the movement amplitudes seemed to be mainly related to timbre rather than dynamic changes in comparison to the predominant movement types.

In contrast, the detailed correlation analysis showed rather complex results. The correlations between the variances of the body movements and the acoustic parameters across all players indicated that only the motion range of the knees was associated with changes in the spectral centroid. This finding suggests that timbral brightness was higher when the knees were stretched. Bending the knees seems to be associated with a reduction in brightness. This effect can be directly attributed to the typical sound radiation of the clarinet: With a fixed recording microphone position, the change in distance between the clarinet (especially its bell) and the microphone is largest for the PkneeM compared to the other types of movements. Even here, the movements are too small to achieve noteworthy differences in the dynamics, however, they are large enough to cause timbral differences related to the spectral centroid: Due to the fact that the sound radiation of the clarinet becomes more and more directional with increasing frequency, the higher frequencies of the clarinet radiate more directly toward the microphone at some points (with knees outstretched) and more below the microphone at others (with buckled knees; for the sound radiation pattern of the clarinet at higher frequencies, see Meyer, 2009). Due to that effect, the timbral variance cannot be explained as an intentional product of the players movement in those cases.

When looking at the relations between the acoustic parameters and the motion trajectories, the pitch and the RMS energy were most frequently correlated with the visual motions. This suggests that specifically intended ancillary movements were often synchronized with the melodic structure and accompanied by a louder playing. However, the correlation table yielded that for some players both acoustic features were not directly connected. Some showed only correlations with the pitch, but not with the RMS energy. This indicates that the link between visual movements and the melodic trajectory seemed to be stronger than with dynamic changes. Nevertheless, the peak analysis found that especially for the PkneeM motion type, when performing a strong knee bending, the loudness was significantly higher compared to a more upright position. This however, could not be observed in the detailed correlation analysis. It therefore seems that this particular movement behavior was only relevant at strong peak levels and not during the whole playing. Most interestingly, two of the three PkneeM players synchronized their arm movements more with the acoustic features similar to the players of the other motion types. This might suggest that the knee behavior in this motion type seemed to follow an expression more visually intended.

The finding that higher notes were preferably played with more straightened legs overall, leads to the assumption that the knee movements form some sort of visual assistance of the notes. As the melodic progression in each phrase consists of low notes at the beginning followed by higher notes toward the end, the movements of the knees seemed to follow these melodic structures. This might support the idea of a musical gesture (Godøy and Leman, 2010) demonstrating a music-induced connection between movement and melody. However, since this study only used one piece of music, which has a particular musical structure, a specific relationship can only be presumed.

The players of the LowMP motion type performed with only very small knee movements. This was particularly difficult for the movement peak analysis, as the turning points were rather sparse and very close to the threshold of the detection process. With that, the validity of the correlations with the knee movements was supposedly rather low. It is therefore assumed that these players did not use the knee movements for any specific purpose but for standing in an upright position providing optimal playing and breathing conditions. In contrast, the arms were very much correlated with the acoustic features. Even though they did not perform as pronounced arm movements as other motion types, they too connected this motion behavior considerably close with the acoustics.

In summary, the analysis suggests that the visual movements of the arms and knees contained clear expressive components that were related to the musical structure. During the performance, they followed melodic elements but also were consistent across players at particular musical positions, i.e., transitions and at the end, confirming previous findings (Thompson and Luck, 2012). Moreover, those movements were not only of ancillary character but contained certain aspects of instrumental movements. The players seemed to perform a particular adaptation in the use of the body movements between addressing a musical gesture and providing a necessary physiological posture for playing and breathing. These different elements of movements interact with each other but at certain musical requirements, the physiological movements become more prominent.

LIMITATIONS

As has been mentioned before, the small sample sizes within the motion types are potentially problematic. However, the study in Weiss et al. (2018) was able to identify clear differences between the four player types regarding the movement areas of the knees and the arms. In this current study, it was shown that there was no clear relation between those distinct motion types and acoustic features. The results rather indicate that the relations between the visual and acoustic performance seemed to be were very individual for each player.

A limitation with regard to the detailed correlation analysis between the measured motion angles and the acoustic features

per player (e.g., **Table 2**), is that the individual measurements over time are not independent since both types of measurements (motion and acoustic) are time series data that can be autocorrelated to some degree (Dean and Dunsmuir, 2016). Moreover, it has to be kept in mind that many combinations (of player, audio feature and motion angle) are included in this detailed analysis, so the significance of each individual correlation has to be interpreted with caution. A further analysis could include a linear mixed modeling approach in order to better account for those effects.

Since the study investigated a wind instrument, the strong aspect of breathing should be taken into account. The main regions of ancillary movements were found in the upper body parts (i.e., torso, arms, and shoulders) and the lower body (i.e., the legs). Both provide a main contribution to the respiration process as the respiratory physiological movements in wind instruments form a specific part of instrumental movements. It would therefore be interesting to learn more about the physiological relationship between breathing and arm movements, for example, in order to be able to describe the overlaps between expressive and physiological movements in a more differentiated way.

In addition to the body areas knees and arms, a particular movement of players is the side-to-side swaying. Since the previous study on the visual movements (Weiss et al., 2018) found that this was performed very individually and without certainty, this movement area was not taken into account here. However, it would be interesting to compare different playing situations of clarinetists regarding visual and audio aspects. In particular, a comparison between the standing and the sitting position could be interesting because in orchestras, the players mostly perform in a sitting position. This would follow the findings in trombone players where abdominal muscle activity was significantly reduced when sitting (Price et al., 2014).

CONCLUSION

The results of this study showed that clarinetists used their body movements very individually, but played with rather similar motion patterns during certain musical phrases, such as at transitions between melodic parts. The relationship between these movements with changes in the sound was also found to be rather individual. Only a few general associations could be identified. It was found that on average players with large movements in the arms or the knees connected these motions mainly with the dynamics of the sound.

Regarding the body movements, the players seem to perform in two different ways: with ancillary movements and with instrumental movements simultaneously following the goal of expressing musical intentions and providing a proper posture for playing and breathing. These two aspects of movements interact with each other according to the musical structure.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the University Clinic Freiburg. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MN did mainly the data collection. IC-E, CR and MN performed the statistical analyses. All authors contributed to the article and approved the submitted version.

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REVIEW
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Investigating the Links Between Performers' Self-Compassion, Mental Toughness and Their Social Environment: A Semi-Systematic Review

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Being mentally tough while evaluating oneself in a compassionate way is still a difficult path for performers. Self-compassion, characterized by the ability to be kind to oneself, to see one's experiences as part of the larger human experience and have a balanced awareness to one's emotions and thoughts, was recently studied as a stepping stone to performance optimization and personal development. Despite a mistrust of this concept in the sports world, various studies show its benefits within athletes. A major question remains the environment that fosters or hinders the development of self-compassion: when role models extend compassionate attitudes, does it allow performers to respond in more self-compassionate ways? The relationship between self-compassion, mental toughness, and social environment is still unclear and is an important direction for future research within performers. This semi-systematic literature review aims at proposing an overview of the state of the art regarding self-compassion, mental toughness, and the influence of performer's, and social environments. Sixteen studies were retrieved. We conclude that the number of multi-day intervention programs and longitudinal studies should be increased. The studies should also consider assessing the specific aspects of performance culture and settings. In addition, overall performance-specific measures could be developed to assess general levels of self-compassion. The development of a theoretical framework explaining how self-compassion affects a performer, the role of their entourage and its link to other psychological resources, such as mental toughness, could help to better understand this concept.

Keywords: self-compassion, mental toughness, social environment, performing arts, sport

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INTRODUCTION

Performance, in different manner, is often at the heart of our daily activities, whether at work (e.g., Van Daalen et al., 2009) or in our personal lives (e.g., DeGroot and Vik, 2021). It is even more present in the domains of sport and performing arts. Promoting athletes' and, more broadly, performers' (i.e., artists, musicians, dancers) mental health is a significant

area of scientific research in sport and performance sciences to enable high-performance over time (Donohue et al., 2018; Van Slingerland et al., 2019). How can athletes and performers be accompanied in developing their mental health and personal resources to cope with this challenging world and maintain high-performance level? What key approaches could help to nurture successful, resilient performers and consider their mental health and well-being?

Athletes must often, if not constantly, give their best and do their utmost to achieve high performances. Physical preparation, practicing their sporting skills, nutritional follow-up, and the planning and management of their training sessions are all frequently put forward as essential elements in their struggles to achieve great things (Baker et al., 2003; Macquet and Skalej, 2015). Over the last few decades, but especially in the last 10 years, mental training and sport psychology have become integral parts of an athlete's preparation and support. Mental training and sport psychology aim to prepare athletes to handle the stress, pressure, and emotions they are confronted to. It helps them learn about themselves to better cope with challenges (Ong and Harwood, 2018).

The mental toughness of high-level performers is often put forward when discussing their performances (Bauman, 2016; Gucciardi and Hanton, 2016; Morais and Gomes, 2019). Athletes or their relatives frequently turn to sports psychologists or mental trainers with the request to become mentally tough or develop this toughness (Gee et al., 2010). Indeed, mental toughness is often considered an essential personal characteristic of top performers, consisting of aspects of psychological individuality including positive cues resulting from personal resources (e.g., self-efficacy, optimism) (Gucciardi et al., 2017). However, mental toughness is often followed by harmful beliefs. High-performance environments foster conditions in which a performer's personal resources, such as those encompassed by mental toughness (e.g., overcoming obstacles, perseverance), become so highly valued that athletes may be less likely or willing to seek help for mental health issues (Gucciardi et al., 2017). Furthermore, athletes' mental toughness is influenced by their social environment and surroundings (Antonini Philippe et al., 2016; Bean et al., 2019). Research has investigated the mechanisms linking elements of coach-created environments to certain positive and negative indicators of athletes' well-being and mental toughness (Gagne, 2003; Reinboth and Duda, 2004). Similarly, weak social support appears to be a significant risk factor in overall mental health (Rice et al., 2016).

Also, to perform at their best, performers not only have to remain mentally strong, but they need to understand the mistakes and difficulties they encounter to find solutions to move forward. Sport psychology research, to cope with difficulties, was interested, for example, in the concepts of resilience (e.g., Sorkkila et al., 2019), grit (e.g., Newland et al., 2020) or, more recently, self-compassion (Doorley et al., 2022). Self-compassion was showed to have significant impact on athletes' motivation and capacity to bounce back after difficult times (e.g., injuries, failure). However, research in this field is relatively new; therefore, we still have to understand what influences and helps develop self-compassionate competencies.

Through a semi-systematic review, defined as a review methodology for "topics that have been conceptualized differently and studied by various groups of researchers within diverse disciplines […] and useful for detecting themes, or common issues within a specific research discipline" (Snyder, 2019), this article will investigate the concepts of mental toughness, self-compassion within performers and the links with their social environment. Mental toughness and self-compassion are also being studied in the world of performing arts and, as proven by some authors, bridges can be built between the world of sport, performing arts, music, and dance (Pecen et al., 2018). Therefore, the word *performers*, in this article, includes athletes, musicians and dancers.

Mental Toughness, Self-Compassion, and the Social Environment: A Winning Combination for Performers' Well-Being and Performances

Experiences of failure, leading to emotional distress, which are inherent to high-performance fields, can be detrimental to performers' future performances and mental health. As previously mentioned, high-performance activities are often symbolized by courage, grit, and mental toughness (Baltzell et al., 2020). However, this mental toughness can have detrimental elements (Gucciardi et al., 2017). One emerging concept being studied and highlighted as a counterbalance and complement to mental toughness is self-compassion (Baltzell et al., 2020). Self-compassion, or treating oneself with kindness (Neff, 2003a), "can help performers deal with failure and can serve as a buffer against negative emotional psychological reactions" (Ceccarelli et al., 2019, p. 1). Neff examined the positive psychological functions of self-compassion and reported that self-compassionate individuals were more likely to think positively, have greater self-awareness, and make accurate self-appraisals (Neff et al., 2007; Neff, 2009; Neff and Germer, 2013). Self-compassion is defined by a supportive attitude toward oneself and includes being kind to oneself, common humanity, and mindfulness (Neff, 2003b). Common humanity is defined as seeing one's experiences as part of the larger human experience rather than seeing them as separate and isolating (Baltzell, 2016). Mindfulness corresponds to the ability to take a step back from our overarching emotions and thoughts and 'be in the moment.' Researchers working in the field of sport psychology have begun to address this concept with athletes (Ferguson et al., 2015; Mosewich et al., 2019), finding links between self-compassion and performance-related factors. Athletes with relatively high levels of self-compassion perform better and cope more effectively with sport stressors (Baltzell, 2016). Athletes with higher levels of self-compassion have also been shown to be relatively more positive, more persistent, less ruminative, and more willing to take responsibility (Ferguson et al., 2015). Finally, they also seem to have relatively greater experience in self-discipline along with less body shame (and thus less body monitoring), less fear of failure, less fear of negative evaluations, and less social physical anxiety (Mosewich et al., 2011; Baltzell, 2016). However, some athletes have

assumptions about self-compassion, such as that if they were more compassionate with themselves, they would lose their intrinsic motivation and feel sorry for themselves (Baltzell et al., 2020). When athletes are more compassionate with themselves, it is easier for them to 'tolerate' the (primarily negative) emotions they go through when faced with undesirable experiences in their sport (Reis et al., 2015). More research into this concept is therefore essential as it has enormous potential in improving well-being and performance. Furthermore, it is interesting to look at performers in a broader sense (including dancers and musicians) because self-compassion among these populations has received little attention to date (Tarasoff et al., 2017; Kveton-Bohnert, 2018; Johnson, 2020).

Moreover, in the last 20 years, different authors have been interested in how a performer's social environment can affect their performances and well-being (Jowett and Poczwardowski, 2007; Antonini Philippe et al., 2011; Wachsmuth et al., 2020). When talking about the social environment's influence, we assume the way performers perceive and appraise their environment, interactions and conditions often conveyed by coaches through the creation of a certain type of environment (e.g., autonomy supportive, compassionate). Studies have revealed that developing caring environment and compassion for self and others have a range of benefits on psychological processes (Neff, 2011; Jazaieri et al., 2013; Keltner et al., 2014) and social relationships (Penner et al., 2004; Crocker and Canevello, 2012; Neff and Beretvas, 2013; Neff and Pommier, 2013). Research in sport psychology has highlighted that when role models show an accepting attitude toward performers, regardless of outcomes, these positive interactions also encourage athletes to respond in more self-accepting ways (Ingstrup et al., 2017). A coach or a parent's attitude can maximize a performer's potential in terms of performance as well as toward their personal and psychological development (self-esteem, self-confidence, motivation). According to the study by Pecen et al. (2018), performers, among their many challenges, may also face difficulties from within their social environment, such as a bad or abusive coach, manipulative parents, dangerous advice, sexual harassment, or abuses of power and positions of influence. Coaches and parents are instrumental in creating social environments that can influence an athlete's physical growth and, psychological and subjective well-being (Jowett and Cockerill, 2003; Blanchard et al., 2009; Bartholomew et al., 2011).

Previous Literature Reviews on Self-Compassion, Physical Activity, and Sport

Previous literature reviews have focused on the concept of self-compassion within sport or physical activity in general. Röthlin et al. (2019) did a scoping review of the published evidence on self-compassion research in competitive sport. They answered the question about whether self-compassion is beneficial to competitive athletes. They were interested in the methodologies used in self-compassion studies. Overall, the review highlighted self-compassion's benefits and revealed how it influenced well-being, reduced feelings of shame and self-criticism, and improved the ability to deal with failures. However, few of these studies investigated personal and social variables. Some highlighted that when athletes have the impression that they are supported socially (e.g., by teammates), self-compassion tends to increase. It seems that social and personal variables can be either the antecedents or consequences of self-compassion. Also, a gap underlined in that scoping review were that studies rarely analyzed real-time reactions to failure and stress.

Another literature review on self-compassion and physical activity was conducted by Wong et al. (2021), focusing on self-care and differing from Röthlin et al.'s (2019) study in that it looked at the general population rather than high-level performers. The authors highlighted that self-compassion was a trait allowing a positive and healthy self-care engagement. Self-compassionate individuals were more likely to practice positive thinking, possessed greater self-awareness, and made more accurate self-appraisals. Self-compassion can also be a coping strategy when facing a failure to transform negative or neutral emotions into more positive ones. The authors stated that participating in physical activities was a way to release negative psychological symptoms and improve mental health. Self-compassion seems to enhance people's physical health and health-related behaviors. Wong et al. (2021) wanted to study the relationship between physical activity and self-compassion. Their main question was: how does physical activity relate to self-compassion? The results' studies highlighted that self-compassion was associated with self-regulation and thus much likely to process goal settings, behavior evaluation and action-taking. This regulatory behavior, found among highly compassionate people, also applies to evaluations of physical health conditions and yet leading to physical activity-related acts and hence leading to a stronger intrinsic motivation in physical activity engagement (Magnus et al., 2010; Cox et al., 2019), as well as exercise re-engagement after exercise failure or exercise setbacks (Semenchuk et al., 2018).

The present semi-systematic review focuses on the impact and influences between social environments and the psychological competencies of self-compassion and mental toughness within performance settings (sport, music, and dance). It aims to demonstrate the degrees of association and causality between self-compassion, mental toughness, and the social environment within a context of high performance (sport and performing arts).

MATERIALS AND METHODS

This semi-systematic review was developed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2015). An inclusive search strategy was applied, meaning that we sought out both published studies from databases and studies from the gray literature. Review questions were defined, and selection tools were decided before data extraction (inclusion and exclusion criteria). Studies containing the selected keywords were identified *via* a comprehensively search of the following bibliographic

databases: APA PsyNet, Renouvaud, ScienceDirect from Elsevier, Pubmed and Google Scholar. A manual search of publication was also done to identify possible missing studies. Studies with relevant titles published in the International Journal of Sport and Exercise Psychology, the Journal of Applied Sport Psychology, Psychology of Sport and Exercise, the Journal on Dance Science, and Psychology of Music were also screened. Additionally, a snowballing technique was adopted to pursue references in referenced articles. The search terms and keywords were developed and checked comparing them with previous literature reviews examining self-compassion, social relationships (interpersonal relationships), and mental toughness. The search terms were: [performance] sports, performing arts, music, dance; [self-compassion] self-kindness, common humanity, mindfulness, isolation, over-identification, self-judgment, self-compassion; [social environment] coach, parents, teammates; [mental toughness] mental toughness. The review identified studies that looked at the relationship between sport or performing arts, self-compassion, social environments, and mental toughness. To ensure that studies' outcomes were up to date, only relevant studies published since the birth of the concept of self-compassion, in 2003-onwards, were identified. Finally, specific research questions were developed:

1. What associations can be made between mental toughness and self-compassion?
2. What kind of influence do social environments have on the development of self-compassion?

Inclusion Criteria

No boundaries were set as to the ages of the performers mentioned in the studies reviewed. The study inclusion criteria were as follows: articles and studies written in English or French, including original research or peer-reviewed articles published from 2003 to 2021; examining sport or performing arts settings (music and dance); using qualitative or quantitative methods. Endnote reference management software was used to store and organize all the relevant studies, for screening, and to delete duplicate records. The titles and abstracts of all relevant studies were screened and selected for full-text retrieval and review, based on the inclusion and exclusion criteria. Any study limitations or criticisms that arose on examination, such as sample representativeness or study reliability and validity, were also considered. Articles that did not meet our inclusion criteria were removed from the review process. A flow diagram describing the study identification process is shown in **Figure 1**.

Data Extraction

Data from each study included in the review were extracted and coded, including information on the study design and methodology, demographic information including performers' ages and activity types, as well as the types of instruments used to assess levels of self-compassion, mental toughness, and role or influence of social environments (**Table 1**). A single investigator extracted the data and screened and reviewed all the papers that met the study's inclusion criteria.

Outcomes

The primary outcomes were the degrees of association and causality between self-compassion, mental toughness, and the effects of the social environment. Secondary outcomes included the characteristics of the activities examined in the studies reviewed, such as the types of sports practiced, or arts performed.

DATA SYNTHESIS

Our semi-systematic literature review extracted sixteen studies. The main results were synthesized and classified according to the two research questions (**Table 2**). These results are then discussed in three sections: self-compassion and mental toughness, self-compassion and the social environment, and self-compassion and the performing arts.

Self-Compassion and Mental Toughness

Can mental toughness and inner kindness toward oneself work together to support mental health and performance? Despite differences, it seems that mental toughness and self-compassion share many commonalities (Wilson et al., 2019; Johnson, 2020; Stamatis et al., 2020; Maranan and Lopez, 2021). To the best of our knowledge, Wilson et al. (2019) were the first to explore the compatibility of these two concepts with regards to athletic performance.

Their results suggested that mental toughness and self-compassion were indeed compatible, complementary concepts (Wilson et al., 2019; Johnson, 2020; Stamatis et al., 2020; Maranan and Lopez, 2021). Self-compassion helped performers cope with difficult situations, whereas mental toughness seemed to be helpful in maintaining high motivation, concentration, and resilience (Wilson et al., 2019; Stamatis et al., 2020). Wilson et al. (2019) suggested that if a person cannot move on after facing adversity, they may not be able to maintain an attitude of mental toughness. Therefore self-compassion is crucial to performers.

The participants in the studies investigating these two concepts were mainly women (Wilson et al., 2019; Stamatis et al., 2020). Both quantitative (Stamatis et al., 2020; Maranan and Lopez, 2021) and qualitative (Wilson et al., 2019) methods were used to investigate the relationship between self-compassion and mental toughness. Researchers (Wilson et al., 2019; Johnson, 2020; Stamatis et al., 2020; Maranan and Lopez, 2021) emphasized the importance of working on and developing mental toughness and self-compassion to equip performers to face the challenges they will encounter while allowing them to take care of their mental health. In some athletes, a high level of mental toughness but a low level of self-compassion can lead to difficulties in controlling their emotions in difficult moments (Maranan and Lopez, 2021). Self-compassion can then be useful, filling these gaps by helping these performers to develop an open, understanding attitude toward themselves. Researchers have also looked at parallel concepts such as athletic identity or communication (Maranan and Lopez, 2021).

According to the participants in Wilson et al.'s (2019) study, on the one hand, mental toughness was expressed through perseverance (the capacity to continue despite the

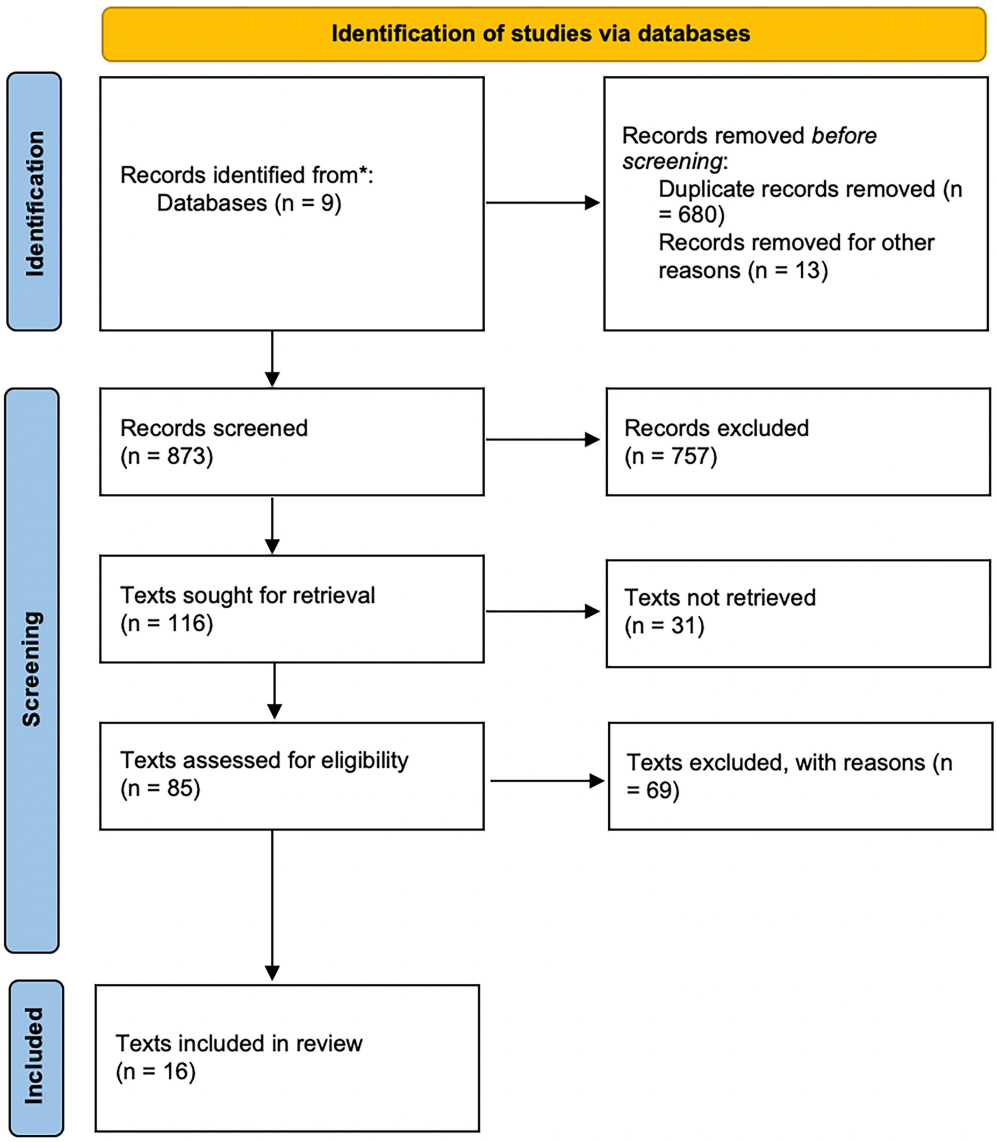


FIGURE 1 | PRISMA diagram of reviewed texts (Page et al., 2021).

difficulties encountered), presence (the capacity to re-focus on what one is doing), perspective-taking and the capacity to prepare oneself for a demanding situation (e.g., competition). On the other hand, despite a lack of understanding of the concept, self-compassion would allow one to develop personal coping resources by feeling that one was not alone and that others sometimes experienced similar situations (i.e., common humanity). In addition, mindfulness—an important aspect of self-compassion— allows performers to keep their attention on the present moment and avoid being caught up in thoughts and emotions (Johnson, 2020; Stamatis et al., 2020; Maranan and Lopez, 2021). Finally, self-compassion was mainly used through positive internal discourse.

Self-compassion seems to help performers develop their mental toughness by allowing them to develop an understanding of what is happening to them, re-evaluate the situation, and then move on (Wilson et al., 2019; Stamatis et al., 2020; Maranan and Lopez, 2021). Some participants also perceived self-compassion as necessary because without it, performers could not be self-aware, supportive, and compassionate enough (with themselves) to deal with the difficult emotions they faced. Self-compassion protected them from the potential pitfalls of a sporting culture of mental toughness that encouraged resilience but emotional avoidance (Johnson, 2020). Self-compassion may lead to mental toughness by developing a better understanding of self-regulation strategies, for example, and thereby help become mentally tough. Moreover, acceptance of injury-related physical limitations (e.g., reduced training intensity and duration) was also important, as it contributed to greater self-awareness. Stamatis

TABLE 1 | Overview of the information retrieved from the abstracts and articles' description retained for review.

References	Study aims	Sample	Methods
1. Graham-Williams (2013)	Explore transformative changes in self-esteem, self-perception of dance ability, and expressions of spirituality that may occur when adolescent girls not only participate in classical ballet classes but also learn in a teaching model emphasizing compassion, encouragement, discipline, and technique.	27 adolescent girl ballet dancers aged from 14 to 19 years old.	Dancers were divided into 2 groups to compare a traditional, five-week classical ballet class with an experimental class emphasizing compassion, encouragement, discipline, and technique. These attributes were pre- and post-tested using the Rosenberg Self-Esteem Scale (RSES), the dance subscale of Vispoel's Arts Self-Perception Inventory (ASPI), and the short version of MacDonald's Expressions of Spirituality Inventory (ESI)
2. Baltzell et al. (2015)	Examine the perceptions of a university women's Division I soccer coaching staff of their participation with their team in Mindfulness Meditation Training for Sport (MMTS). Report the coaches' perceptions of the value of the MMTS program to themselves and their athletes, and offer suggestions of how to improve the intervention's design and delivery.	Three coaches and 19 female soccer players from a Division I varsity women's soccer team.	Coaches underwent face-to-face interviews after they completed a 6-week, twice-weekly mindfulness and compassion training intervention with their team. Researchers sought to ascertain coaches' experiences, perceived benefits to their team, and recommendations for improving the design and delivery of the MMTS program.
3. Jeon et al. (2016)	Examine whether self-compassion mediates the relationship between social support and subjective well-being, as perceived by athletes and investigate the structural relationships between these variables.	333 Korean high school or university athletes: 144 university students (123 males, 21 females; mean = 21.5 years, SD = 1.2) and 189 high school students (131 males, 58 females; mean = 17.9 years, SD = 0.8).	Quantitative survey through the completion of the following questionnaires: Self-Compassion Scale, Subjective Well-being Scale, Satisfaction with Life Scale, Korean Emotional Experience Scale, Social Support Scale
4. Fontana et al. (2017)	Examine the relationships between athletes' perceptions of the motivational climate (caring, task-, and ego-involving) to their levels of compassion, self-compassion, pride, and shame in a recreational sport setting.	164 athletes in a competitive Wiffle Ball tournament.	Quantitative survey through the completion of the following questionnaires: Perceived Motivational Climate in Sports Questionnaire, Caring Climate Scale, the Compassionate Love Scale, the Self-Compassion Scale, the Pride Scale's Fear of Experiencing Shame and Embarrassment Subscale
5. Tarasoff et al. (2017)	Explore self-compassion in relation to self-evaluative thoughts and behaviors in an evaluative ballet environment.	57 women undergraduate students of whom 30.4% had past dance experience (mean = 20.59 years, SD = 3.81) completed an online questionnaire.	Questionnaires measuring self-compassion, social physique anxiety (trait and state versions), fear of negative evaluation (trait and state versions), as well as reactions, thoughts, and emotions to a hypothetical 'first day of beginner ballet class' scenario consistent with the common characteristics of the dance environment.
6. Kveton-Bohnert (2018)	Explore how today's dancers think about their critical, competitive, and immersive training and how their environment of mirrors, continual teacher correction, and performance demands affects their self-image, emotions, behaviors, and psychological development.	Three age groups of dancers offered narratives: 6 present-day, teenaged, classical ballet students, 6 professional ballet dancers, and 8 adult ballet instructors.	Semi-structured interviews were conducted to gather descriptions of how ballet shapes a dancer's psyche.
7. Crozier et al. (2019)	Explore the relationship between athletes' self-compassion and their teammates' perceived self-compassion.	Team sport competitive athletes (N = 108; mean = 23.1 years; SD = 4.68) from soccer (n = 12), cricket (n = 11), volleyball (n = 10), basketball (n = 10), ice hockey (n = 8), broomball (n = 8), wheelchair basketball (n = 7), and netball (n = 6).	Descriptive norm questions examined participants' perceptions of teammates' self-compassion. Three items from the SCS-AV2 scale were modified to reflect perceptions of descriptive norms, targeting athletes' perceptions of how frequently their teammates acted self-compassionately
8. Hilliard et al. (2019)	Examine the moderating role of self-compassion on the relationship between public stigma and self-stigma, and how self-stigma was associated with attitudes toward seeking counseling.	(n = 97 female, n = 146 male) representing student athletes from National Collegiate Athletic Association (NCAA) Division I (n = 93) and Division III (n = 150) institutions. The participants ranged in age from 18 to 23 (M = 19.38, SD = 1.25).	Quantitative survey through the completion of Self-compassion scale, Self-stigma scale, Stigma Scale for Receiving Psychological Help, Attitudes Toward Seeking Professional Psychological Help-Short Form

(Continued)

TABLE 1 | Continued

References	Study aims	Sample	Methods
9. Wilson et al. (2019)	Explore how elite women athletes perceived and experienced mental toughness, self-compassion, and their compatibility in the pursuit of athletic success and stress management.	Seven participants (14 interviews) aged 22–34 (mean = 28.3 years; SD = 5.1), including two half-pipe snowboarders, a swimmer, an ice skater, a downhill mountain-biker, a trampolinist, and a rock climber.	Semi-structured interviews adopting an interpretive, constructionist approach.
10. Kelley and Farley (2019)	Examine how college-age music students report self-compassion in comparison to non-music students.	Participants included 49 music majors and 52 non-music majors (N = 101; 56% female).	Two data collections using the 26-item Self-Compassion Scale with an added self-report prompt examining frequency of performance anxiety in the second study.
11. Stamatis et al. (2020)	Investigate self-compassion (SC), mental toughness (MT) and mental health (MH) in a National Collegiate Athletic Association (NCAA) environment for the first time and provide practical suggestions for NCAA MH best practice No.4.	542 student athletes participating across Divisions (mean = 19.84 years; SD = 1.7).	Data were collected using the Mental Toughness Index, the Self-Compassion Scale, and the Mental Health Continuum-Short Form.
12. Johnson (2020)	Explore the relationship between mental toughness and self-compassion in a sport injury context.	Women (n = 51) and men (n = 30) athletes (Mean = 22.6 years; SD = 4.1) from different sports: ice hockey, soccer, basketball, cross-country, football, gymnastics, rugby, swimming, track and field, volleyball, wrestling.	Mixed methods: Quantitative– currently injured athletes (n = 81) completed measures of mental toughness, self-compassion, coping resources, self-esteem, and self-criticism; Qualitative– four semi-structured interviews with athletes from the quantitative study.
13. Frentz et al. (2020)	Explore how high-performance athletes shifted from self-critical to self-compassionate approaches to manage their sporting challenges.	Eleven athletes (6 men, 5 women) aged 19–35 years old (M 1/4 24.7, SD 1/4 4.22), from American football, field hockey, cross-country running, curling, wheelchair rugby, Brazilian jiujitsu, soccer, ice hockey, bobsleigh, swimming, and dance.	One-on-one semi-structured interviews
14. Scott et al. (2021)	Consider how Positive Coaching Alliance (PCA) Triple-Impact Competitor (TIC) workshops could be used to help create positive climates for recreational sport club athletes, and examine how perceptions of a positive team climate related to indices of psychological well-being among sport club athletes.	Recreational college sport club athletes (N = 109; 64.2% male; 35.8% female) at a Midwestern university. Mean age = 20.42 years (SD = 1.84).	Facilitating 90-min TIC workshops at the beginning of the fall 2018 season and 30-min follow-up TIC workshops at the beginning of the spring 2019 season for all the officers and coaches of each sport club team. In parallel, conduct a survey including: the Caring Climate Scale; Perceived Motivational Climate Scale; Subjective Happiness Scale; Hope Scale; and Self-compassion Scale
15. Diehl (2021)	Explore how college-student athletes experience and cope with shame-inducing events in their sport and understand the impact of various intrapersonal (self-compassion) and interpersonal (team climate) factors as potential resources or barriers to shame resilience for US college-student athletes.	40 college-student athlete participants (quantitative study) and 15 college-student athlete participants (qualitative study).	Mixed methods: A survey including the Performance Failure Appraisal Inventory's Fear of Experiencing Shame and Embarrassment subscale, the Perceived Motivational Climate in Sports Questionnaire, the Self-Compassion Scale-Short Form, the Athletic Identity Measurement Scale, Multidimensional Inventory of Perfectionism in Sport, Basic Needs Satisfaction in Sport Scale; There were also semi-structured interviews
16. Maranan and Lopez (2021)	Identify mental skills that aid the development of mental toughness by assessing and exploring the relationships between athletic identity, self-compassion, and intra-team communication.	230 college-student athletes (mean = 20 years; SD = 1; 57% male, n = 131) participating in a singles table tennis event.	Multi-part questionnaire using the Athletic Identity Measurement Scale-Plus, Self-compassion Scale (SCS), Scale of Effective Communication in Team Sports (SECTS-2), and the Sports Mental Toughness Questionnaire (SMTQ)

et al. (2020) also proposed practical implications. However, there remains a lack of clear guidelines on how athletes, coaches, or parents can proceed to accompany or develop these psychological skills in practice. Skillful use of mental toughness components (e.g., goal commitment, perseverance, task focus) and self-compassion might involve knowing which characteristic to use in a given situation. For example, mental toughness components' might be useful during competition and self-compassion afterward. The way these psychological processes (e.g., self-compassion, goal setting, perseverance) should be used seems to vary depending on the situation (e.g., during competition, afterward) and the performer itself (e.g., personal characteristics, or need at one specific moment). Anyhow, it seems that these psychological processes are central

TABLE 2 | Synthesis of the articles' aims and results (retrieved from the abstracts) according to the two research questions.

References*	Research question 1. What associations can be made between mental toughness and self-compassion?	Research question 2. What kind of influence do social environments have on the development of self-compassion?
9. Wilson et al. (2019)	Aims: Explore how elite women athletes perceived and experienced mental toughness, self-compassion, and their compatibility in the pursuit of athletic success and stress management. Results: Self-compassion and mindfulness were worthy of investigation among elite women athletes, particularly regarding their utility in coping with sport-related adversity and achieving a mentally tough mindset. Self-compassion and mental toughness are compatible processes that may both require mindfulness and, if used in an effective, complementary balance, could create optimal mindsets for the pursuit of athletic success.	
10. Kelley and Farley (2019)	Aims: Examine how college-age music students report self-compassion in comparison to non-music students. Results: The studies revealed no significant difference in self-compassion levels between the groups, although a significant correlation was detected between experiences of performance anxiety and the self-compassion subcomponent of over-identification. Although the results revealed no difference between groups, performance anxiety among musicians may be related to perceived self-compassion.	
11. Stamatis et al. (2020)	Aims: Investigate self-compassion (SC), mental toughness (MT) and mental health (MH) in a National Collegiate Athletic Association (NCAA) environment for the first time and provide practical suggestions for NCAA MH best practice No.4. Results: MT, SC (including mindfulness) and MH were positively correlated. Males scored higher than females on all three scales. No differences were found between divisions. SC partially mediated the MT–MH relationship, but moderation was not significant. The authors offered a preliminary step toward promoting resilience and wellness.	
12. Johnson (2020)	Aims: Explore the relationship between mental toughness and self-compassion in a sport injury context. Results: Quantitative study findings showed that self-compassion was a significant predictor of mental toughness, coping resources, and self-criticism, beyond the effects of age and self-esteem. Qualitative results described how self-compassion was needed to be mentally tough and that mental toughness was needed to be self-compassionate in sport. They suggested self-compassion was needed to be mentally tough, and vice versa. Future research should examine the relationship between mental toughness and self-compassion over time.	
16. Maranan and Lopez (2021)	Aims: Identify mental skills that aid the development of mental toughness by assessing and exploring the relationships between athletic identity, self-compassion, and intra-team communication. Results: Findings indicated high levels of athletic identity and intra-team communication among the participants, but moderate levels for self-compassion and mental toughness. On one hand, self-compassionate participants who highly recognize their role as athletes, and communicated with their team were mentally tougher. On the other hand, uncompassionate self-responding led student athletes to become mentally weak. The study provided practitioners with useful insights for designing mental skills training geared toward the optimal functioning and psychological wellness of young athletes.	Aims: Identify mental skills that aid the development of mental toughness by assessing and exploring the relationships between athletic identity, self-compassion, and intra-team communication. Results: Findings indicated high levels of athletic identity and intra-team communication among the participants, but moderate levels for self-compassion and mental toughness. On one hand, self-compassionate participants who highly recognize their role as athletes, and communicated with their team were mentally tougher. On the other hand, uncompassionate self-responding led student athletes to become mentally weak. The study provided practitioners with useful insights for designing mental skills training geared toward the optimal functioning and psychological wellness of young athletes.

(Continued)

TABLE 2 | Continued

References*	Research question 1. What associations can be made between mental toughness and self-compassion?	Research question 2. What kind of influence do social environments have on the development of self-compassion?
1. Graham-Williams (2013)		Aims: Explore transformative changes in self-esteem, self-perception of dance ability, and expressions of spirituality that may occur when adolescent girls not only participate in classical ballet classes but also learn in a teaching model emphasizing compassion, encouragement, discipline, and technique. Results: There was no significant statistical analysis, but the study's observational findings acknowledged the potential impact of student–teacher rapport in the compassion- and empowerment-based teaching of classical ballet to adolescent girls.
2. Baltzell et al. (2015)		Aims: Examine the perceptions of a university women's Division I soccer coaching staff of their participation with their team in Mindfulness Meditation Training for Sport (MMTS). Report the coaches' perceptions of the value of the MMTS program to themselves and their athletes, and offer suggestions of how to improve the intervention's design and delivery. Results: In the main findings, coaches reported experiencing less emotional reactivity to their own negative thoughts and emotions while coaching on the field (at games and practices). They also observed positive changes in how players recovered from mistakes on the field emotionally. Findings suggested that including coaches in mindfulness meditation training programs was beneficial to both coaches and athletes.
3. Jeon et al. (2016)		Aims: Examine whether self-compassion mediates the relationship between social support and subjective well-being, as perceived by athletes and investigate the structural relationships between these variables. Results: Self-compassion partially mediated the relationship between social support and subjective well-being. This confirmation demonstrated that self-compassionate attitudes could be fostered by social support, and that, in turn, had a positive effect on an individual's subjective well-being.
4. Fontana et al. (2017)		Aims: Examine the relationships between athletes' perceptions of the motivational climate (caring, task-, and ego-involving) to their levels of compassion, self-compassion, pride, and shame in a recreational sport setting. Results: Athletes' perceptions of a caring and task-involving motivational climate were associated with higher levels of compassion for others, but no difference in self-compassion was found. Results suggested that participants in adult recreational sports might benefit from experiencing a positive, supportive team climate.
5. Tarasoff et al. (2017)		Aims: Explore self-compassion in relation to self-evaluative thoughts and behaviors in an evaluative ballet environment. Results: Self-compassion was negatively related to trait and state social physique anxiety, trait and state fear of negative evaluation, total negative affect, personalizing thoughts, and catastrophizing thoughts, as well as positively associated with behavioral equanimity. Finding self-compassion to be associated with lower negative self-perceptions within the context of an evaluative beginner ballet class replicated past correlational research and advanced the literature by contextualizing self-compassion to a specific evaluative environment.

(Continued)

TABLE 2 | Continued

References*	Research question 1. What associations can be made between mental toughness and self-compassion?	Research question 2. What kind of influence do social environments have on the development of self-compassion?
6. Kveton-Bohnert (2018)		Aims: Explore how today's dancers think about their critical, competitive, and immersive training and how their environment of mirrors, continual teacher correction, and performance demands affects their self-image, emotions, behaviors, and psychological development Results: The participants indicated that although ballet training was moving away from authoritarian methods, and despite their deep love for the art, they still struggled with negative body image and perfectionist ruminations about flaws. Ballet training should incorporate strategies to build resilience, mindfulness, and self-compassion, which would help dancers develop a healthy inner voice and a growth mindset to sustain them throughout their training and careers. This included fostering self-agency, autonomy, optimism, environmental mastery, personal growth, purpose and meaning, self-acceptance, and positive relations with others. Ways to enhance ballet training to promote intrinsic satisfaction and resilience using mindful learning and a growth mindset were discussed through the lens of positive and humanistic psychology. The goal was to improve dancers' training to forestall unnecessary suffering and enhance well-being and wholeness.
7. Crozier et al. (2019)		Aims: Explore the relationship between athletes' self-compassion and their teammates' perceived self-compassion. Results: Athletes' self-compassion was related to their perceptions of how often their teammates were self-compassionate. Coaches and sport psychologists should encourage athletes to build awareness about how their cognition and behavior relate to others' cognitions and behaviors.
8. Hilliard et al. (2019)		Aims: Examine the moderating role of self-compassion on the relationship between public stigma and self-stigma, and how self-stigma was associated with attitudes toward seeking counseling. Results: Self-compassion was not found to moderate the relationship between public stigma and self-stigma. However, public stigma was positively associated with self-stigma, and self-stigma was negatively associated with attitudes toward counseling. A multigroup analysis found no differences between males and females in this model. The study's results had implications for professionals working with college-student athletes, suggesting that efforts should aim to reduce stigma and examine alternative factors that might improve attitudes toward seeking help with mental health.
13. Frentz et al. (2020)		Aims: Explore how high-performance athletes shifted from self-critical to self-compassionate approaches to manage their sporting challenges. Results: Five themes emerged, covering the key factors in participants' shifts toward self-compassion: (a) role of the coach, (b) influence of other athletes, (c) impact of important others, (d) developing balanced self-awareness, and (e) maintaining an accepting mindset. Study findings will inform future interventions to support adaptive athlete experiences.

(Continued)

TABLE 2 | Continued

References*	Research question 1. What associations can be made between mental toughness and self-compassion?	Research question 2. What kind of influence do social environments have on the development of self-compassion?
14. Scott et al. (2021)		Aims: Consider how Positive Coaching Alliance (PCA) Triple-Impact Competitor (TIC) workshops could be used to help create positive climates for recreational sport club athletes, and examine how perceptions of a positive team climate related to indices of psychological well-being among sport club athletes. Results: Athletes' perceptions of a caring and task-oriented climate were significantly and positively related to their hope, happiness, and self-kindness. Results suggested that the PCA TIC training was an inexpensive strategy that could foster positive environments within university sport club teams and assist in programs promoting indices of psychological well-being among club sport athletes.
15. Diehl (2021)		Aims: Explore how college-student athletes experience and cope with shame-inducing events in their sport and understand the impact of various intrapersonal (self-compassion) and interpersonal (team climate) factors as potential resources or barriers to shame resilience for US college-student athletes. Results: (1) Sport-based shame may negatively impact sport competence and experience; (2) the internalization of the performance ethic (i.e., worth based on outcome success) may lead to sport-based shame; and (3) self-compassion may represent an intrapersonal shame-coping strategy for sport-based shame. In addition, one qualitative-dominant divergent finding revealed that interpersonal support (empathic accuracy, situational feedback, and task/mastery team climates) might lead to intrapersonal shame resilience for college-student athletes.

*The numbers in front of the references correspond to the numbers in ***Table 1***.

to become an adaptative and stronger performer, but more research is needed to understand how and when to exercise these different skills.

Mindfulness is also a key link between mental toughness and self-compassion. Wilson et al.'s (2019) and Johnson's (2020) participants used it to regulate attention and emotion (two key dimensions of Gucciardi's concept of mental toughness). This may also support the notion that mindfulness should be studied further as a possible component of not only self-compassion but also mental toughness (e.g., a possible additional key dimension in Gucciardi's one-dimensional concept of mental toughness).

Self-Compassion and the Social Environment

Our literature review found that the environment in which performers practiced had a crucial impact and influence on the development of self-compassion (Graham-Williams, 2013; Fontana et al., 2017). A performer's social environment is often created by their coach as well as by their peers and parents (Frentz et al., 2020). The coach appears to have a crucial role to play in the development of skill of self-compassion (Frentz et al., 2020). Fontana et al. (2017) highlighted the link between perceptions that an environment was caring and the level compassion one might feel for peers, teammates, or a coach. For others, compassion seems to be influenced by a caring environment (Fontana et al., 2017; Crozier et al., 2019). Some researchers have also highlighted the negative correlation between ego-centric environments and how forgiving one might be toward teammates who make mistakes or failure (Fontana et al., 2017). In contrast, the link between self-compassion and a caring atmosphere is not as clear (Fontana et al., 2017; Hilliard et al., 2019). Some studies have highlighted the need to develop a self-compassion tool specific to the world of performers because, to date, Neff's (2003b) scale to detect self-compassion in the general population might be interpreted by them as self-pity, depending on the items (Fontana et al., 2017).

Some studies have focused on implementing intervention programs to help coaches and/or performers develop skills in mindfulness and self-compassion (Baltzell et al., 2015; Scott et al., 2021). Data have highlighted that these different types of themes could have impacts on coaches: increased sensitivity to their athletes' feelings, increased knowledge and awareness of their own feelings, and improved coach–athlete relationships (Baltzell et al., 2015; Frentz et al., 2020), as well as increased skills in self-compassion and well-being (Scott et al., 2021). Athletes appear to be more effective at recovering emotionally after a difficult situation and feel more care and warmth for themselves and their peers. Creating compassionate environments seems to enable athletes to create better adaptation mechanisms (Scott et al., 2021).

Studies looking at self-compassion or its development through the creation of a compassionate environment have mainly focused on performers' perspectives (Fontana et al., 2017). Coaches, as well as the performers circle of acquaintances (e.g., parents, peers), have been studied less (Baltzell et al., 2015; Frentz et al., 2020) and it would be interesting to investigate coaches' influence and ability to develop compassionate environments for performers' performance and well-being. Social support and the creation of supportive and compassionate environments do, however, appear to effect self-compassion (Graham-Williams, 2013; Jeon et al., 2016), despite the mixed results revealed by Fontana et al. (2017). Social support and the creation of supportive environments can improve a performer's coping skills and contribute to more positive emotions and greater perceived self-worth (Graham-Williams, 2013; Jeon et al., 2016; Crozier et al., 2019; Frentz et al., 2020; Diehl, 2021). Individuals' attitudes toward themselves are influenced by the evaluations of significant others.

Studies with athletes show that the feeling of social support (Jeon et al., 2016) or perceiving teammates to be highly self-compassionate (Crozier et al., 2019) increases well-being. Other situational features, such as the motivational atmosphere, are not correlated with self-compassion (Fontana et al., 2017). Thus, studies investigating self-compassion should consider these aspects to be potential moderators (e.g., whether athletes in teams demonstrating little self-compassion, great concerns about perfectionism, or low levels of social support would benefit markedly from greater self-compassion).

Self-Compassion and the Performing Arts

To date, some research on self-compassion has been done among dancers (Graham-Williams, 2013; Ingstrup et al., 2017; Tarasoff et al., 2017; Kveton-Bohnert, 2018). However, to the best of our knowledge, only one study focusing on self-compassion has been carried out in the music field (Kelley and Farley, 2019). It is, therefore, important to consider these few studies considering broader research in the field of performance psychology. These performers face many challenges—as do athletes—that need to be overcome and learning environments are likely to be a key location where performers can be equipped with skills such as self-compassion and mental toughness.

Research in the field of the performing arts has focused primarily on dance, highlighting the deleterious role that their working environments sometimes have on dancers' well-being and level of self-compassion (Graham-Williams, 2013; Tarasoff et al., 2017). Researchers point out that the environments in which dancers practice and perform subject them to a form of constant evaluation that is not conducive to looking at oneself with compassion and kindness, leading to detrimental effects on one's self-image (Kveton-Bohnert, 2018). Researchers have provided evidence that a musician or dancer's level of self-compassion can be improved using therapeutic means that can lead to better mental health outcomes (Tarasoff et al., 2017; Kveton-Bohnert, 2018; Kelley and Farley, 2019). The results of these studies were like those exploring self-esteem in the performing arts or self-compassion among athletes. Graham-Williams (2013) looked at dance education methods and their influence on dancers' levels of self-compassion. The results were not significant but teaching with a focus on compassion and caring nevertheless seemed to have beneficial effects on those performers' well-being.

The field of performing arts is still under-researched. It would seem important, when studying self-compassion and mental toughness, to include musicians, dancers, and performers to create a bridge between the worlds of sport and the performance arts, which are not so different from each other in many respects.

DISCUSSION

This semi-systematic literature review examined the relationships between self-compassion, mental toughness, and the influence of social environments on performers (athletes, dancers, and musicians). The review showed that self-compassion was positively correlated with social support and was a good complement to mental toughness. But it also showed that there was a lack of knowledge about this concept in the field of the performing arts (dance and music). Moreover, the results highlighted the importance of looking at why self-compassion does or does not develop and, more importantly, how to help performers and those around them develop it.

Most of the studies covered in this review examined the potential benefits of self-compassion on well-being and social relationships. Few, however, examined the influence of self-compassion on sports and artistic performance. Developing studies highlighting the links between self-compassion and performance could improve acceptance of ideas about this concept among these populations.

The literature reviewed showed that the positive relationships between self-compassion, mental toughness, and social environments exists in populations of athletes (Fontana et al., 2017; Wilson et al., 2019; Frentz et al., 2020; Johnson, 2020; Stamatis et al., 2020; Maranan and Lopez, 2021). Studies suggest that self-compassion is a psychological resource that should be developed alongside mental toughness and that the use of either concept depends on the context and setting. Self-compassion and mental toughness are related but distinct concepts, and they have been insufficiently studied together from the perspective of mental health or performance in sport and the arts. Both help to enhance performance and well-being by supporting performers as they attempt to manage stress, regulate thoughts and emotions, focus and re-focus their attention, and persevere despite setbacks.

The interacting effects of mental toughness and self-compassion on mental health are, therefore, an unresolved issue that deserves further investigation. Are they buffering, reinforcing, or antagonistic effects? Optimal mental health in sport may not only be about mental toughness and self-compassion, but also about the timing and context of their application. One hypothesis would be to adapt the concept of self-compassion to the world of sport by competency through mental toughness, two concepts to be studied in parallel (Adam et al., 2021). Self-compassion would also help

performers overcome feelings of stigmatization over their vulnerabilities by allowing them to seek help. The research reviewed showed that more self-compassionate athletes reported seeking the help they thought necessary more frequently than their less self-compassionate peers (Scott et al., 2021). Future studies should include more representative samples from a wider range of performers (i.e., athletes, dancers, and musicians) to investigate the potential effects of different performance cultures.

This review sought to provide an overview of the current literature on self-compassion, mental toughness, and the social environment in the worlds of sport (athletes) and performing arts (dancers and musicians). We conclude that the number of multi-day intervention programs and longitudinal studies should be increased. These studies should consider assessing the specific aspects of performance culture and settings that could alter the effectiveness of these interventions. In addition, overall performance specific measures could be developed to assess general levels of self-compassion. The development of a theoretical framework explaining how self-compassion affects a performer, the role of their entourage and its link to other psychological resources, such as mental toughness, could help to better understand this concept. The development of self-compassion has also proven to be an important driver in the search for psychological help (Heath et al., 2017) in the general population. Indeed, it could be hypothesized that developing a compassionate and caring environment around performers would help them to develop self-compassion which, as shown in various research studies, improves well-being and performance (Jeon et al., 2016; Frentz et al., 2020; Scott et al., 2021). It could also lead to performers being more open to seeking psychological help when needed (Adam et al., 2021). This might make it possible to better prevent certain psychological shifts or difficulties (e.g., doubting their personal capabilities, feeling bad about themselves) that performers currently keep silent for fear of appearing weak.

It is also important to emphasize the practical implications of applying self-compassion to the worlds of sport and the performing arts. Based on the current literature, self-compassion seems to be particularly useful when trying to increase performers' well-being or help them better deal with stress, failure, and setbacks. Athletes' skepticism about self-compassion should also be taken seriously. Interventions intended for performers should first check whether participants have concerns about the concept, explain clearly why self-compassion has the potential to improve performance (e.g., by helping athletes deal with failure), demonstrate the links between self-compassion and mental toughness, and acknowledge that current research is still ongoing on how to apply self-compassion in performance contexts. Moreover, further research should be carried out to design interventions adapted to performers' entourages (i.e., coaches, parents), stakeholders who play crucial roles in the development of psychological skills such as self-compassion and mental toughness.

AUTHOR CONTRIBUTIONS

CK, RAP, and VP contributed to the conception and the design of the study. CK organized the database, performed the analysis, and wrote the first draft of the manuscript. CK and RAP contributed to manuscript revision. All authors contributed to the article and approved the submitted version.

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Music students' workload, stress, and coping in higher education: Evidence-based policymaking

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Evidence-based policies are needed to support students as they cope with their experiences of workload and stress in higher music education. This subject was explored in the Music Student Workload Project as a collaboration between Finland and the United Kingdom in seven studies: (1) a theoretical study scrutinizing diverse higher music education systems in connection with equality and cultural reproduction; (2) a systematic review mapping international research on music students' workload; (3) a methodological study discussing the transcendental phenomenological approach as a method for obtaining a meaningful understanding of music students' experiences in higher education; (4) a qualitative study exploring music students' workload experiences in connection with their meaningful engagement in music; (5) a mixed-method study shedding light on music students' proactive coping styles in connection with workload and stress; (6) a mixed-method study examining music students' experienced workload, stress, and livelihoods; and (7) a qualitative study exploring teachers' ways of supporting music students' workload and stress. The meta-narrative synthesis was conducted by triangulating the key elements of these studies to generate four actionable policy and intervention recommendations to inform educational policies and practices for supporting students in coping with workload and stress in higher music education: (1) support music students' proactive coping skills; (2) find solutions to the unequal workload and stress experiences between low-income and well-off students, different genders, and different study programs; (3) ensure teachers' continuing professional development, particularly in the learner-centered pedagogical approaches; and (4) invest resources for providing more longitudinal, cross-cultural, and interventional research investigating music students' discipline-specific experiences of workload and stress.

KEYWORDS

workload, stress, coping, music student, experience, intervention, policy recommendation, meta-narrative synthesis

Introduction

Students' workload in higher education affects their experiences in studying and wellbeing (Salmela-Aro and Read, 2017). Research in the context of higher education in Finland has shown alarming trends in the growth in students' psychological distress, which may be connected to various and increased environmental and institutional demands on

students (Oksanen et al., 2017). These pressures have become part of the current academic culture, in which neoliberalism has influenced many higher education policies (Gyamera and Burke, 2018), and which, in turn, has led to the situation where economic ideals guide students' choices in studying, graduating, and working life (Johnston, 2011). Although egalitarianism as an element of social progression has become a common and self-evident concept in educational policies (Kalalahti and Varjo, 2012), current educational systems with business-minded administrations and expectations for productivity and efficiency may nevertheless include elements that enhance or even introduce new inequalities (Reay, 2017). In the United Kingdom, the implementation of a neoliberalization policy agenda brought with it increased tuition fees for public higher education (Maisuria, 2014). Higher education in Finland did not have a tuition fee system before 2010 when the new university law separated higher education institutions from the state and gave them "an independent legal personality, either as public corporations or as foundations under private law" (Pekkola, 2009, p. 2). This neoliberal university reform seems to have strengthened the reproduction of social inequalities between genders and between classes and the polarization between privileged and less privileged individuals within the institution, as it involves the culturally and situationally specific forms of ideal academic boasting (Lund, 2020). For example, within this neoliberal reform, "students and workers are encouraged to internalise the values and presuppositions of the culture of innovation, to consider their work projects as their personal projects, to identify their advancement at the professional markets with their personal growth, to think, feel, perceive and sense in terms dictated by the economy" (Pekkola, 2009, p. 4). When looking particularly at higher music education policies and practices in Western countries, Bull (2020) argues that the historical roots in cultural reproduction have strengthened the middle class, maintained gendered patterns, and legitimized hierarchical, competitive, and exclusive practices in music education. Therefore, to pursue broader progress in educational equality, it is important to make public the evidence for inequalities in educational policies and practices. One way to produce this kind of evidence is to investigate music students' experiences of their workload and stress as they try to cope with the demands of higher education studies.

Student workload is a topic that has already been researched widely in higher education contexts (e.g., Chambers, 1992; Lockwood, 1999; Marsh, 2001; Kember, 2004; Bowyer, 2012). Previous research also shows how it is possible to support students in their coping with study workloads, for example with teachers' professional development work in their universities (Giles, 2009); assessment that supports learning processes (Hernesniemi et al., 2017); and constructive cooperative teaching (Kember and Leung, 2006). Reducing students' perceived overload is important because an overly heavy workload can have a negative effect on students' wellbeing and success in studying (Hernesniemi et al., 2017). On the other hand, teachers can increase both the demands and quality of learning without increasing students' perceived workload if teachers are able to maintain a cooperative atmosphere in the class (Kember and Leung, 2006). Scholars investigating students' workload emphasize that more research is needed, in particular about students' time and stress management and how increasing coping skills can affect students' ability to deal with workload, learning, distress, and burnout in higher education (Jacobs and Dodd, 2003; Kember, 2004; Amirkhan and Kofman, 2018).

Although exploring students' perceptions is a common approach to investigating their workload (Kember, 2004; Kember and Leung, 2006), the research on students' experiences of their workload (*experienced workload*), in particular in the field of music, can provide deeper knowledge for developing policies when higher music education institutions are seeking ways to support music students as well as possible. Indeed, in the higher education context, music students experience specific field-related challenges when compared to that of students in other disciplines. Performance anxiety, perfectionism, and career concerns are common sources of stress in studying music (e.g., Bernhard, 2007). Music students also suffer from painful musculoskeletal conditions and other health issues in studying music (e.g., Ginsborg et al., 2009), and there have been reported differences in experienced stress, particularly between genders, and in mood, bodily tensions, and somatic symptoms between music students studying in different programs (Zetterberg et al., 1998). Sudden and unexpected changes in learning circumstances, such as that which the COVID-19 pandemic has caused, may also affect music students' wellbeing (Habe et al., 2021), practice habits, and behaviors, as well as their everyday lives (Rosset et al., 2021).

In the context of studying music, workload is often connected to the negative consequences that difficult or unmanageable study situations may result in for music students, such as burnout (Bernhard, 2007) and mental illness (Koops and Kuebel, 2021). When aiming to support music students' ability to cope with workload, it is interesting to take note of their experiences of meaningful engagement in music, such as their passion and love for music, because they can be positive sources of workload for them (Park et al., 2007). It is also important to explore which environmental and intra-individual factors may be connected to music students' experienced workload in higher education. Thus, expanding our knowledge of music students' experiences in studying music is essential to understanding both the stressors and the resources associated with their workload, and to supporting the students' health, wellbeing, and learning (Koops and Kuebel, 2021). Moreover, Bresler (2005) argues that research focusing on lived experiences of musicianship and studying music have the potential to contribute to research methodologies in general, not only in music education but also in the social sciences and educational research. Research-based evidence on music students' experiences, when connected to the development of pedagogical practices in higher music education, can support the efforts of teachers and administrations to gain a deeper understanding of the diversity in student populations and the

individual circumstances of their students (see, e.g., Harrison, 2014). This kind of approach may help educational institutions to improve their support systems for students, to develop teaching and learning environments, and to advance educational policies.

Because research-based findings regarding students' experienced workload in higher music education are still lacking to a great extent, the Music Student Workload (MSW) Project was established in 2017 as a research collaboration between University of the Arts Helsinki in Finland and Royal Northern College of Music in the United Kingdom. The primary aim was to investigate music students' experiences of workload, stress, and coping in higher education. The researchers in this project were interested in all aspects of music students' workload during their years of study in higher education, such as the nature, meaning, and components of their workload. The interest was also in more concrete aspects of student workload while studying (such as attendance at lectures, rehearsals, and practice sessions), and also at other times (such as paid and unpaid work). Both negative aspects, such as burnout, and positive aspects, such as flow, were considered to be workload components. In particular, the interest was in the quality of music students' workload and its overall consequences. Therefore, the aim was to investigate how the students themselves experience their workload rather than measuring evidence for its quantity (such as time spent studying, completed credits, and grades). The data were collected in seven higher music education institutions in Finland and the United Kingdom. Over 4 years, a total of seven studies were conducted in the MSW Project (see study characteristics in Table 1): (1) a theoretical study scrutinizing diverse higher music education systems in connection with equality and cultural reproduction (Jääskeläinen, 2021); (2) a systematic review mapping international research on music students' workload (Jääskeläinen et al., 2022b); (3) a methodological study discussing the transcendental phenomenological approach as a method for obtaining a meaningful understanding of music students' experiences in higher education (Jääskeläinen, 2022b); (4) a qualitative study exploring music students' workload experiences in connection with their meaningful engagement in music (Jääskeläinen, 2022a); (5) a mixed-method study shedding light on music students' proactive coping styles in connection with workload and stress (Jääskeläinen et al., 2022a); (6) a mixed-method study examining music students' experienced workload, stress, and livelihoods (Jääskeläinen et al., 2020); and (7) a qualitative study exploring teachers' ways of supporting music students' workload and stress (Jääskeläinen and López-Íñiguez, 2022).

In order to illustrate how experienced workload was approached in the MSW Project when listening to music students' lived experiences, Figure 1 shows some quotations from research participants. The first experience is about a music student's coping with their workload, the second experience is about workload relating to the teaching and learning environments in the field of music, and the third experience is about a music student's workload in their interactions with teachers.

The objective of the present study is to bring together new and previous research on music students' workload in higher education by synthesizing the findings and results of the MSW Project through a meta-narrative approach for generating evidence-based policy and intervention recommendations. More specifically, the aims of the study are to:

1. map previous and new research on music students' experienced workload,
2. review the key elements of the findings and results from the seven studies in the MSW Project to provide policy and intervention recommendations, and
3. triangulate these key elements to build a synthesis of policy and intervention recommendations for supporting music students in coping with workload and stress in higher music education.

Materials and methods

Meta-narrative approach

The MSW Project incorporated diverse approaches to generating evidence about music students' experienced workload. In order to synthesize the heterogeneous evidence that had been studied in various ways in the seven studies, the MSW Project team chose to use an adaptation of the meta-narrative approach (originally developed by Greenhalgh et al., 2004, 2005). A meta-narrative synthesis develops an overarching narrative through story lines that show how research for a particular topic evolves over time and throughout different disciplines, leading to key insights (Greenhalgh et al., 2005). The six guiding principles of the meta-narrative method were followed (Greenhalgh et al., 2005; Wong et al., 2013): (1) pragmatism: the included information was reviewed according to its usefulness to the policy and intervention recommendations; (2) pluralism: the topic was considered from multiple perspectives in the seven studies; (3) historicity: the included information was presented according to its development over time, as there were no date restrictions on the systematic literature review; (4) contestation: conflicting information was used to generate higher-order insights; for example, data were collected in two countries with different higher education systems, and both frequentist and Bayesian statistics were used in the statistical analyses; (5) reflexivity: there was continual reflection on the studies in the MSW Project team, and the findings and results were also presented and discussed in several international conferences; and (6) peer-review: each of the seven studies went through an international, blinded peer-review process before publication in research journals.

We adapted the phases of the meta-narrative review according to Greenhalgh et al. (2004, 2005), including (1) a planning phase, where a MSW Project team—comprising the author of the present study as a principal investigator and three co-researchers/

TABLE 1 Study characteristics.

Study	Study design	Main research question(s)	Data collection	Sample	Analysis	Main findings and/or results
1. Tuition fees, entrance examinations and misconceptions about equity in higher music education (Jääskeläinen, 2021)	Theoretical study	How are equality and cultural reproduction connected to tuition fees and entrance examinations in higher music education institutions?	Not applicable	Not applicable	Not applicable	Tuition fee systems in higher music education institutions may aim at improving equality, equity, and justice for students but they can also enhance inequalities. Traditions in the field of music have created a strong culture of entrance examinations that is not easy to change because the roots of cultural reproduction are deeply embedded in educational systems.
2. Music students' experienced workload in higher education: A systematic review and recommendations for good practice (Jääskeläinen et al., 2022b)	Systematic literature review	1. What factors have an impact on students' experienced workload? 2. What are music students' experiences of workload in relation to their studies?	Systematic literature search	12 studies on students' experiences of workload in higher education and 17 studies on music students' experiences of workload in studying music	Extended meta-ethnography	A total of 24 recommendations for good practice to (a) increase music students' ability to cope with their workload, (b) provide tools for teachers to support music students to manage and cope with workload, and (c) develop learner-centered environments in higher music education
3. Using a transcendental phenomenological approach as a model to obtain a meaningful understanding of music students' experienced workload in higher education (Jääskeläinen, 2022b)	Methodological study	In what ways can a transcendental phenomenological research approach offer insights into music students' lived experiences in higher education?	Not applicable	Not applicable	Not applicable	Transcendental phenomenological research approach provides a practical model for addressing music students' unique and meaningful experiences in relation to future administrative and teaching developments in higher music education institutions, such as processing and incorporating students' feedback into improvements in teaching and learning environments.

(Continued)

TABLE 1 Continued

Study	Study design	Main research question(s)	Data collection	Sample	Analysis	Main findings and/or results
4. "Music is my life": Examining the connections between music students' workload experiences in higher education and meaningful engagement in music (Jääskeläinen, 2022a)	Qualitative study	What does engagement in music mean to 29 music students in higher education in Finland and the United Kingdom, when they reflect on the experiences of their studies and workload?	Interviews	29 music students in higher education in Finland and the United Kingdom	Transcendental phenomenology approach	Various holistic workload experiences: (1) the music students' intense and complex experiences (2) their development as musicians (3) their creative self-expression (4) their interactions with others (5) their personal growth and coping approaches (6) their transcendental musical experiences
5. Experienced workload, stress, and coping among professional students in higher music education: An explanatory mixed-method study in Finland and the United Kingdom (Jääskeläinen et al., 2022a)	Multi-strategy study	How do professional students in higher music education in Finland and the United Kingdom experience workload and stress and use proactive coping styles?	Questionnaire and interviews	155 music students in higher education in Finland and the United Kingdom	Frequentist statistics and transcendental phenomenology approach	Statistically significant differences among music students in genre groups and study programs in relation to experienced study workload; in genders, genre groups, and study programs in relation to experienced stress; and in genders in relation to use of coping styles. Study workload is a significant predictor of stress. Music students have their issues and ways to cope with workload and stress.
6. Music students' experienced workload, livelihoods and stress in higher education in Finland and the United Kingdom (Jääskeläinen et al., 2020)	Multi-strategy study	What are the predictors and determinants associated with music students' experiences of workload in relation to their livelihoods and stress in higher education?	Questionnaire and interviews	155 music students in higher education in Finland and the United Kingdom	Bayesian statistics and transcendental phenomenology approach	There is a need to pay attention to workload especially with undergraduate-level students, to stress especially regarding junior and doctoral-level study, and to particular areas of study, especially music education. Working while studying has an impact on music students' workload and stress, thus affecting students' relationship with studying and being a musician.

(Continued)

TABLE 1 Continued

Study	Study design	Main research question(s)	Data collection	Sample	Analysis	Main findings and/or results
7. Tools for teachers to support music students in managing and coping with their workload in higher education (Jääskeläinen and López-Íñiguez, 2022)	Qualitative study	What constructive tools for teachers can support music students in managing and coping with their experienced workload in higher education?	Questionnaire and interviews	155 music students in higher education in Finland and the United Kingdom	Transcendental phenomenology approach	A total of 43 constructive tools for teachers based on the music students' experiences.in the interactions with teachers concerning (1) the structure of workload (2) a music student's individual workload (3) workload relating to teaching and learning environments (4) psychological and physiological issues.

supervisors in Finland and one co-researcher/supervisor in the United Kingdom—was compiled; (2) a search phase, where previous research was searched with a systematic literature review and complemented with new research by conducting one theoretical, one methodological, and four empirical studies; (3) a mapping phase, where the findings and results from these seven studies were used to establish the key elements of music students' experienced workload, stress, and coping in higher education; (4) an appraisal phase, where the key elements were critically appraised for their validity and relevance to policy and intervention recommendations; (5) a synthesis phase, where a narrative account of included key elements for policy and intervention recommendations was prepared through a triangulation; and (6) a recommendations phase, where the findings from the triangulated key elements were summarized and policy and intervention recommendations were made for supporting music students in coping with workload and stress in higher music education.

Results

A planning phase

The planning phase started in 2017 when the research collaboration between University of the Arts Helsinki in Finland and Royal Northern College of Music in the United Kingdom was established and the MSW Project team was compiled. The research plan was written by the first author and critically commented by the three co-researchers/supervisors in Finland and one co-researcher/supervisor in the United Kingdom. The ethical evaluations were carried out for the research by the University of the Arts Helsinki Ethics Committee in 2018 and the Conservatoires United Kingdom Research Ethics Committee in 2019, and the statements were favorable. The research permissions were obtained from seven randomly chosen participating institutions in Finland and the United Kingdom.

A search phase

When starting the search phase, it was important to take a closer look at the similarities and differences of higher music education systems in different countries—particularly because the MSW Project was a cross-cultural research project—and to understand how these systems might be connected to educational equality, equity, and justice, and cultural reproduction. These topics were discussed in the theoretical study (i.e., Jääskeläinen, 2021), which was conducted in 2018. In the same year, we prepared the protocol for the systematic review (registered in PROSPERO CRD42020140497) and performed the systematic search of literature in 23 electronic databases and 19 music research journals. After screening the references which were found in the searches, 29 qualitative, quantitative, and multi-strategy studies fulfilled the inclusion criteria. These studies were conducted in the United States ($n = 8$), the United Kingdom ($n = 5$), Australia ($n = 3$), Finland ($n = 3$), Hong Kong ($n = 2$), New Zealand ($n = 2$), Belgium ($n = 1$), China ($n = 1$), Italy ($n = 1$), Pakistan ($n = 1$), Puerto Rico ($n = 1$), Spain ($n = 1$), and Sweden ($n = 1$). A total of 13,596 students took part in the 29 studies, of whom 2,261 were music students. Figure 2 shows the process of selecting studies following the guidelines of Preferred Reporting Items for Systematic Reviews (PRISMA). After selecting the studies, we conducted an extended meta-ethnography (EME)—a method of systematic review

developed by Booker (2010)—to create a synthesis. The process and results were reported in the systematic review (i.e., Jääskeläinen et al., 2022b).

The theoretical study and systematic review were complemented with new methodological and empirical research. For the empirical studies, the assessment instrument—the Workload, Stress, and Coping questionnaire—was created by combining and adapting sections from two validated questionnaires from the learning sciences. The first instrument was the standardized study workload and stress section of the Learn questionnaire used in the Finnish higher education context (i.e., Parpala and Lindblom-Ylänne, 2012). The second instrument was the Proactive Coping Inventory for Adolescents (PCI-A), developed in Canadian higher education (i.e., Greenglass et al., 2008). The Workload, Stress, and Coping questionnaire also included demographic items and open-ended questions about workload, stress, coping, and the students' interactive experiences with teachers. The experienced study workload scale included five items. The scale assessed students' workload experiences when considering their studies as a whole, in their main subject (or principal) studies (e.g., "I must work very hard with my main subject studies"). A single item assessed students' current feelings of experienced stress. The proactive coping section included seven different scales assessing proactive coping styles, with a total of 55 items (e.g., "I plan my strategies to change the situation before I act"): proactive coping, reflective coping, strategic planning, preventive coping, instrumental support seeking, emotional support seeking, and avoidance coping (PCI-A, see Greenglass et al., 2008).

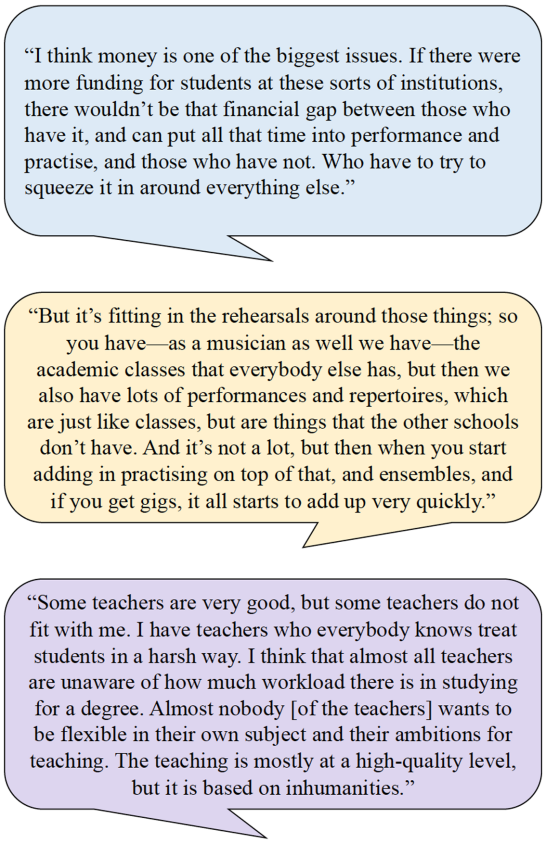


FIGURE 1
Research participants in the MSW Project telling about music students' experienced workload.

The data were gathered online through an institutional Surveypal-questionnaire during the spring term of 2019. We randomly selected seven university-level music institutions in Finland and the United Kingdom. We sent the invitation to participate in the research via student email lists, thus potentially reaching over 7,000 music students. A total of 155 music students from five different institutions (including a total of 5,900 music students) completed the questionnaire in Finland ($n = 108$) and the United Kingdom ($n = 47$). The total response rate was relatively low (9% in Finland and 1% in the United Kingdom), which is quite common for online surveys among students, because of the survey fatigue they are typically exposed to (Porter et al., 2004). Of the questionnaire respondents, 29 music students volunteered to participate in the interviews. Semi-structured in-depth interviews were conducted, either in contact meetings or remotely, ranging from 30 to 90 min. The topics consisted of questions that encouraged students to reflect on their workload, stress, and coping as professional students in higher music education. Demographic characteristics of all participants are given in Table 2.

The quantitative data in the questionnaire were analyzed with SPSS using frequentist statistics and with RStudio by using Bayesian statistics. Atlas.ti was used to code and analyze the qualitative data concerning the answers to the open-ended questions in the questionnaire and transcribed interviews, by adapting the analytical process of transcendental phenomenology (Moustakas, 1994). The analysis was performed by the author in collaboration with one co-researcher/supervisor who specializes in the psychology of music education, who coded 5% of the qualitative data in order to enhance the reliability and trustworthiness of the research process. The inter-rater agreement of the two independent coding choices was calculated by using Holsti's (1969) method and Krippendorff's (1980) alpha, and was favorably calculated as 0.924 and 0.918, respectively, with both values indicating very high levels of reliability. A thematic coding framework (see Figure 3) was built based on the 13 codes, four categories, and three overarching themes that were derived from the deductive systematic review (Jääskeläinen et al., 2022b). Next, an additional 14 themes that were extracted from the interview data using inductive analysis were added to the framework, to contextualize the music students' responses relative to the existing literature on workload experiences in higher music education. The analysis continued through the process of horizonalization, in which all the students' responses that are relevant to their workload were listed, grouped, and coded for each individual participant's data. The procedure of using transcendental phenomenological approach was presented and discussed more in detail in the methodological study (i.e., Jääskeläinen, 2022b). At this point, the excerpts which were coded

as *meaning of musicianship*, were explored more deeply, because *engaging in music* seemed to be a topic for which the interview participants expressed lots of positive emotions while speaking about their workload experiences. These findings were reported in the empirical study (i.e., Jääskeläinen, 2022a).

Next, all the coded expressions were grouped into four categories and three overarching themes based on the context of the music student's experienced workload, and for the empirical studies, we continued the analysis with the extracts linked to each of the overarching themes: (1) *student* in Jääskeläinen et al. (2022a), (2) *environment* in Jääskeläinen et al. (2020), and (3) *teacher* in Jääskeläinen and López-Íñiguez (2022). The Finnish participants' quotes were translated from Finnish into English by the author, who speaks both languages, and refined in English by a native language editor.

A mapping phase

In the mapping phase, the findings and results from these seven studies were used to establish the key elements of music students' experienced workload, stress, and coping in higher education. Next, the key elements are presented in each MSW Project's study. The findings of the theoretical study (i.e., Jääskeläinen, 2021) focused on the comparison of higher music education systems in three different countries. A critical debate about the role and impact of tuition fees and entrance examination systems is needed in higher music education, and this discussion should be situated within an evaluation of contemporary educational policy trends. According to Bull (2020), crucial topics include: (1) social inequalities; (2) genres, class, genders, and race, (3) sexual, emotional, and physical abuse in the field of music; and (4) creative collaboration with other social groups. Moreover, it is vital to listen to music students talk about their joys and concerns, such as coping with workload and stress, and to integrate their voices into the music institutions' developmental work. Addressing and sharing individual experiences of inequality and oppression in educational systems can make more inclusive education possible (Reay, 2017). Reimer (2007) argues that although inequities and injustices are not going to disappear in music education, it is crucial to pursue broader equality, equity, and justice. All efforts, even those with modest positive results or resulting in only slight progress, are valuable.

The systematic review (i.e., Jääskeläinen et al., 2022b) revealed three overarching themes, offering a total of 24 recommendations for good practice for students, teachers, administrators, and student health and wellbeing services, as to how to deal with music students' workload. As a result, a framework of music students' experienced workload was constructed based on three contexts where developmental actions could be recommended in higher music education: (1) music students' studying and coping strategies, (2) teachers' interaction with music students; and (3) aspects in teaching and learning environments, such as university institution and livelihoods.

The transcendental phenomenological approach was an essential method for the MSW Project. That is why a closer look was taken at it in the methodological study (i.e., Jääskeläinen, 2022b). This study provided a detailed description of how music students' lived experiences can be approached and analyzed through transcendental phenomenology, in order to obtain a meaningful understanding of music students' experienced workload.

In the first empirical study (i.e., Jääskeläinen, 2022a), music students' experiences of workload, which were coded as *meaning of musicianship*, were explored more deeply. When researching students' workload, the examined themes often emphasize negative aspects of workload, such as overload, stress, burnout, and mental illness. However, workload also includes positive aspects that are as important as the negative aspects, such as music students' meaningful *engagement in music*, that can help students find a way to continue their studies. In Figure 4, the findings of this study show how music students' workload experiences in higher education are connected to their constructed meanings of engaging in music. These connections as a whole can be understood as various holistic experiences that comprise the following constructed meanings of musical engagement: (1) the students' intense and complex experiences, (2) their development as musicians, (3) their creative self-expression, (4) their interactions with others, (5) their personal growth and coping approaches, and (6) their transcendental musical experiences. In addition, the several students who expressed their ambivalent views (illustrated by the lightning in Figure 4) have been included next to their constructions of Personal growth and coping approaches, in order to highlight how listening to the students' different views can provide important knowledge on how to better nurture these students' engagement in music throughout their studies in higher music education. The students' emotional reactions as they spoke about the meaning of engaging in music have shown that music is a source of vitality to them, and, furthermore, that one's experiences of engaging in music is a complex phenomenon that many of the participants found difficult to describe. This participant's quotation illustrates an example of a music student's experience in the Personal growth and coping approaches:

> *"Yeah, music to me is everything. Yeah, I guess it [music] is my life. I would not be who I am today without music."*

In the second empirical study (i.e., Jääskeläinen et al., 2022a), Figure 5 shows the integration of the qualitative findings with the quantitative results. The results indicate that there are statistically significant differences among music students in different genre groups and study programs in relation to experienced study workload; in genders, genre groups, and study programs in relation to experienced stress; and in genders in relation to the use of proactive coping style. Music students' study workload is a significant predictor of stress. However, proactive coping and strategic planning can be used to reduce this stress, because they

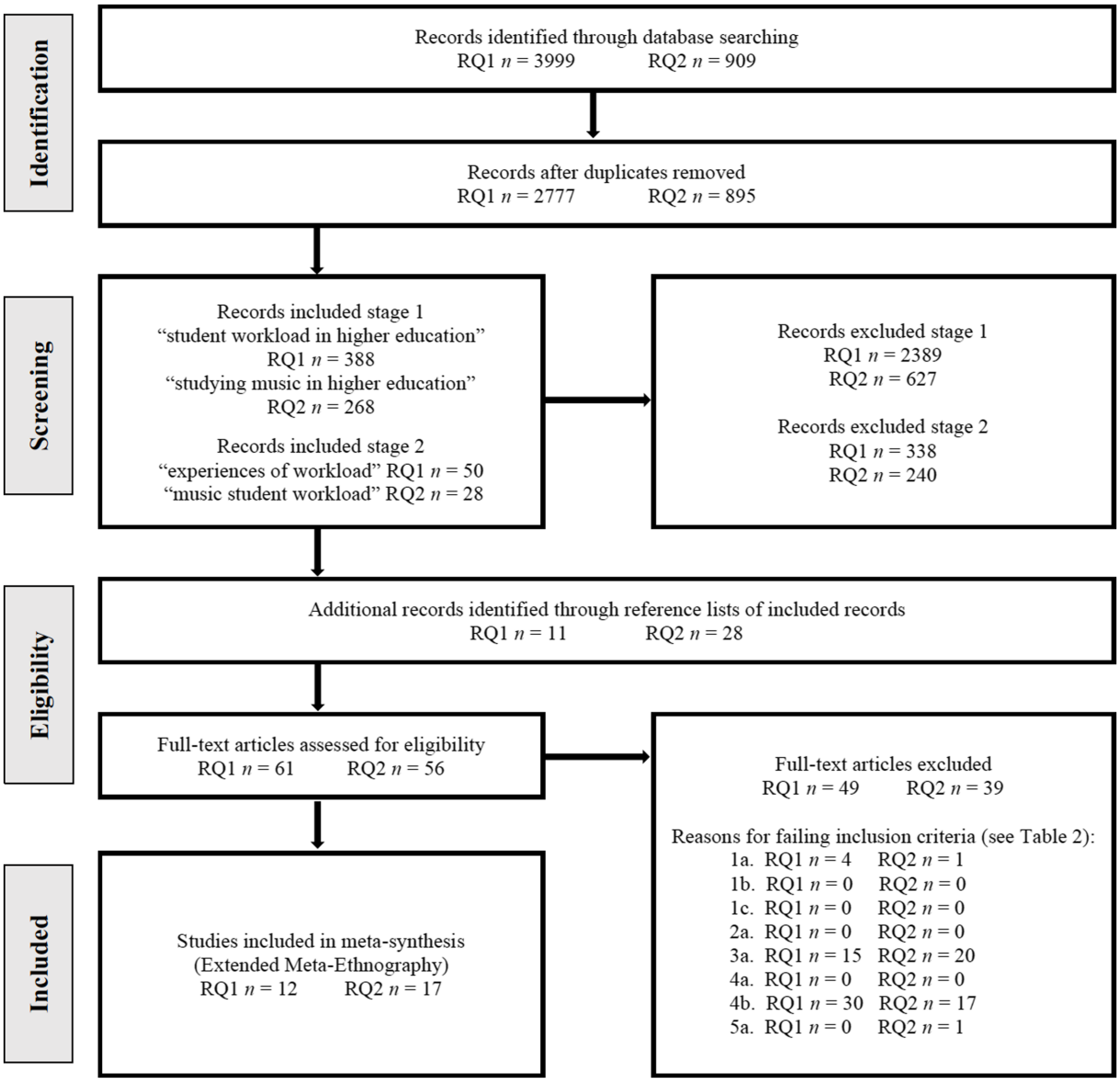


FIGURE 2
Process of selecting studies grouped by two research questions (RQ) in PRISMA flowchart 2009 (Moher et al., 2009).

predict stress negatively. Professional music students have their own issues and ways to cope with workload and stress concerning, for example, working alongside studying, competing with peer-students, handling information on social media, and finding support for music-specific physical and psychological problems. This participant's quotation illustrates a music student's experience in using an emotional support-seeking coping style:

> *"I got peer support from the other students. You hear that very many of your peer students have also had enormous stress. It has been very encouraging to notice that people also talk openly to each other about these issues. And also, for example, recommend to each other that there is this kind of study counsellor where you can go."*

In the third empirical study (i.e., Jääskeläinen et al., 2020), Figure 6 shows the full model of music students' experienced main subject workload, which indicates that, when connected to these characteristics of livelihoods, stress was the strongest predictor of workload. There was also an effect for funding, such that music students with partial funding or no funding at all were less likely to report experiencing workload than students with full funding. Work related to music had a greater effect than work not related to music, but the total amount of work undertaken alongside a student's studies had a negligible

TABLE 2 Demographic characteristics of all participants in the sample (*N*=155).

Background	%	Main subject studies	%
Country		Genre group	
Finland	69.7	Classical music (UG or PG)	43.2
United Kingdom	30.3	Music education (UG or PG)	24.5
Gender		Other genres	32.3
Female	68.0	Study program	
Male	30.1	Classical string	13.5
Non-binary gender	2.0	Classical wind	9.7
University level		Classical piano	6.5
Undergraduate (UG)	52.9	Classical early music	3.2
Postgraduate (PG)	42.6	Classical other instruments	3.2
Other (junior or doctoral)	4.5	Classical voice and opera	7.1
		Music education	24.5
Interview participants ($n = 29$)	18.7	Composition	7.7
Finland ($n = 20$)		Church music	12.3
United Kingdom ($n = 9$)		Folk and global music	4.5
Female ($n = 21$)		Other programs	3.9
Male ($n = 8$)		Doctoral programs	3.9

effect on workload. Female music students were likely to report experiencing more workload than male or non-binary gender students. The level of the university studies, in general, had a relatively small impact on the results; however, undergraduate music students were likely to report experiencing more workload than postgraduate students or junior and doctoral students. The music genre studied had little influence on the level of experienced workload, although studying music education had a greater effect compared to other genres, whereas the classical music genre had a negligible effect. Figure 7 shows the full model of music students' experienced stress, which indicates that, when connected to the characteristics of livelihoods, music students in the United Kingdom are more likely to report experiencing stress than music students in Finland. Workload was the strongest predictor of stress in the full model. There was also a noticeable effect for gender, such that female music students were more likely to report experiencing stress than male students. With the non-binary gender, there was a positive effect on stress, which was contradictory to the negligible effect on workload in the previous full model. Both work not related to music and the total amount of work undertaken alongside studying had a small effect, but work related to music did not have an influence on stress. Junior or doctoral music students were much more likely to report stress than postgraduate students or undergraduate students, which contradicts the full workload model, in which being an undergraduate student had more influence on workload. The use of loans had no effect on stress (nor on workload in the previous model). This participant's quotation illustrates a music student's workload experience relating to teaching and learning environments:

> *"But contact teaching is sometimes very hard, if the allowed amount of absences is strict. Unfortunately, many students have to work, both for their prestige and CV, for their artistic career, or to earn extra income, although working is not recommended whilst studying."*

In the fourth empirical study (i.e., Jääskeläinen and López-Íñiguez, 2022), based on music students' experiences, four themes emerged in the synthesis process as recommendations for tools for teachers to support music students in managing and coping with their workload in higher education. The findings included a total of 43 recommendations. Figure 8 shows one example of these recommendations for each theme. This participant's quotation illustrates an experience of music student's workload in interaction with teachers:

> "Even if you were not prepared well for that lesson, or even if you were extremely well-prepared, that does not matter, because when the teacher is motivated and interested in teaching you and listening to you, then you as a student are ready to work hard for learning."

An appraisal phase

In the appraisal phase, we critically appraised the key elements for their validity and relevance to policy and intervention recommendations. Next, the key elements for policy and intervention recommendations in each study are presented.

1. Theoretical study: Misconceptions about equity in higher music education should be revealed—for example by investigating music students' experiences of their workload and stress as they try to cope with the demands of higher education studies—to raise and maintain a critical debate about the role of tuition fee systems, as they are connected with the economics of higher education, and about entrance examinations as reproducing social class inequalities (Jääskeläinen, 2021).
2. Systematic review: Good practices are needed (a) to increase music students' ability to cope with their workload; (b) to provide tools for teachers to support music students

Thematic coding framework in the Music Student Workload Project

13 literature-based codes *		14 interview-derived codes		Four categories of different workload meanings drawn from columns 1 and 2		Three overarching themes of proposed recommendations for good practice related to music students' workload in higher education
Structure of student workload Work	+	Competition Funding Musician career Social media	→	Structure of workload	→	Music students' ability to cope with their workload (including excerpts related to 'the student' in four of the categories to the left) *** Tools for teachers to support music students to manage and cope with workload (including excerpts related to 'the teacher' in four of the categories to the left) **** Developing learner-centred environments in higher music education (including excerpts related to 'the environment' in four of the categories to the left) *****
Approaches to learning Experiences in the first year of study Flow Time management	+	Coping Enjoyment Meaning of musicianship ** Practising Religion	→	A student's individual workload		
One-to-one tuition Teaching and learning environments	+	Assessment Curriculum Group tuition Student feedback	→	Workload relating to teaching and learning environments		
Burnout Health Musculoskeletal problems Performance anxiety Stress	+	Physical exercise	→	Psychological and physiological issues		

Results reported in *Jääskeläinen, López-Íñiguez, and Phillips (2022), **Jääskeläinen (2022a, 2022b), ***Jääskeläinen, López-Íñiguez, and Lehikoinen (2022), ****Jääskeläinen and López-Íñiguez (2022), and ***** Jääskeläinen, López-Íñiguez, and Phillips (2020).

FIGURE 3
Music Student Workload Project's thematic coding framework.

to manage and cope with workload; and (c) to develop learner-centered environments in higher music education (Jääskeläinen et al., 2022b).

3. Methodological study: A practical research-based model is needed in order to process and incorporate music students' feedback into future administrative and teaching developments in higher music education institutions, such as addressing students' experiences in relation to curricula-related improvements (Jääskeläinen, 2022b).
4. First empirical study: An understanding of music students' lived experiences of studying music should be utilized to improve the learning and teaching environments of institutions, and also to better support music students' wellbeing, learning, and future careers (Jääskeläinen, 2022a).
5. Second empirical study: Studying music has its unique characteristics compared to other fields in higher education, and exploring professional music students' particular ways of using proactive coping styles could result in valuable models for students to better cope with their studies in higher music education (Jääskeläinen et al., 2022a).
6. Third empirical study: Attention should be paid to certain aspects in higher music education in relation to workload, such as the differences between study programs and the gap between well-off students compared to low-income students who need to work, and stress, particularly with female and non-binary gender students (Jääskeläinen et al., 2020).
7. Fourth empirical study: The emphasis on music students' workload experiences could offer a way to strengthen students' voices so that they will be integrated into the

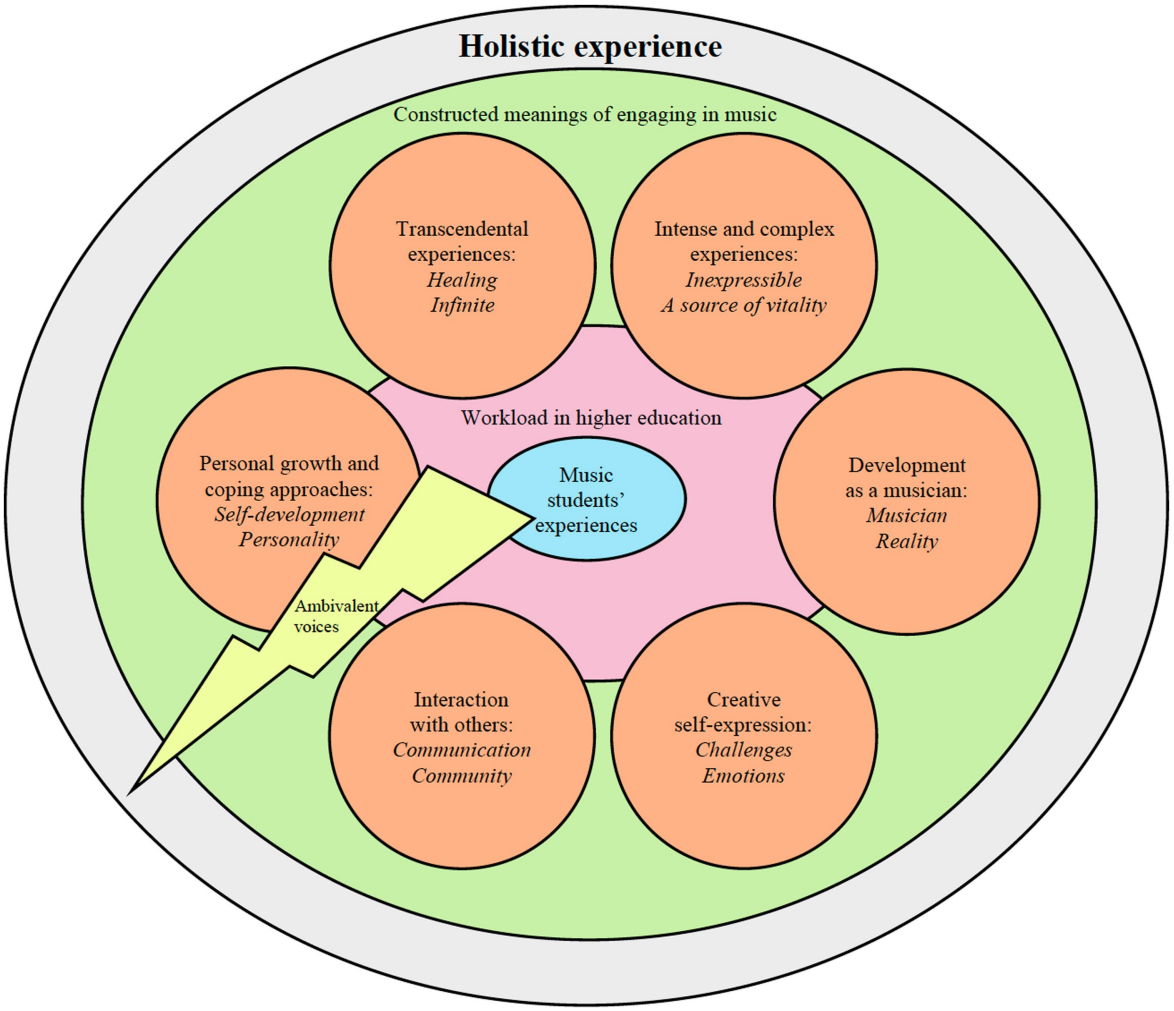


FIGURE 4
Music students' workload experiences in higher education connected to their constructed meanings of engaging in music.

development of teaching that trends toward more democratic practices between master and apprentice in higher music education (Jääskeläinen and López-Íñiguez, 2022).

A synthesis phase

In the synthesis phase, we prepared a narrative account of included key elements for policy and intervention recommendations through a multiple triangulation approach (Denzin, 1970): (1) investigator triangulation in the collaboration between researchers from Finland and the United Kingdom; (2) theory triangulation by combining theories from educational psychology and music education; (3) data triangulation with two different datasets (literature and human experiences); and (4) methodological triangulation by using both quantitative method (with frequentist and Bayesian statistics) and qualitative method. In addition, triangulation helped to explain the results and findings of the studies (Noble and Heale, 2019). For example, systematic review and empirical studies complemented each other, and using multiple methods in the empirical studies led to the same concerns of differences between genders and genre groups in the music students' experienced workload and stress.

Figure 9 illustrates how, in the synthesis phase, the recommendations for good practice, which were derived from the systematic review, further distilled the findings and results from the empirical studies in the MSW Project. It was important to triangulate the seven studies in this way to be able to construct the meta-narrative review by complementing the previous research with the new empirical results and findings regarding music students' lived experiences. This also provided the possibility of strengthening the music students' voices before continuing to build policy and intervention recommendations through the theoretical study and

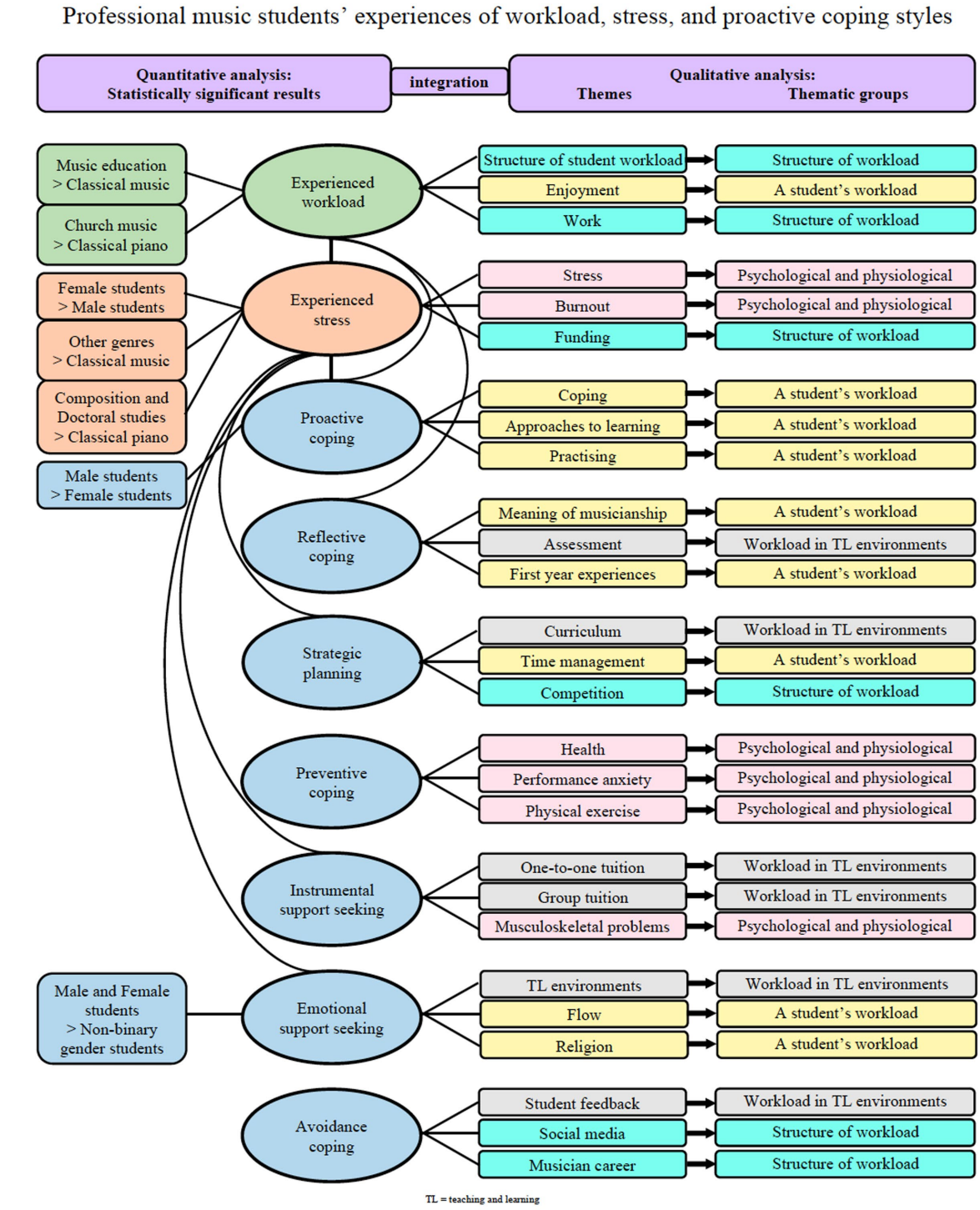


FIGURE 5
Integration of the results of the quantitative analysis and the findings of the qualitative analysis concerning professional music students' experiences of workload, stress, and proactive coping styles.

methodological study, in order to better support music students with their experiences of workload, stress, and coping in higher education. In addition, the triangulation helped to compare the multiple sources (Noble and Heale, 2019). Thus, we were able to conclude that the seven studies in the MSW Project had no conflicting results and findings.

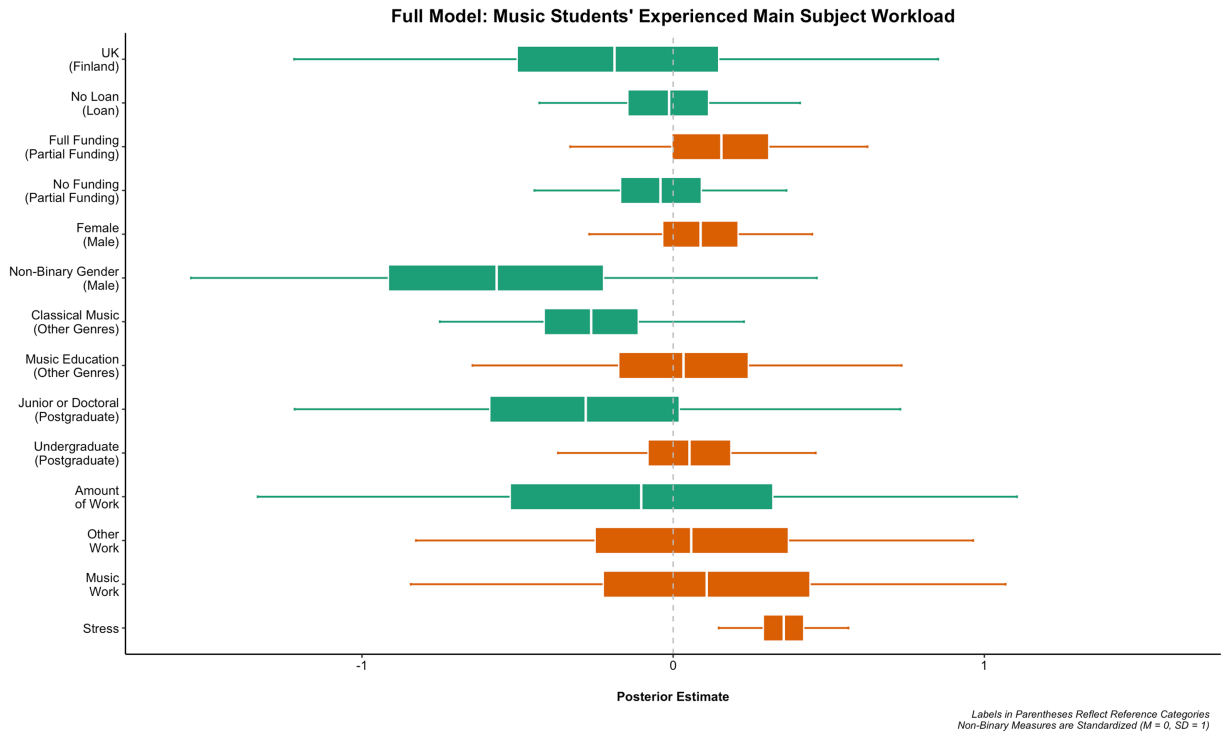


FIGURE 6
Population-level predictors of experienced main subject workload, derived from a Bayesian mixed-effect probit regression. The boxes indicate 50% posterior intervals, and the lines indicate 95% posterior intervals. With binary items, the left-hand side boxes indicate a smaller effect on workload than in the reference group in brackets, and the right-hand side boxes indicate a greater effect on workload than in the reference group in brackets. With the working and stress items (the four bottom items on the figure), the left-hand side boxes indicate a negligible effect on workload and the right-hand side boxes indicate a greater effect on workload the nearer the box is to the right-hand side.

A recommendation phase

In the recommendation phase, we summarized the findings from the triangulated key elements, and we made policy and intervention recommendations for supporting music students in coping with workload and stress in higher music education. The recommendations represent triangulation in that each of them consists of studies including data from two sources (literature from the systematic review and human experiences from the empirical studies). These four recommendations are presented here and discussed more in detail in Discussion section:

- Recommendation 1: Support music students' proactive coping skills (Jääskeläinen et al., 2022a,b).
- Recommendation 2: Find solutions to the unequal workload and stress experiences between low-income and well-off students, different genders, and different study programs (Jääskeläinen et al., 2020, 2022a,b).
- Recommendation 3: Ensure teachers' continuing professional development, particularly in the learner-centered pedagogical approaches (Jääskeläinen et al., 2022b; Jääskeläinen and López-Íñiguez, 2022).
- Recommendation 4: Invest resources for providing more longitudinal, cross-cultural, and interventional research investigating music students' discipline-specific experiences of workload and stress (Jääskeläinen et al., 2020, 2022a,b; Jääskeläinen, 2021, 2022a,b; Jääskeläinen and López-Íñiguez, 2022).

Discussion

In the MSW Project, the aim was to view music students' experienced workload as a very human phenomenon and an everyday issue. When the viewpoint was connected to educational arrangements and inequalities, it offered a way to lighten the load placed solely on music students' shoulders and also to address concerns about students' workload as a consequence of higher education practices and policies. In the present study, we adapted the six phases of the meta-narrative review according to Greenhalgh et al. (2004, 2005). As a result, the synthesis of the seven studies provided four actionable policy and intervention recommendations that will allow higher music education institutions to better support music students' abilities to cope with their workload and stress.

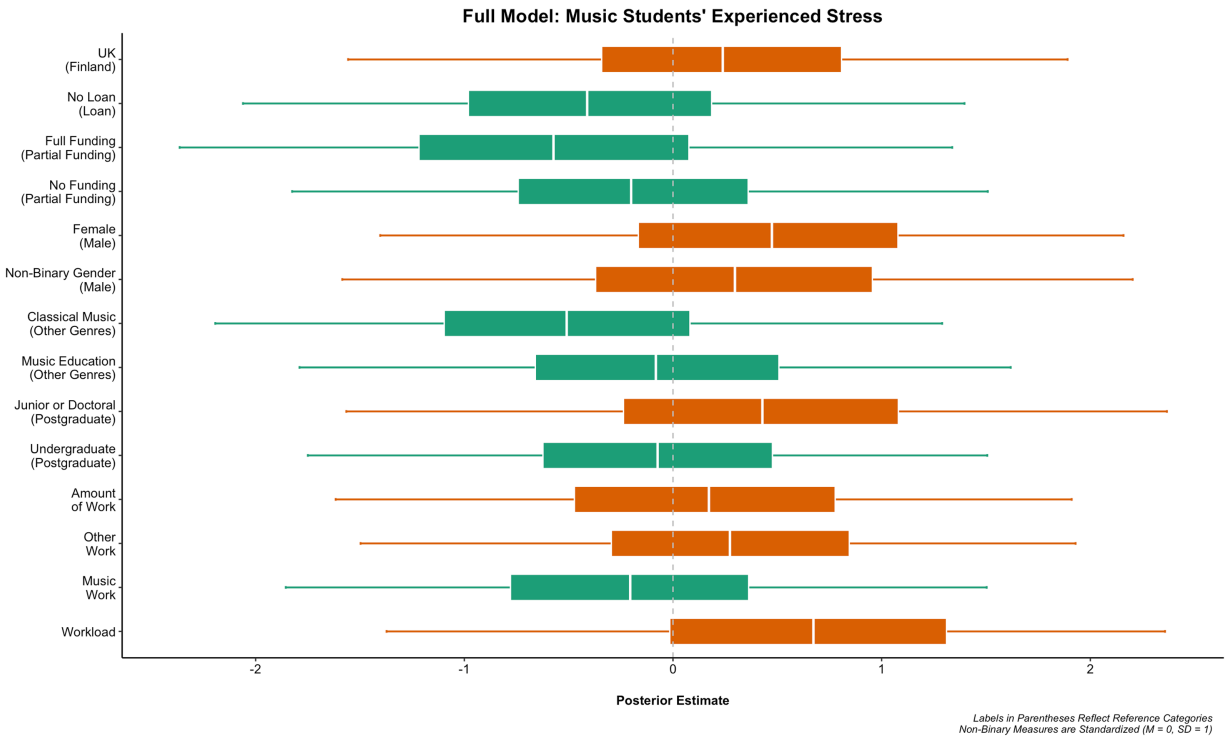


FIGURE 7
Population-level predictors of experienced stress, derived from a Bayesian mixed-effect probit regression. The boxes denote 50% posterior intervals and the lines denote 95% posterior intervals. With binary items, the left-hand side boxes indicate a smaller effect on stress than in the reference group in brackets, and the right-hand side boxes indicate a greater effect on stress than in the reference group in brackets. With the working and workload items (the four bottom items on the figure), the left-hand side boxes indicate a negligible effect on stress and the right-hand side boxes indicate the greater effect on stress the nearer the box is to the right-hand side.

Recommendation 1: Support music students' proactive coping skills

Students' study skills and wellbeing could be developed through institutional practices that support students in using positive coping strategies that minimize their distress and maladaptive coping during their studies (Deasy et al., 2014). Studying music has its own unique characteristics compared to other fields in higher education (Jääskeläinen et al., 2022b). For example, the ability to cope with stress connected to stage fright is particularly important for music students (Nogaj, 2017). In our study (Jääskeläinen et al., 2022a), we showed examples of how music students use proactive coping styles: proactive coping, reflective coping, strategic planning, preventive coping, instrumental support seeking, emotional support seeking, and avoidance coping (Greenglass, 2002). Our results indicated that music students' study workload is a significant predictor of stress; however, proactive coping and strategic planning can be used to reduce this stress. In addition, the more music students use either a proactive coping style or a reflective coping style, the less they experience study workload. It is worth noticing that in our study, female students reported experiencing statistically significantly more stress than male students; however, male students reported using the proactive coping style statistically significantly more than female students did. In addition, non-binary gender students reported using the emotional support-seeking coping style statistically significantly less than female and male students, which raises the concern that non-binary gender students may not find suitable support for themselves in the current educational structures. This confirms the fact that music students' proactive coping skills should be better supported in order to help them manage stress and workload in their studying.

Recommendation 2: Find solutions to the unequal workload and stress experiences between low-income and well-off students, different genders, and different study programs

To tackle the negative impact of university culture on students' wellbeing, and to be able to acknowledge students' diverse backgrounds and circumstances while studying (Jääskeläinen et al., 2022b), higher education institutions should utilize research on music students' health (Williamon and Thompson, 2006; Ginsborg et al., 2009) and consider certain actions, such as shifting the typically competitive atmosphere toward a more cooperative university culture (Fernández-Herrería and Martínez-Rodríguez, 2016; Fitzpatrick, 2019) and developing the study programs by utilizing more diverse

Structure of music students' workload:
Teachers should obtain more knowledge about the whole *structure of workload* in studying music in higher education. Studying in higher education brings along overload, overlapping schedules, and performance anxiety for music students, particularly at the bachelor level. Research-based evidence on music students' experiences could help teachers better understand students' multifaceted circumstances with workload in their studies.

Music students' workload relating to teaching and learning environments:
It is important for teachers to understand that students have mostly positive learning experiences in the *teaching and learning environments,* but some students have suffered unfortunate, unfavorable, or even abusive behaviour from their music teachers, and these experiences may affect students' current workload.



A music student's individual workload:
Teachers could best support students' *approaches to learning* by treating them as autonomous individuals. Students also need clear advice from teachers, for example with technical aspects in practising. Instead of the traditional master-apprenticeship model, where teachers have an authoritative role, students would like to receive advice in a learner-centered way.

Music students' psychological and physiological issues:
It is important to teach students in higher education how to deal with *stress*, because too much stress is often connected to overload, and it affects most aspects of the students' physical and mental health, and can even lead to *burnout.*

FIGURE 8
Examples of recommendations in four categories as tools for teachers to support music students in managing and coping with their workload in higher education.

sources of knowledge (Cannella and Koro-Ljungberg, 2017). Our study (Jääskeläinen et al., 2020) of music students' workload and stress, for which the country of study and music students' livelihoods were combined as results predictors, suggested that a neoliberal university culture with high tuition fees that impacts students' livelihoods alongside their studying is likely to increase music students' experienced stress, but not directly impact on the workload associated with their main subject studies. However, participants' lived experiences confirmed the fact that stress has a great effect on students' experiences of their workload (Jääskeläinen et al., 2020, 2022a). These results and findings show differences in workload and stress between genders and study programs, and emphasize a particular concern over the unequal workload and stress experiences between low-income and well-off students. These differences should be further investigated with regard to the connection between higher music education systems and their curricula, in order to identify the reasons why these unequal differences exist and determine solutions for how study programs could be developed to have an appropriate and equal workload for all music students.

Recommendation 3: Ensure teachers' continuing professional development, particularly in the learner-centered pedagogical approaches

The emphasis on researching music students' workload experiences offers a way to strengthen students' voices so that they can be integrated into developmental work in teaching (Jääskeläinen et al., 2022b). This research-based evidence could be utilized to shift teacher-centered and product-oriented methods of teaching music toward learner-centeredness in teacher training that promotes "a deep understanding based on the integration of students' prior knowledge and curricular outcomes, as well as helping students to take metacognitive control of their own learning" (López-Íñiguez et al., 2014, p. 158). In our study (Jääskeläinen and López-Íñiguez, 2022), we presented tools for teachers that would enable them to support music students in coping with their workload and stress by taking a constructive approach that would provide more spaces for learner-centeredness and agency (see, e.g., Pozo et al., 2022). Such practical tools may particularly help those teachers and students who experience difficulty in consciously accessing their cognitive and metacognitive processes when the stability and internalization of their conceptions make them strongly resistant to change (Atkinson and Claxton, 2000; Pozo et al., 2006). The research-based knowledge on students' workload, stress, and coping as part of the teachers' continuing professional development, when connected to the principles of conceptual change (in line with Vosniadou, 2013), can support the development of instruction toward more democratic practices between master and apprentice in higher music education (see, e.g., Gaunt and Westerlund, 2013).

Recommendation 4: Invest resources for providing more longitudinal, cross-cultural, and interventional research investigating music students' discipline-specific experiences of workload and stress

It is particularly important to invest resources for producing research-based evidence on the different aspects of music students'

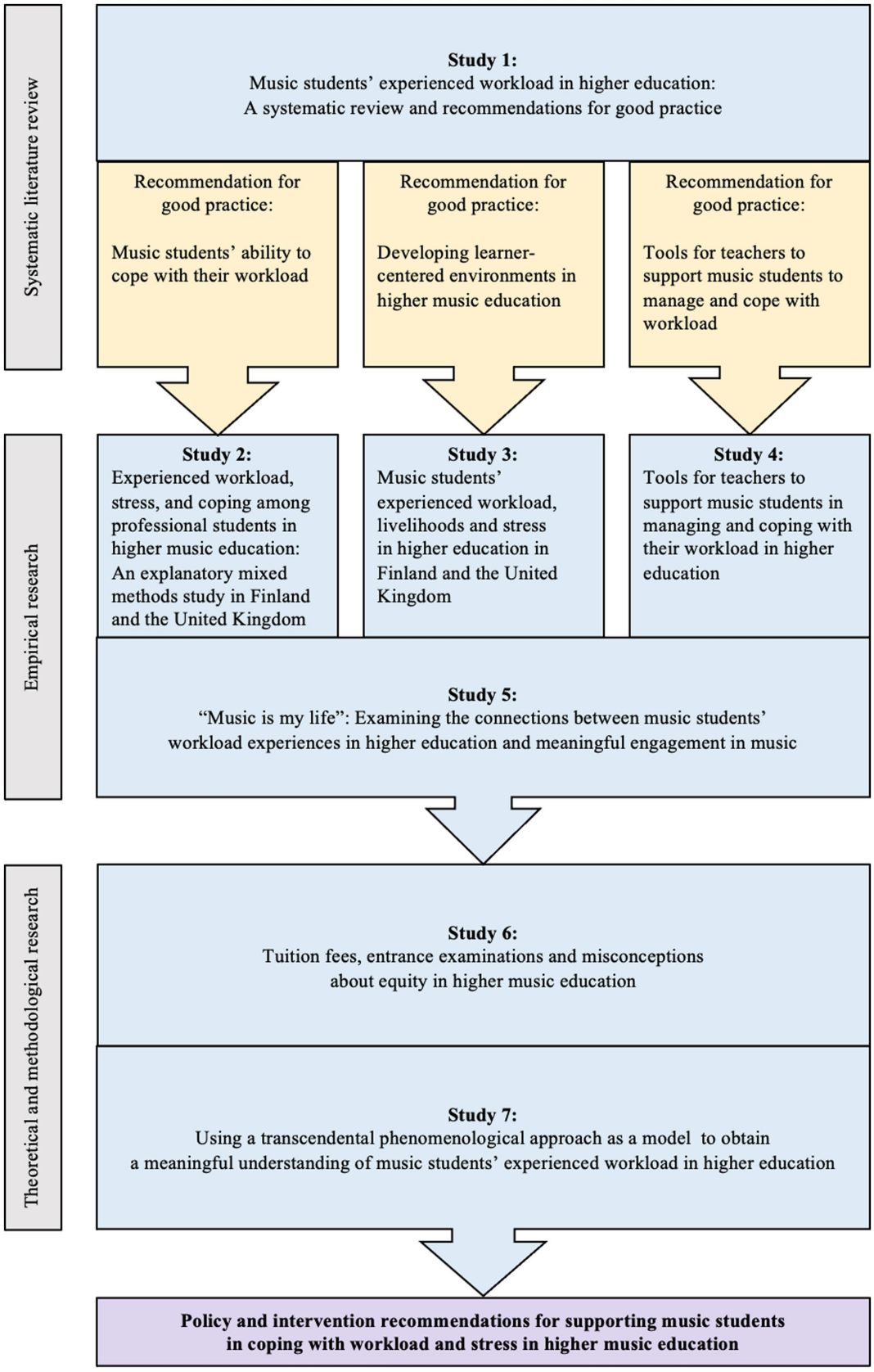


FIGURE 9
Triangulation of the seven studies in the MSW Project to create evidence-based policy and intervention recommendations.

experienced workload and stress because these experiences are different from the workloads in other fields (Jääskeläinen et al., 2022b); for instance, music students' responsibilities include demonstrating their musical progress and managing their own coursework (Bernhard, 2007). According to Hallam and Papageorgi (2017), it is also important to nurture music students' love and enjoyment of music alongside their studies. In line with this sentiment, in our study (Jääskeläinen, 2022a), we provided valuable insights into what engaging in music means to music students in relation to their experienced workload during their studies in higher education. Our results align with the growing need to conduct more research on students' emotional wellbeing in higher music education (Ginsborg et al., 2009; Araújo et al., 2017), particularly attending to minority and marginal groups (Beban and Trueman, 2018) as became evident in our empirical results of non-binary gender music students who reported using less emotional support seeking coping style than female and male students (Jääskeläinen et al., 2022a) and experiencing stress but not workload in their main subject studies (Jääskeläinen et al., 2020). This may bring to light new knowledge that may better inform future administrative, teaching, and curriculum developments in higher music education (Jääskeläinen, 2021; Jääskeläinen and López-Íñiguez, 2022). In our study (Jääskeläinen, 2022b), we also presented the detailed analytical steps in transcendental phenomenology as a practical model for music institutions to gather and analyze this kind of very specific qualitative data of music students' workload experiences during their studies. We also showed in our study (Jääskeläinen et al., 2020) how in the context of higher music education institutions, where the study programs are quite small, a Bayesian approach is a good option for analyzing quantitative data because it can produce valid results for small samples and combine both quantitative and qualitative feedback from students (Low-Choy et al., 2017). Thus, the multi-strategy approach utilized in the MSW Project may offer a valuable model of how to utilize students' feedback in the most beneficial way to feed into developmental work in universities and educational policies. Furthermore, institutions should employ a researcher who is able to conduct longitudinal, cross-cultural, and interventional research on music students' workload, stress, and coping, and to incorporate students' feedback as accurate results and findings to contribute to the developmental work in the institutions.

Theoretical implications

Because research-based findings regarding music students' experienced workload in higher education were lacking to a great extent, the findings and results of the theoretical, methodological, and empirical studies in the MSW Project showed specific developmental areas—in line with the results of the systematic review—which were further reflected in the four recommendations above. The meta-narrative synthesis shows that the higher education context for music students has specific challenges and resources associated with music students' coping with workload and stress when compared to those of students in other disciplines. These discipline-specific characteristics should be acknowledged in general educational theories concerning students' workload to better inform the educational practices and policies which have an impact not only on music students' coping, learning, wellbeing, and future careers as musicians but also on the preparedness of higher music education teachers and the development of more equitable and just education systems.

Practical implications

When aiming to support music students' coping with their workload and stress experiences, higher music institutions should concentrate on scrutinizing the workload in the current educational systems, for example in the curriculum and the academic culture. Student workload has been an ongoing topic in higher education for decades; however, discussing is not enough when there is growth in students' psychological distress. Urgent actions are needed, for example by following the present study's practical implications:

1. Listen to music students as experts of their experiences so that the support systems that help students cope with workload and stress can function properly, both in future times of crises and in everyday circumstances.
2. Recruit an institutional researcher to conduct longitudinal, cross-cultural, and interventional research on music students' experiences of workload, stress, and coping.
3. Invest resources to disseminate research-based evidence on music students' coping with workload and stress to inform the curricular, administrative, and teachers' and students' professional development.

Limitations

The MSW Project is not without limitations. The included studies in the systematic literature review were mostly from Western countries, and the participants in the empirical studies were from only two countries, which limits the generalizability of the findings for other countries. In addition, extending the statistical representativeness of sample sizes in the empirical studies would increase the results' generalizability. Another limitation concerns the use of self-reported experiences by music students. Biophysical data of students' workload and stress could complement self-reported data (see, e.g., Asikainen and Katajavuori, 2021), and thus increase the validity of workload research for building educational policy recommendations.

Future research

Because, before the MSW Project, there was practically no previous research on music students' workload experiences in higher music education, more research is needed on this specific topic in order to guide and inform curricular decisions

(Koops and Kuebel, 2021). This may help to foster an academic culture that encourages more positive learning environments as a way to meet the specific needs of music students (Papageorgi et al., 2010). Similarly, Blackwell et al. (2020) argue that research-based evidence on teaching conditions that increase students' experiences of wellbeing may be an efficient way to improve teaching and learning environments in higher music education.

Conclusion

In the MSW Project, we listened to music students' experiences and showed how their valuable voices can contribute to a wide spectrum of knowledge and become a form of research-based evidence that can potentially be utilized in better supporting students and furthering both the development of academic practices and educational policies. A meta-narrative review of the seven studies in the MSW Project was conducted to map previous and new research on music students' experienced workload. We reviewed the key elements of the findings and results from these seven studies. After triangulating the key elements, we built a synthesis to provide four actionable policy and intervention recommendations for supporting music students in coping with workload and stress in higher music education: (1) support music students' proactive coping skills; (2) find solutions to the unequal workload and stress experiences between low-income and well-off students, different genders, and different study programs; (3) ensure teachers' continuing professional development, particularly in the learner-centered pedagogical approaches; and (4) invest resources for providing more longitudinal, cross-cultural, and interventional research investigating music students' discipline-specific experiences of workload and stress. The present study has several implications. Higher music education institutions should acknowledge that higher education context has specific challenges and resources associated with music students' coping with workload and stress; thus, music students should be listened as experts of their experiences. In order to incorporate students' feedback as accurate results and findings to the developmental work in the institutions, a researcher should be recruited and resources should be invested to produce and disseminate research-based evidence on music students' coping with workload and stress.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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METHODS
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A Perceiver-Centered Approach for Representing and Annotating Prosodic Functions in Performed Music

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Musical prosody is characterized by the acoustic variations that make music expressive. However, few systematic and scalable studies exist on the function it serves or on effective tools to carry out such studies. To address this gap, we introduce a novel approach to capturing information about prosodic functions through a citizen science paradigm. In typical bottom-up approaches to studying musical prosody, acoustic properties in performed music and basic musical structures such as accents and phrases are mapped to prosodic functions, namely segmentation and prominence. In contrast, our top-down, human-centered method puts listener annotations of musical prosodic functions first, to analyze the connection between these functions, the underlying musical structures, and acoustic properties. The method is applied primarily to the exploring of segmentation and prominence in performed solo piano music. These prosodic functions are marked by means of four annotation types—boundaries, regions, note groups, and comments—in the CosmoNote web-based citizen science platform, which presents the music signal or MIDI data and related acoustic features in information layers that can be toggled on and off. Various annotation strategies are discussed and appraised: intuitive vs. analytical; real-time vs. retrospective; and, audio-based vs. visual. The end-to-end process of the data collection is described, from the providing of prosodic examples to the structuring and formatting of the annotation data for analysis, to techniques for preventing precision errors. The aim is to obtain reliable and coherent annotations that can be applied to theoretical and data-driven models of musical prosody. The outcomes include a growing library of prosodic examples with the goal of achieving an annotation convention for studying musical prosody in performed music.

Keywords: prosody, segmentation, prominence, annotation, representation, music performance

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1. INTRODUCTION

Acoustic variations in music can be studied through the concept of musical prosody. The term musical prosody is described by Palmer and Hutchins (2006) as the way acoustic properties are manipulated by performers to be expressive, without changing any existing categorical information (e.g., the pitch and duration categories of the notes in a score remain the same). Musical prosody can be applied to musical concepts such as melodic salience, expressive accents, musical phrases, and pauses. This view of music prosody borrows from speech, in particular, linguistics research

that focuses on the phonetic features of speech sounds. In speech, prosody refers to phenomena involving the physical parameters of sound and the functions they serve in linguistic structure. The study of speech prosody is concerned, for example, with how frequency, duration, and intensity are used in stress, rhythm, and intonation (Speer and Blodgett, 2006), which has parallels in music. Music in and of itself can exhibit prosody, just like speech. Our focus here is on the prosody of the music content itself, although the term musical prosody has also been used to refer to that of the lyrics embedded in a song, which is often related to, but distinct from, that of the music content. For example, work by Migliore and Obin (2018) defines and analyzes musical prosody as a function of the "syllables of the words and beats of the measure". In the remainder of the paper, we use the definition of musical prosody as given by Palmer and Hutchins (2006) and applied to instrumental music.

In Palmer and Hutchins (2006), musical prosody is described as carrying out four main functions: (1) segmentation (separating relevant elements in the music), (2) prominence (highlighting important events), (3) coordination (communicating with other performers while playing together), and (4) emotional response (reactions that the audience experiences when listening to the performance). We concentrate on the first two functions of musical prosody: segmentation and prominence. It should be pointed out that although segmentation and prominence are two distinct functions of musical prosody, they are not mutually exclusive. For instance, prominence is employed extensively by performers with the goal of highlighting segmentation, and by segmenting the music, changes in it are made more prominent. For the purpose of this paper, we present applications of our method to solo instrumental piano music, so we will not include studies of coordination. Emotional response is outside the scope of this paper, although our method could also be used to study and explain emotional reactions to music.

The definition of musical prosody as a topic is generally centered on studying how specific musical constructs, with or without considering their acoustic correlates, serve a given prosodic function. Palmer and Hutchins (2006) report how tempo, intensity and pitch modulations indicate the hierarchy of phrases, how articulations mark metrically important events, and how a tone duration can be mistaken when placed in an unexpected position in a phrase, to name just a few examples. This can be viewed as a bottom-up approach to musical prosody. Keeping the definition of musical prosody, we propose to explore its meanings in a different way, from a top-down perspective. That is, using the functions of segmentation and prominence as a starting point, given these constructs, we seek to understand how they are created. Ultimately, this will allow us to model the relationships between prosodic functions and the acoustic properties that form them, giving us a more complete understanding of these structures in performed music.

In developing our method, we asked two questions: (1) What kind of framework is necessary to represent and annotate segmentation and prominence? and, (2) how can we harness human perception to find these structures in performed music?

To answer the first question, we took inspiration from annotation protocols in speech, more specifically, from the ToBI (**To**nes and **B**reak **I**ndices) annotation standard. ToBI is a system that enables the transcription and annotation of speech prosody based on two concepts: tonal events (pitch accents, boundary tones, and phrase accents) and break indices (cues about phrase segmentation into words). Annotations are created in tiers and have their own labels. For example, the prosodic grouping of words is marked by vertical lines that have five different levels from 0 (most conjoint) to 4 (most disjoint) (Beckman and Ayers, 1997). Large communities of annotators have created their own versions of ToBI for multiple languages, each one with its own rules based on a specific language's prosodic structure. In a similar fashion, we have created the CosmoNote annotation platform (described in Section 2.2), drawing from the ToBI logic, for creating complex performed music structure visualizations and annotations.

To respond to the second question, we employ the citizen science paradigm to devise an experimental protocol aimed at gathering annotations on musical prosody. The umbrella term citizen science, is broadly defined across different fields encompassing many scientific goals. We defer to its characterization by Haklay et al. (2021) of participatory practices where people, called *citizen scientists*, get involved in research (e.g., collecting and analyzing data) without it being a part of their paid work. Some projects in citizen science encourage participants to adopt larger roles as they learn about the research subject, others foster co-creation of the research goals with members of the community to solve real-world problems (Senabre Hidalgo et al., 2021). This type of research is of interest because it allows researchers to reach a diverse population of people (who in our case enjoy music), and who have the potential to be involved in a project beyond the role of data gatherers, for example, by volunteering their thinking and reasoning capacities.

The rest of this article is organized as follows: Section 2 presents the CosmoNote web-based citizen science platform and other technical details of the protocol. Section 3 introduces the annotation method as applied to the prosodic functions of segmentation and prominence. While the specific musical structures that make up these functions are not fully known, we mention some plausible performed music structures within these categories, and recount some strategies for marking these structures systematically. Sections 4 and 5 discuss the anticipated results from collected data and the implications of answering our research questions for music performance science.

2. MATERIALS

In order to study what are the structures that musicians create in performance, and how they could be represented, we need a set of tools to annotate listeners' and performers' perceptions of structures. Our approach is to record people's annotations of performed structures through a computer interface in intuitive and human-friendly ways as close as possible to how performers and listeners might think of these structures. The conveniences afforded by a digital platform that can be exploited include being able to see multiple layers of representations encoding different types of information, the ease of recognizing patterns over small

and large time scales, and the ability to automate and scale certain annotation actions. Furthermore, annotations created in software have the advantage of being easily editable, accessible, and shareable.

There are several well-known computational tools for annotating, representing, and analyzing time-based media like music, speech, and video. In the realm of audio, many offer ways to markup structures in visual representations of audio descriptors such as the waveform, spectrogram, fundamental frequency, spectral centroid, or some similarity matrix. For example, Linguists use Praat (Boersma and Van Heuven, 2001) and ELAN (Brugman et al., 2004) to analyze, transcribe and annotate speech and video; musicologists use Sonic Visualizer (Cannam et al., 2010) and its vamp plugins, Eanalyse (Couprie, 2012), and Telemeta (Fillon et al., 2014) to study, analyze, and mark up electroacoustic music with or without collaborative web access.

2.1. Recordings and Data From Performances

In order to capture performed structures, we start with performance data, made up of audio and MIDI recordings along with the accompanying XML score of the music that was recorded. We record audio and MIDI and from live performances by professional pianists on a Bösendorfer 280VC ENSPIRE PRO Disklavier. Music representations and descriptors are extracted automatically from these source files.

We also use pre-recorded MIDI from various performance collections including the Bösendorfer Legendary Artists Library, or audio and MIDI from the Stanford Piano Roll Archive (SUPRA), and Steinway's Glenn Gould Goldberg Variations—MIDI files of the 1955 recording meticulously created for re-performances by Zenph Studios.

2.2. The CosmoNote Annotation Tool

To present our performance data to participants, we load the data into CosmoNote[1], a web-based interactive annotation platform that we built specifically for this purpose. It is custom software that facilitates music annotation tasks through an accessible interface that is both familiar for music enthusiasts and powerful enough for advanced users. CosmoNote was created to fill the gap in online collaborative markup tools by having both standard music representations as well as other descriptors important for expressiveness (Fyfe et al., 2021) such as loudness, tempo, and harmonic tension (see **Figures 1A–E**).

2.2.1. Audio and Visualizations

Participants can listen to the performances as well as view various visualizations derived from the performance data. The waveform visualization provides a graphical representation of the music sound wave, giving a classic indication of the intensity and duration of sounds in the music. The piano roll visualization shows the notes or pitches over time along with their onset velocities (an approximation of loudness). The darkness of each note is an indicator of its velocity (darker is louder, lighter is quieter) and the length represents its duration. Sustain, soft, and sostenuto pedals are shown as graphical areas of different colors, showing the depth to which each pedal is pushed down; the color is a marker of the pedal type.

Additionally, three types of descriptors are computed from the audio, MIDI, and score data. Perceived loudness is estimated per frequency band using a psychoacoustic model implemented by Pampalk (2004) and plotted as a single smoothed, scaled curve. Tempo is computed using the inter-beat interval from automatic score alignment (Nakamura et al., 2017) or manual annotations when automatic alignment fails. Harmonic tension uses the spiral array model of tonality to visualize the dissonance (cloud diameter), chord change rate (cloud momentum), and distance from the tonal key (tensile strain) (Herremans and Chew, 2016).

2.2.2. Annotations

Participants mark performance structures using four annotation types: boundaries of varying strengths (numbered 1 through 4), regions, note groups, and comments. Each of these constructs can be assigned their own labels and may be combined to denote a given performed structure. Annotations are displayed in shades of red on top of other visualization layers. Although allowing custom color coding for annotations could be useful, the visualization layers already use different colors. We thus decided to represent all annotations with red hues for a high visual contrast against other data. Annotations can be placed either by using mouse clicks or by using the keyboard. Embedded in each annotation type are several properties useful for analysis like the date of creation, timestamp (*start-end* for regions and just the *start* for all the rest), strength (for boundaries), and note information (note groups).

Boundaries were primarily designed to mark segmentation. They are drawn as vertical lines that span the whole visualization pane height. Boundaries have 4 increasing strength levels (from 1 to 4) and are displayed as a function of the line's thickness and its transparency (see **Figure 2A**). The choice of 4 boundary strengths was made to provide granularity without overwhelming the annotators with too many options. Boundaries can optionally be placed with the keyboard while the sound is playing using the numbers 1–4, allowing for placement while listening.

Regions are multi-functional annotation types that highlight all the elements inside a temporal selection with defined start and end times. Regions are drawn as semi-transparent red rectangles that span the whole visualization pane height (see **Figure 2B**). If two regions overlap, for example by marking the start of region *Y* before the end of region *X*, their individual transparencies are summed as a visual cue of the overlapping area.

Note groups are meant to single out individual salient notes, or groups of notes, that are meaningful in a given segment or prominent structure like a tipping point. Note groups are drawn as red rectangles on top of the normal blue rectangles that represent the notes of the piano roll visualization (see **Figure 2C**). Individual notes can be shared between different note groups.

Comments can be used as a way to write an observation about the performance at a specific time that is not otherwise represented by the other annotation types. They are drawn as

[1]https://cosmonote.ircam.fr

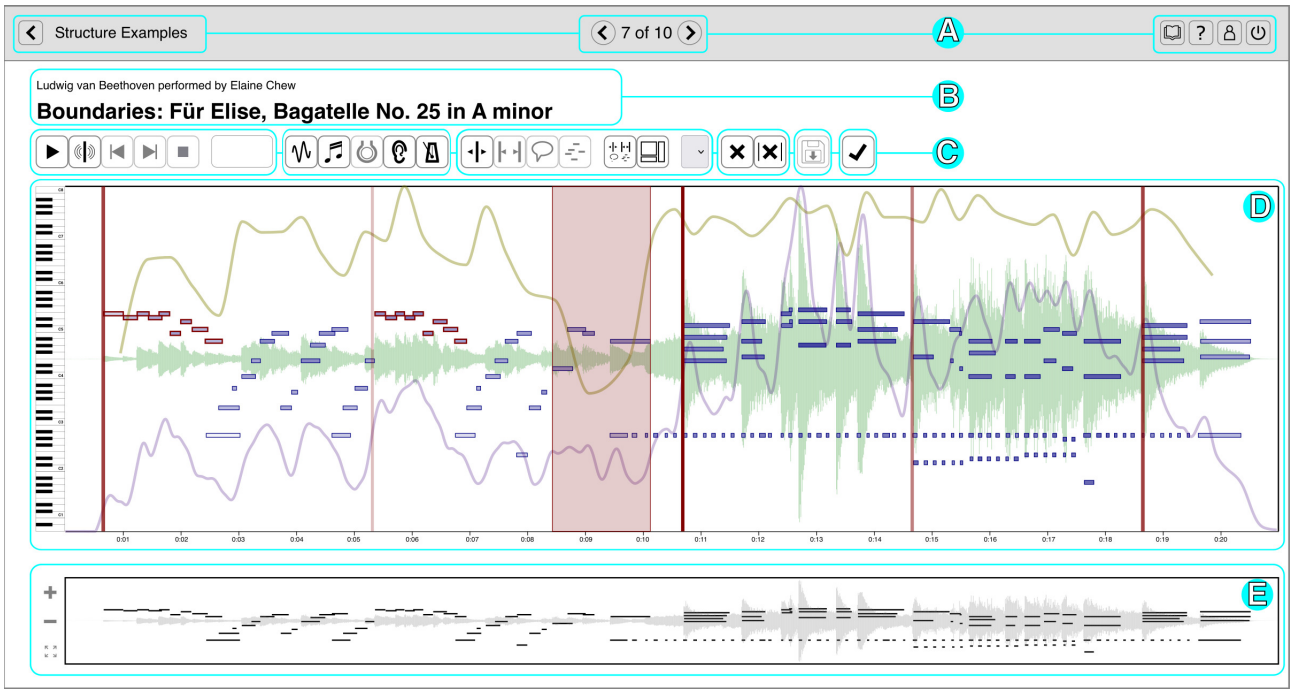


FIGURE 1 | The main CosmoNote interface showing an annotated excerpt of Beethoven's Für Elise. The cyan rectangles highlight the different elements: **(A)** Navigation bar for the collection and account options; **(B)** Names of the piece, performer, composer; **(C)** Audio controls, annotation types, and other control buttons; **(D)** Visualization pane—annotations are displayed in shades of red on top of the waveform (pale green), piano roll (shades of blue), loudness (mauve), tempo (olive), and harmonic tension (shades of brown, not shown); and **(E)** Contextual zoom. See **Supplementary Video 1** in the **Supplementary Materials** to hear the music presented in this Figure.

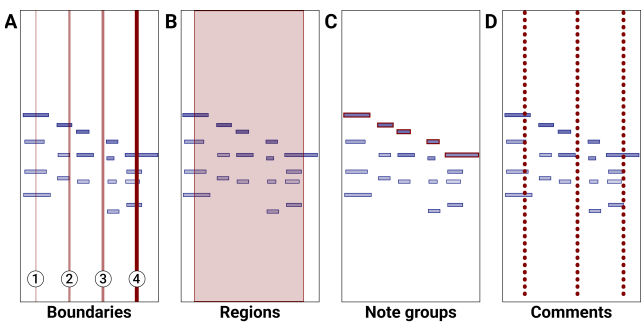


FIGURE 2 | CosmoNote's four annotation types (shades of red) placed over the same sequence of notes (blue rectangles). **(A)** Four boundaries of different levels; **(B)** One region; **(C)** One note group containing five notes; **(D)** Three comments.

dotted lines that span the whole height of the visualization pane (see **Figure 2D**).

2.3. Participants

Participants are citizen scientists interested in music and the research goals of discovering how performers create structures in performances and how listeners understand them. In order to use the interface to annotate the recorded performances, the user should have either headphones or speakers, and a computer with stable internet access. Participants first create an account using a valid email address and password to access the CosmoNote annotation platform, agreeing to the terms of the study and that they are over the age of 18.[2] At a time of their choosing, participants may answer a short questionnaire (see **Supplementary Materials**). adapted from the Goldsmiths Musical Sophistication Index (Gold-MSI, by Müllensiefen et al., 2014) to describe their relationship to music in a more nuanced way than a simple *musician-non-musician* classification. Even though the annotation conventions are suitable for expert performers who may annotate their own work, no formal musical training is assumed or needed to contribute. An audio calibration stage allows participants to adjust their sound volume to a comfortable listening level and researchers to learn about the users' listening environments, i.e., their sound reproduction system and their hearing. It is based on a procedure by Cartwright et al. (2016) whereby participants are asked to count a number of random, equally loud, pure tones.

A training collection allowing participants to familiarize themselves with the interface and the annotations is always accessible to all annotators before completing the main annotation tasks. This training module currently features 3 short excerpts (around 20 s each) of the following pieces: Beethoven's "*Für Elise, Bagatelle No. 25 in A minor*", Bach's "*Minuet in G minor BWV Anh 115*", and Beethoven's "*Symphony No. 5 in C*

[2]https://cosmonote.ircam.fr/agreement.html

minor, Mvt II". The excerpts were chosen for being both simple and familiar to a wide audience while exhibiting good examples of prosodic functions in music. This collection is a sandbox environment where participants can create and save annotations that won't impact their work with the actual task. In addition, the main CosmoNote Youtube channel[3] (also accessible from the CosmoNote website) has training material in the form of video examples showing how to place the different annotations.

2.4. Getting Feedback

After annotating a full set of performances in a collection, participants are invited to answer a questionnaire, giving feedback about their experience with the interface and with the annotation task. For example, for a boundary annotation task, the instructions will indicate the intent of boundary strengths while the feedback questionnaire will ask about the strategies annotators used, which will tell us how participants viewed/used the tools (see **Supplementary Materials**). As the experience and/or task may be different depending on the collection, custom feedback questionnaires can be shown for each collection. Participants are only asked to provide feedback after annotating a full collection because tasks usually involve annotating many pieces with similar properties. If a collection involved pieces without shared properties, a simplified version of the questionnaire could be implemented in the future. In this phase of studies, we want to minimize the time participants spend answering questionnaires and maximize the time they spend annotating music. Incidentally, annotators can include text labels on every annotation type and the special "Comment" annotation type is designed for immediate feedback (i.e., it allows users to mark something they find interesting or out of the ordinary). Although these questionnaires are the main avenue for receiving feedback, some studies will involve direct conversations with participants. Additionally, participants can reach the CosmoNote team *via* email (shown on the main site) for any other observations or comments they may have. The feedback will be used to iteratively refine the CosmoNote interface over subsequent annotation campaigns.

3. THE ANNOTATION TASK

The performance annotation task, done with CosmoNote, is central to our method. Participants listen to audio recordings of the recorded piano performances while viewing the various music visualization layers (see Section 2.2 and **Figure 2D**) and are asked to mark segmentation and prominence in the music (as detailed in Sections 3.1 and 3.2). Participants are provided with annotations instructions that they can access at any time. Annotators currently have to read approximately one page of instructions though the exact amount of instruction/training needed may itself be the subject of future studies. Annotation instructions are tailored to specific collections of recorded performances, allowing us to run complementary studies as needed. There is no time constraint for making annotations. This means that participants will have the option of completing a set of annotations over multiple listening sessions, in a recurrent fashion. They may also revise their annotations over separate hearings before clicking the finish button which freezes the annotations, no longer allowing further changes.

Figure 3 shows an organic annotation workflow highlighting the five most frequent interface interactions that listeners are faced with when marking musical prosody in CosmoNote: (1) listening/visualizing (using the sound controls and visualization options), (2) annotating (placing any of the four annotation types), (3) editing (adding labels to, moving, or deleting annotations), (4) saving (syncing to the database), and (5) finishing (concluding the process for a given piece). The following subsections describe the annotating of segmentation and prominence respectively. It should be understood that these are not necessarily separate tasks but rather are two areas of focus within the overall annotation task.

3.1. Annotating Segmentation

Segmentation is the process of dividing something, in this case music, into meaningful units. It has been extensively studied in the fields of phonetics, speech perception, music analysis, and music information retrieval. For example, music theorists have famously studied the grouping processes that segment music into coherent chunks (Lerdahl and Jackendoff, 1996; Cambouropoulos, 2006), and how musical phrases, note lengthening, and intensity variations signal important segments to listeners.

Although prosodic cues can arise from composer-determined structures, our approach is focused on interpretive (that is performer-specific) use of musical prosody to segment musical streams. As a starting point, we examine how generalized concepts (Boundaries, Transitions, and Pauses) are traditionally defined, and in which ways they are likely to be shaped by performers.

Boundaries are well-studied structures that are used to describe segmentation (Wang et al., 2017). Even though their precise location can be ambiguous, annotated boundaries should indicate, by definition, clear points in time dividing the music stream into segments. These segments should be coherent (e.g., a complete musical idea or a musical thought) and help listeners make sense of the music. **Figure 4** shows example boundary annotations.

Segmentation is mainly marked with the *Boundary* annotation type in CosmoNote. The four level *strengths* offer more granularity and provide more details for the data analysis. It is worth mentioning that, for this protocol, boundaries do not act as a nested hierarchy. This means for example that a boundary of level 1 is not contained in superior levels (2, 3, 4); and by extension, only one level is allowed at each time point. We can make sure that annotators understand how different boundary strengths mark segmentation (from 1-weak to 4-strong) by giving clear instructions. Boundary profiles aggregated from data of many participants will minimize effects of blunders (e.g., an annotator meant to press 1 but pressed 3) and outliers (e.g., an annotator marked a boundary where no one else did). Boundary levels can be a priori mapped to many types of segments. We describe below one of many possible mappings.

[3]https://www.youtube.com/channel/UCEOzV1aQ4zOM2RLUq-AV0Og

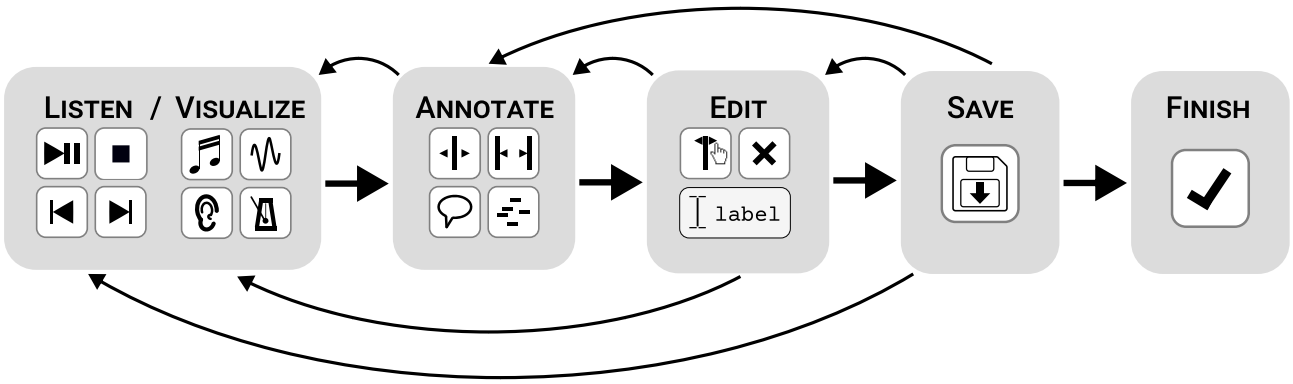


FIGURE 3 | A diagram of 5 steps proposed to listeners for annotating a piece using CosmoNote, from left to right: listening/visualizing, annotating, editing, saving, and finishing. Notice that users are able to go back and forth between all intermediary stages until finishing.

Motives, are the smallest indivisible succession of notes and/or rhythms detectable as a unit in music (Kennedy and Kennedy, 2013). They may be delineated by subtle cues like accents or micro pauses executed by the performer. In speech, letters attain meaning when they are turned into words. Likewise, individual notes or rhythms are imbued with meaning when grouped into musical motives. Musical motives are often repeated in a piece and may represent different concepts such as: the seed of a musical idea to be developed (e.g., the main motive in Beethoven's First Movement of his 5th Symphony in C minor) or symbolize a character or an idea (e.g., in opera, a sequence of notes called *leitmotif* is repeated each time a character enters the scene). When motives have a larger priority in a piece, they are also called *figures*.

Sub-phrases are parts of a *Phrase*, which is a complete self-contained musical statement. Phrases and sub-phrases are often notated on the score using slurs, which give articulation cues to the performer. It is noticeable that these musical terms are directly linked to phrases in speech, which are governed by syntax. In that sense, the harmonic structure of a phrase (in tonal music) usually follows a set of syntactic rules (Rohrmeier and Pearce, 2018) that help to punctuate where musical phrases end; for example by using a cadence to arrive at a resting melodic or harmonic position. A common case of sub-phrases that constitute a larger phrase are antecedent and consequent sub-phrases, which resemble each other rhythmically and are complementary to each other.

Sections as defined by Spencer and Temko (1994) are major structural units made up of a number of smaller structural phenomena. They contain, for example, phrases and motives that are related between them and function as larger parts of a whole inside a piece. Sections represent a complete, but not independent musical idea, which is why pieces are generally composed of more than one section. Since they represent important parts of a piece, composers may notate sections in a score using double bar lines and they are often labeled alphabetically in musicological analysis with capital letters (e.g., *A*, *B*, *A'*). Similar to what happens with phrases, the end of a section is usually demarcated with some concluding melodic or harmonic device which is perceived as being conclusive; although the resolution is often clearer with sections. For example, performers may demarcate sections using a longer pause or larger tempo change compared to what they do with other boundaries.

Transitions may be musical passages that set up a change that is coming in the music, for example from one idea to the next. They can be seen as a link between sequential musical ideas. Transitions typically blur changes (boundaries) in the music by moving slowly through them. There are many ways to introduce a transition in music. For instance, elements from the following structure could be hinted at (e.g., a forthcoming motive is heard in a secondary voice) and/or new phrases can be introduced specifically to function as a bridge between ideas (e.g., the last passage of the third movement of Beethoven's 5th symphony shown in **Figure 5** transitions to the fourth movement). To execute a transition musically, performers can use tempo, dynamics and articulation to prepare the listener for what is coming by intentionally making the contrast between musical ideas smoother and less rigid.

Pauses occur analogously in speech and music as segmentation devices that add space between two adjacent structures. In music, this concept is related to the timing of the notes in a piece and is executed by the performer *via* lingering on notes or by using silence. Silence is a very powerful tool in music. It is used for separating musical elements, to hold the audience in suspense, or for other expressive effect. Pause are executed before, during, or after a musical event. When notated in the music, pauses are indicated by a comma or a *fermata* symbol placed above a note or a rest. The term *breath* is used either figuratively or literally in relation to the performer's breath when executing a musical passage (**Figure 6**). The duration of a pause is sometimes specified by the composer but the performer makes the ultimate decision of how long it should be depending on the unique circumstances of a performance.

Transitions and pauses may be marked with the *Region* annotation type in CosmoNote. Participants are able to mark the beginnings and ends of these structures and label them accordingly. When the starting/ending times are not clear, especially for

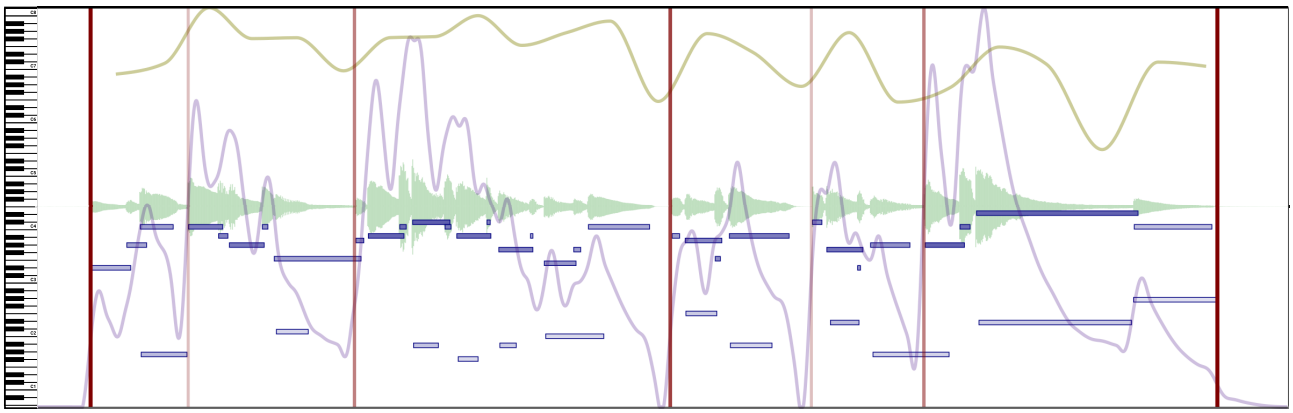


FIGURE 4 | Excerpt of Beethoven's Symphony No. 5 in C minor, Mvt II. Boundaries (red vertical lines) in this example are assigned according to the strength of the change. Stronger boundaries have a thicker, less opaque red color. See **Supplementary Video 2** in the **Supplementary Materials** to hear the music presented in this Figure.

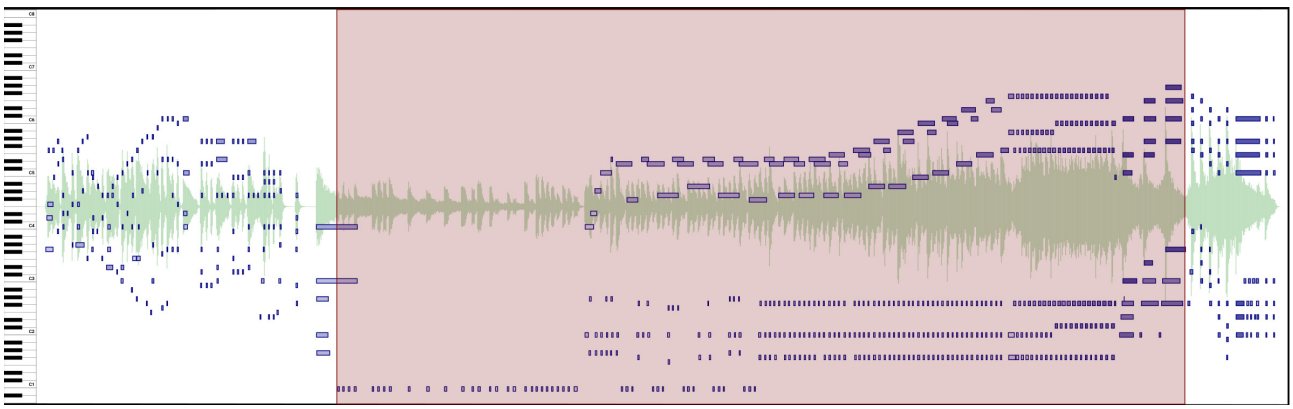


FIGURE 5 | Excerpt of a long transition marked with a region (light red rectangle) between Movements III and IV of Beethoven's Symphony No. 5 in C minor. See **Supplementary Video 3** in the **Supplementary Materials** to hear the music presented in this Figure.

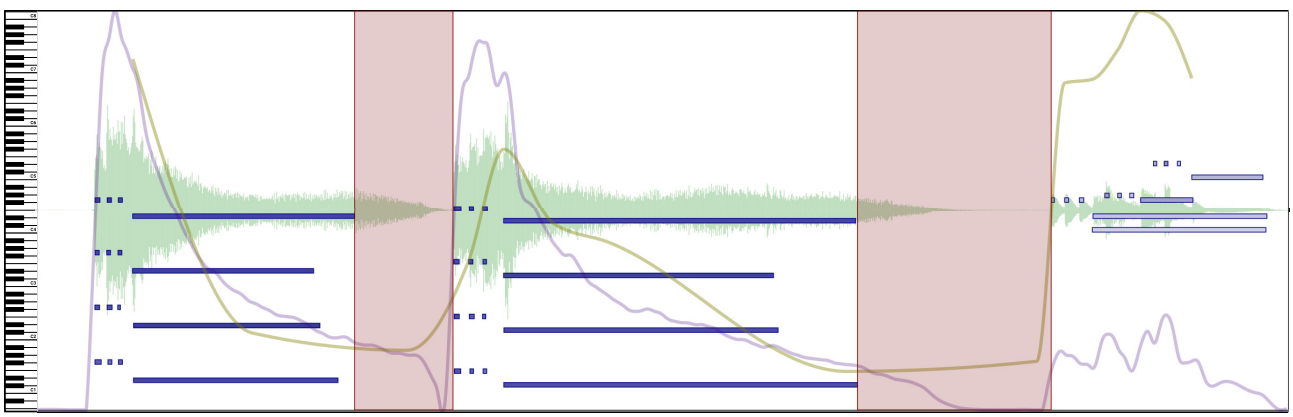


FIGURE 6 | Two pauses marked with regions (light red rectangles) in an excerpt of Beethoven's Symphony No. 5 in C minor, Mvt I. Silence and timing are used to make the music breathe. See **Supplementary Video 4** in the **Supplementary Materials** to hear the music presented in this Figure.

transitions, it is recommended to place them at the outermost value possible. Overlapping regions are allowed as needed.

3.2. Annotating Prominence

Prominence generally characterizes an emphasis drawn toward a certain element of a whole. Prominence in speech is important because speakers are capable of changing the meaning of an utterance by assigning more weight to a certain word or by changing their intonation. In music, experienced performers may make musical structures stand out in a way that helps to resolve ambiguities, particularly in musical meter (Sloboda, 1985). They may also introduce focal points by assigning more weight to a note or a chord.

For this description, we divide musical prominence into two sub-categories: vertical or horizontal based on their temporality. Events that may or may not segment the music but that are easily recognized as belonging to a single moment, using timing and dynamics, are classified as vertical prominence. On the other hand, attention drawn to a particular sequential structure such as a melodic line that cannot be pinpointed to a clear moment, is categorized as horizontal prominence. Since prominence can be viewed as either vertical or horizontal, all vertically prominent structures may be marked using *Regions* (if a preparatory stage exists) and *Boundaries (or Comments)* while horizontally emphasized ones may be marked with the *Note group* annotation type (e.g., notes in an important motive or a salient melody).

As was the case with segmentation (see Section 3.1), we will concentrate on the point of view of the performer in the following descriptions of common prominence creation techniques (stress, melodic salience, and tipping points) that listeners are likely to recognize while annotating prominence.

Stress is an emphasis on a particular element to make it more prominent than those around it. In speech, stress is used to help parse words in a language like English where syllables and words can be stressed to alter the meaning of an utterance (Ashby, 2011). In music, this category is close to how Drake and Palmer (1993) define *rhythmic grouping*, which focuses on event intensity/duration and *metric accents*, which focus on higher order regularities in a sequence. Thus, stress may be indicated by a combination of performer actions like an increase in sound intensity, duration, or even a change in timbre, as seen in **Figure 7**.

Melodic salience is a special case of prominence dedicated to the melody of a piece. It relates to the concept of *melodic accents* by Drake and Palmer (1993). Melodic salience, as shown in **Figure 8**, may be recognized by an increase in loudness and duration (the notes of the main voice in a melody are usually louder and longer) or a variation in timbre (by using a different touch/technique or a different instrument altogether). Performers can indicate melodic salience in piano performances by systematic variation of intensity and duration, even within hands, to enhance the melody (Repp, 1996).

Tipping points, as defined by Chew (2016), are cases of "extreme pulse elasticity" where musical time is suspended in an unstable state beyond which a return to the pulse is inevitable. As such, they are frequently present in musical transitions (a clear distinction exists before and after the tipping point) and musical pauses (a tipping point created at the moment a pause can no longer be stretched). **Figure 9** shows a passage with a melodic tipping point, where the performer plays with the listeners' expectations and delays closure of the sub-phrase.

3.3. Potential Annotation Strategies

Participants are presented with annotation instructions to direct them in doing the annotation task. Yet the specifics of their annotation placement are driven by their individual strategies. The following is an excerpt of the general annotation instructions that participants read when they enter the main annotation campaign in CosmoNote: "*Please mark the boundaries that you hear in the music, and indicate the strength of each boundary. You may be presented with information layers such as the notes, tempo or loudness, but your ear should be your main guide*". Although there are numerous ways to reach this goal, we will center on two branching strategies that are common to all annotations, namely real-time vs. retrospective annotations and analytic vs. intuitive mindsets. These methods will be examined using actual experiences that CosmoNote participants (software testers) had during the development phase, which are used to anticipate and deal with problems that future annotators may confront.

Sometimes, participants wanted to listen to the whole piece, from start to finish, before placing any annotation. These participants found it easier to first concentrate their full attention on the music, forming their own mental model of the piece's structure and of what the performer meant to communicate, and only then proceeding to the annotation stage. This retrospective annotation process could take longer but listeners who adopted it would have to revise their work less. In contrast, some participants preferred annotating in real-time, which meant marking structures while listening to the audio, even for the first time. Since music was listened to and understood retroactively, if listeners were not already familiar with the music, they would need to go back again to correct their work after becoming more familiar with it. To maximize the benefits of real-time and retrospective annotations, we recommend marking only the biggest boundaries on the first play-through. Once the larger segments are defined, annotators may go back, focus on smaller segments and repeat the process, correcting mistakes as needed.

There is also the question of whether to analyze the music intellectually or to annotate by intuition. An analytical approach will vary depending on the person's musical knowledge, experience or formal training. It is important to note that annotating analytically does not mean using traditional music theory or score structure analysis, nor is it about finding repeating patterns within the sounds. Annotating analytically means thinking deeply about the performer-made segments and prominent structures in the music. The counterpart of this strategy is a more intuitive, spontaneous annotation, where citizen scientists try to reduce their cognitive load, be more comfortable, focus less on being *right* and embrace the subjectivity of the task. The potential drawback of this strategy is that listeners could end up annotating the emotions conveyed by the music, which is not the purpose of this methodology. We recommend some balance between the two, where neither

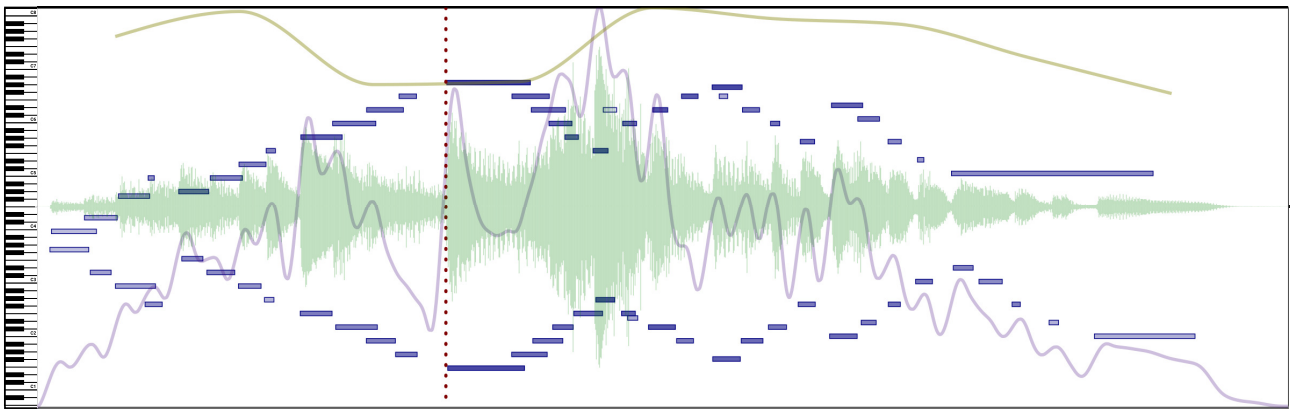


FIGURE 7 | Stress is marked by a comment (red dotted line) at the pinnacle of the progression in this excerpt of Beethoven's Variation No. III from 32 Variations in C minor. See **Supplementary Video 5** in the **Supplementary Materials** to hear the music presented in this Figure.

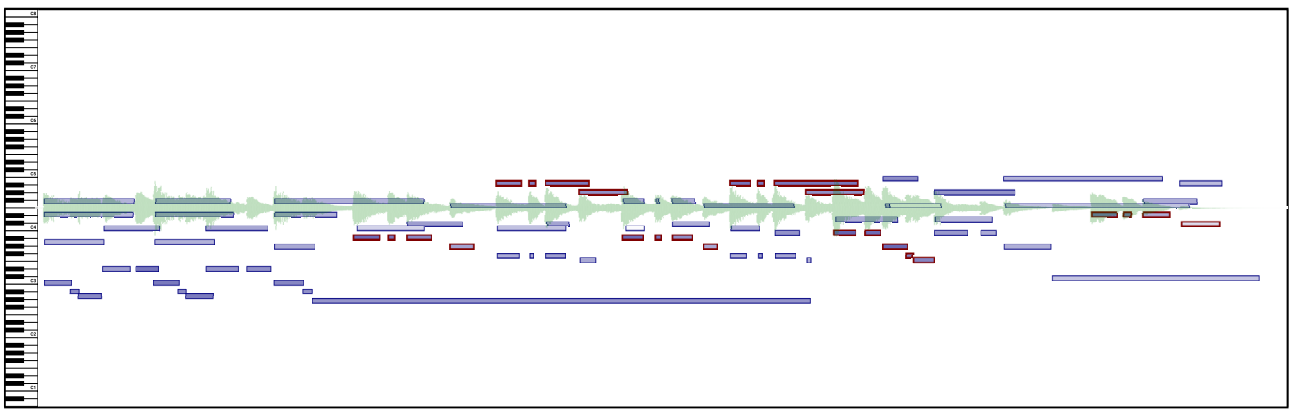


FIGURE 8 | Melodic salience highlighted in note groups (light red rectangles) as the notes of the main motive are made more present by the performer on an excerpt of Chopin's Ballade No. 2 in F major. See **Supplementary Video 6** in the **Supplementary Materials** to hear the music presented in this Figure.

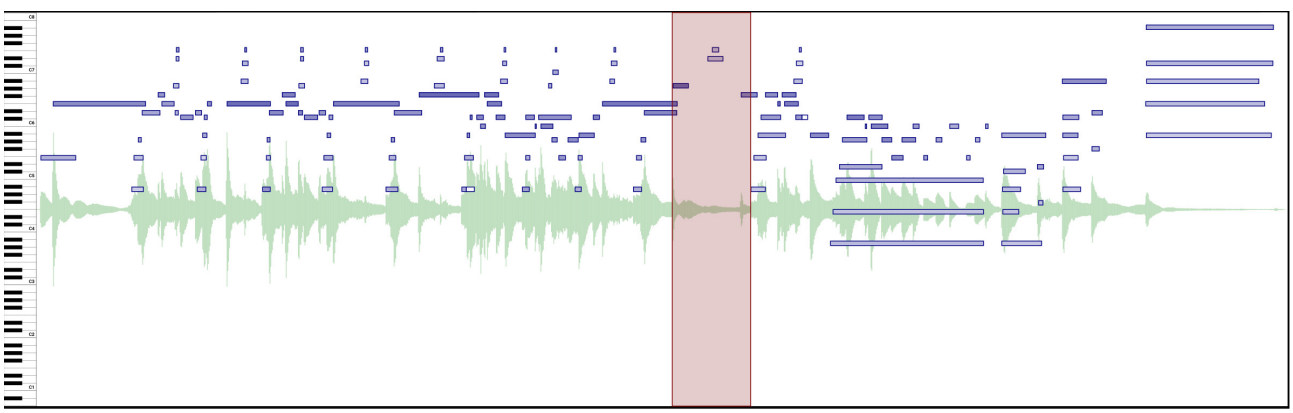


FIGURE 9 | A tipping point marked with a region (light red rectangle) on Grieg's Solveig's Song evidences how a musical moment is stretched to its limit. See **Supplementary Video 7** in the **Supplementary Materials** to hear the music presented in this Figure.

attentive listening nor spontaneity are privileged one over the other.

Since music is primarily an auditory stimulus, participants are discouraged from placing annotations only by relying on visual cues. However, no matter the approach, any complementary information (e.g., visuals or cues like boundary sounds) should be understood more as advice than a prescribed way to perform the task since we do not wish to impose a fixed way in which annotators use the tools in CosmoNote. In fact, we want them to explore the possible uses of the tools and give us feedback on how they use them. Ultimately, any instructions or strategy should be mostly used to help externalize the intuitions that are formed while listening to the music. This is why it is made clear, at various stages, that the most important aspect of the musical annotation process for participants is to trust their ears.

4. ANTICIPATED RESULTS

4.1. Data Structure and Analysis

Data from annotations collected in CosmoNote is organized in a secure database and exported using a `json` (JavaScript Object Notation) format for its analysis. Structures of `json` arrays of paired name/value objects ensure great flexibility and modularity. Data for each of the four annotation types is classified by pseudonymized participant ID numbers. Objects contain primary properties (data) like timestamps and labels, and secondary properties (metadata) such as creation and modification dates. For example, note group annotations not only contain an onset time but also sub-structures like the MIDI note identifier for each note in a group. A scheme of the annotation data structures is shown in **Figure 10**. More properties may be incorporated as CosmoNote evolves, is adopted by more users, or as the need arises. For instance, the data structure does not currently contain information on which music features the annotator chose to display and when. However, since the ability to track user interaction involves a non-trivial amount of development work, it will be part of future work.

For each piece, our main variables are distributed over the quantity and location (time, and pitch when applicable) of each data point from the four types of annotations, each related to a participant and containing auxiliary properties (as described above). In addition, the music features that are computed for visualizations in CosmoNote (MIDI data, loudness, tempo, and harmonic tension curves) constitute important synchronized time-based information for the analysis of the annotation data. To establish relevant relationships between aggregated annotation data, high-level prosodic features, and low-level musical features and acoustic properties, we will use techniques such as change point analysis, cluster analysis, and multiple regressions.

4.2. Accuracy and Precision of Annotations

This protocol relies on manual annotations of musical prosody. This approach is the most appropriate to explore questions about intuitions humans have that machines do not (i.e., the recognition of subtle cues of prominence in ambiguous musical structures). This means that accuracy is not strictly a problem for this method since we do not assume there is a right answer for the placement of annotations. However, precision among the annotations is an issue since the precise timing of segmentation or prominence annotations could differ across participants.

Imprecision will be accounted for by creating a large profile of annotations for a single piece. However, because of the possible deviations in timestamps, each annotation will be weighted to create this profile, where a tolerance proxy is set. For example, ± 3 s or the equivalent of 1 bar of a piece with quadruple meter at 80 bpm (Ong, 2006, p. 58). Comparing the mean profile with each individual profile will help detect outliers in an individual profile. The data will also be checked for internal consistency.

4.3. A Library of Examples

Another outcome of the citizen science studies is the creation of a performance-oriented library of musical prosody examples. It is an easily accessible, free resource intended for music professionals (performers, composers, musicologists, music educators), music enthusiasts (without formal musical training), and the public at large. This nascent library is composed of four main parts: The raw MIDI and audio data obtained from the pieces in the datasets described in Section 2.1, the computed musical features (loudness, tempo, harmonic tension) as described in Section 2.2.1, individual annotations collected using the protocol detailed throughout Section 3, and aggregated data derived from the analysis of individual annotations, as specified in Section 4.2.

Anyone who accesses this library will be able to listen to the music and see the annotations as they were created. They will have total control over what representation they see, how to layer multiple visualizations, which type of annotation is shown, and which labels were assigned at a given point. Users will also be able to use zoom controls to interact with the content at their preferred time scale, and see the aggregation of multiple users' annotations for the same piece when they are available in CosmoNote. The library already contains more than a dozen examples of musical structures and can be accessed through a playlist in YouTube.[4]

4.4. New Models and Conventions for Musical Prosody

We believe that large scale usage and adoption of our method presents a step toward improving current practices for thinking about and annotating musical prosody in performance. Using the citizen science paradigm, we hope to build a community around the research of these structures in performed music. Each and every person that participates in our studies may come with their own motivations (e.g., passing time, learning about music, listening to their favorite artist) but they will also contribute to the same shared goal of understanding musical prosody in performed music. In the process of annotating the music, citizen scientists will refine our protocol and facilitate its wide adoption as part of a set of conventions to annotate musical prosody.

[4]https://youtube.com/playlist?list=PLR0hNEZTO56Nbjc02ciW_EPxrWnmnKlp1

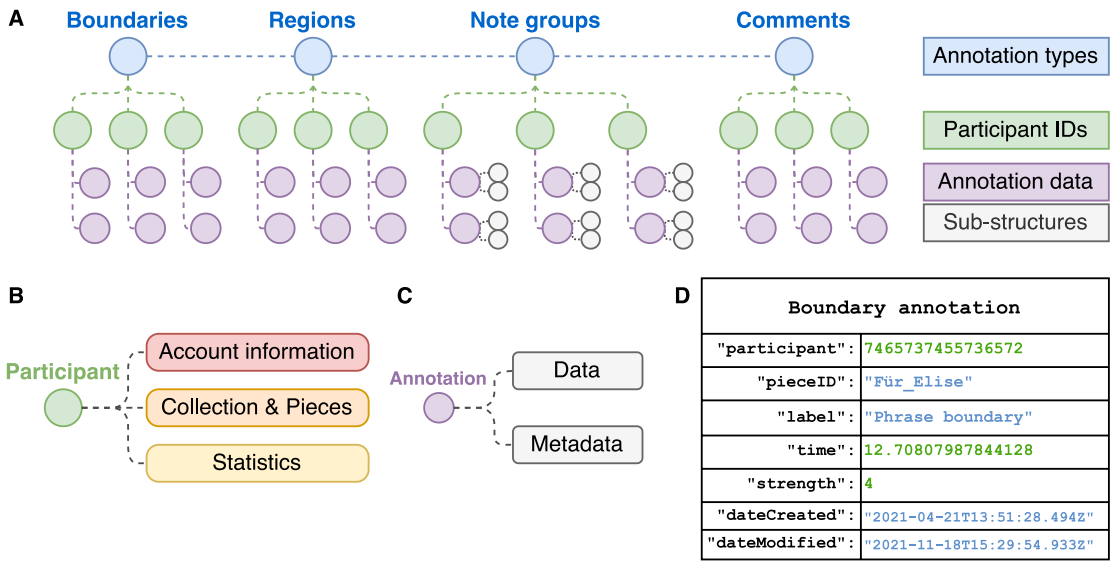


FIGURE 10 | Data structure for the CosmoNote Annotations as organized in `json` objects. **(A)** A representation of nested data in each of the four annotation types; **(B)** A participant object contain information about its Account, Collection & Pieces, and aggregated Statistics; **(C)** Annotation objects contain data (e.g., timestamps, labels) and metadata (e.g., date of creation and last modification); **(D)** An example boundary annotation `json` object.

The data generated from our method will be used to inform new models for prosody perception and production both from theoretical (rule-based) and data-driven (machine learning) analyses. Theoretical models will be informed by our results, representing abstractions in performance that use musical prosody, and that are difficult for machines to recognize. Our analysis will extract a distribution of prosodic structures from which observed patterns can be described and modeled *via* algorithms that can be validated by expert annotators. On the other hand, data-driven models will be constructed by using human annotations to train machines to more naturally identify musical prosody. In any case, our objective is to use our models to mediate the relationship between prosodic structures and acoustic variations from a different perspective, that helps composers, performers, and music lovers in general, to enhance their understanding of the role of prosody in music performance.

5. DISCUSSION

In this article, we have presented a novel and scalable method to represent, identify, annotate and analyze musical prosody in performed music from a top-down, human-centered perspective. This method is supported by an innovative web-based platform that combines traditional and current music representations to improve the annotation experience. The results of data collection studies using this method will contribute to better understanding of how humans perceive prosodic structures in performed music. We aim to construct models that explain how these structures are created and used by performers in their real-world practice. The data we collect will also be used for the development of a library of musical prosody examples that will form the basis for formulating a musical prosody annotation convention.

Many of the advantages of our method are related to how we collect the data. Since the process is self-paced, annotators are not constrained by a fixed time limit. The instructions explain what musical prosody is and provide concrete examples of how prosody may be presented in expressive performance. Thus, annotators can afford to listen attentively, think about their choices, and even modify their annotations during a subsequent markup session. The music visualizations and training examples provide cognitive scaffolding (Yelland and Masters, 2007) for users with the various visual layers giving complementary information. For example, the piano roll visualization layer is helpful to single out the note onsets and intensities of a prominent melody but only gives vague information regarding tempo while more specific information about tempo is provided by the tempo layer. It is worth noting that piano music was chosen for the simplicity of aligning event-based (MIDI) information with an audio signal. However, any music audio can be depicted on the interface and the tools work equally well for denoting expressiveness in music for other instruments, including voice. The main obstacle in this case would be the difficulty of deriving precise note onset and offset information aligned with the music audio, but that is not insurmountable (e.g., with manual annotation). We anticipate that the ways in which the tool is used could evolve to encapsulate many more expressive devices appropriate for other instruments, where the ideas of segmentation and prominence still apply. With regard to the current interface, the tools available in CosmoNote are easy to use by virtue of their simplicity. The audio controls are similar to any music reproduction software

and annotations are placed with a click of the mouse or a keyboard shortcut.

The challenges we encounter are typical of many citizen science projects and include ensuring data quality and sustaining community engagement. As for the data itself, the types of structures that can be marked are potentially limited by technical constraints, the difficulty, and duration of the task. For example, even though there is no time-limit, if a specific action in CosmoNote is cumbersome, it can be perceived as tiring or frustrating. Solutions for these problems are generally complex; one approach is to address them methodically and iteratively at the software development level. For example, if we find that one prosodic marker/annotation type is being used rarely, we could first investigate why by getting direct feedback from the feedback questionnaires and then make changes accordingly. If annotators do not find an annotation type/visualization useful for marking musical prosody, since the representation captured by this feature is not being correctly communicated or is redundant, the feature can be redesigned or removed. The same process would apply if a given interaction is not consistent/intuitive and the user experience could be improved by simplifying the interaction or introducing annotation types in a progressive manner in order to reduce frustration or fatigue.

Our annotation protocol, the training content, and the feedback surveys are means to bolster data validity and reliability (Balázs et al., 2021). For instance, the first campaign was launched to gather annotations while serving the complementary purpose of providing information for improving people's interactions with CosmoNote, thus encouraging further contributions. We are in the process of building a community that shares our goals of understanding how music structures are created and shaped in performance through musical prosody. We rely on members' contributions and feedback; it is with the cooperation of both expert and non-expert annotators that we will iterate and improve upon the components of our annotation method. To ensure sustained community engagement, more collaborative features that connect citizen scientists are planned for the future versions of CosmoNote.

Our method is an ambitious attempt at discerning abstract musical structures in performed music through listeners' annotations. CosmoNote is a flexible and extensible tool suitable for representing and annotating musical prosody in real-world performances. By using it to explore how humans apprehend segmentation and prominence introduced in performance, we will have the means to design models that capture the complex relationships of these structures with musical features and their acoustic properties in a comprehensive way. Subsequent phases in our studies will build iteratively upon the results of previous ones, ensuring continued progress of the annotation method. The long term goal of this research is to open new paths for the general public to think about what is being communicated in expressive music through the performer's segmentation of musical ideas and creation of musical prominence, and to offer new ways to explore and talk about performed music in general.

DATA AVAILABILITY STATEMENT

The Musical questionnaire and Feedback questionnaire, as well as videos showing playback of the musical examples presented in **Figures 1**, **4**–**9** can be found in the **Supplementary Material**. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

LF developed CosmoNote. DB and EC created the annotation protocol and annotated the pieces. EC played the examples. DB recorded them. All authors contributed to the writing and to the design of CosmoNote. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.886570/full#supplementary-material

Supplementary Video 1 | CosmoNote's interface: Video corresponding to **Figure 1**: The main CosmoNote interface showing an annotated excerpt of Beethoven's Für Elise. Different visualizations and annotation types are displayed.

Supplementary Video 2 | Boundaries: Video corresponding to **Figure 4**: Excerpt of Beethoven's Symphony No. 5 in C minor, Mvt II. Boundaries (red vertical lines) in this example are assigned according to the strength of the change. Stronger boundaries have a thicker, less opaque red color.

Supplementary Video 3 | Transition: Video corresponding to **Figure 5**: Excerpt of a long transition marked with a region (light red rectangle) between Movements III and IV of Beethoven's Symphony No. 5 in C minor.

Supplementary Video 4 | Pauses: Video corresponding to **Figure 6**: Two pauses marked with regions (light red rectangles) in an excerpt of Beethoven's Symphony No. 5 in C minor, Mvt I. Silence and timing are used to make the music breathe.

Supplementary Video 5 | Stress: Video corresponding to **Figure 7**: Stress is marked by a comment (red dotted line) at the pinnacle of the progression in this excerpt of Beethoven's Variation No. III from 32 Variations in C minor.

Supplementary Video 6 | Melodic salience: Video corresponding to **Figure 8**: Melodic salience highlighted in note groups (light red rectangles) as the notes of the main motive are made more present by the performer on an excerpt of Chopin's Ballade No. 2 in F major.

Supplementary Video 7 | Tipping point: Video corresponding to **Figure 9**: A tipping point marked with a region (light red rectangle) on Grieg's Solveig's Song evidences how a musical moment is stretched to its limit.

Supplementary Datasheet 1 | Musical Questionnaire: Example of CosmoNote's Musical Questionnaire, adapted from the Goldsmiths Musical Sophistication Index (Gold-MSI, by Müllensiefen et al., 2014).

Supplementary Datasheet 2 | Feedback Questionnaire: Example of CosmoNote's Feedback Questionnaire for a boundary annotation task.

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The influence of modality on input, visuo-motor coordination, and execution in the advanced pianist's sight-reading processes

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In this study, we explored how the modality (major and minor) would affect the input (i. e., fixation), visuo-motor coordination (i.e., eye-hand span and time of performance), and execution (i.e., errors) in the advanced pianist's sight-reading processes, as well as relations among these three phases. Thirty-two advanced pianists with 5–54 years of piano training participated in the study. All participants sight-read three two-voice pieces in either major ($n = 16$) or minor ($n = 16$) mode while their eye movements were measured by an eye-tracking device (30 fps). All pieces were 20-measure long written in 4/4 m, adapted from unfamiliar Baroque pieces. Results showed that sight-readers fixated more frequently and tended to spend more time performing in a minor score than in a major score. This implies that modality of a score affects an efficiency of input and visuo-motor coordination in the advanced pianist's sight-reading. Spearman's correlation coefficients showed that errors were correlated positively with the number of fixations and the duration of performance. These results add more evidence to the notion that efficiencies in input and visuo-motor coordination are related to the accuracy in execution.

KEYWORDS

sight-reading, modality, fixation, eye-hand span, errors

Introduction

Music sight-reading is an indispensable skill for professional musicians, often required to perform an unfamiliar score without any practice. This skill involves complex processes related to many different factors such as a performer's cognitive ability, motor skills, memory, musical ability, and music training (Wolf, 1976; Chang, 1993; Lehmann and Kopiez, 2009; Zhukov, 2014b; Rosemann et al., 2016). Particularly unique in music sight-reading is its involvement of an information conversion process from visual to motor domains (Sloboda, 1983). While performers process music information in a score through vision, their somatosensory cortex executes muscle movements to generate the appropriate sound (Inhoff and Gordon, 1998; Kaketa, 1998). Many researchers have worked tirelessly to be able to elucidate the whole process of sight-reading. This is a complex process that involves at least two types of skills: reading skills and mechanical

skills (Wolf, 1976). It means that performers must encode the musical information presented on the score into the brain (i.e., reading skill), then they need to place the fingers in the right position at the right time and execute it (i.e., mechanical skill). The process of sight-reading also involves auditory feedback (Banton, 1995), because in the end the performer needs to confirm by listening to whether the encoded musical information is consistent with the output. Therefore, it seems that the cognitive processing of sight-reading can be divided into three phases: visual input, visual-to-motor sensory conversion, and execution. In the following, we will describe how each of these three processing phases of sight-reading works and how to evaluate their efficiency.

The first phase called *input*. Sight-reading and text-reading possess similar cognitive processing (Sloboda, 1977; Chang, 1993). In fact, when reading text, our eyes do not operate in a single sustained photographic action like a digital camera, but by projecting the scene reflected in the pupil onto the retina through jumping, discrete eye movements. This is similar to movements such as turning a flashlight on and off at short intervals in the dark (Lehmann and Kopiez, 2009, p. 344). This discrete eye movement is called saccade, and the average length of each saccade is about 5–9 letters in text reading. A temporal pause in eye movement between two discrete saccades is called *fixation*, through which readers encode text information. In music, sight-readers briefly suspend eye gazes at particular locations of a sore to encode information on the score. There is a large difference in eye movements of good sight-readers from those of poor sight-readers. For example, the mean duration of fixation is ≈350–400 ms (Rayner and Pollatsek, 1997). A good sight-reader uses less fixation and shorter duration of fixation in sight-reading a music piece (Goolsby, 1994; Waters et al., 1997; Drai-Zerbib et al., 2012). These and further experimental studies (Furneaux and Land, 1999; Lehmann and McArthur, 2002; Penttinen and Huovinen, 2009) support the classical notion, derived from interviews and observations of professional pianists (Wolf, 1976), that good sight-readers input necessary information in a greater chunk than poor sight-readers and increase the efficiency of visual information processing. On the other hand, the sight-reader not only looks at the score when sight-reading, but also looks down at the keyboard to check the position of the fingers (Banton, 1995). For example, when the sight-reader is unsure of a note to be played or a note that has already been played, he or she will habitually look down at the keyboard. Such an action tends to affect the sight-reader's fixation, making it necessary to pause to look at the musical information, resulting in less efficient input. The efficiency (or inefficiency) of input can also be measured by the duration of performance: A longer performance means a slower tempo that can result in a longer duration and a greater number of fixation (Chang, 1993; Furneaux and Land, 1999; Lim, 2018), which can imply a low efficiency in visual processing.

The duration of performance can also indicate an efficiency of the second phase of sight-reading process, *visuo-motor coordination*. In this phase, sight-readers transform visual information from a score to motor functions so that their hands (or vocal cords) can work appropriately (Rayner, 1998; Adachi et al., 2012). A shorter duration of performance can indicate faster processing of visuo-motor coordination, implying a temporal efficiency in sight-reading. Another measure for the efficiency of visuo-motor coordination is *eye-hand span* (or *EHS*), the distance between a note being played (i.e., hand position) and that being looked ahead (i.e., eye position) (Sloboda, 1974; Rayner and Pollatsek, 1997; Truitt et al., 1997; Furneaux and Land, 1999; Lehmann and McArthur, 2002; Adachi et al., 2012; Rosemann et al., 2016). It has been acknowledged that good sight-readers look further ahead of the notes that are being played (e.g., Sloboda, 1974, 1977; Goolsby, 1994). EHS can be measured by either *time index* (i.e., the duration between a note being fixated and that note being played) or *note index* (i.e., the number of notes looked ahead while playing a particular note). With time index, the average of EHS has been reported ≈0.70–1.48 s in music sight-reading (Furneaux and Land, 1999; Wurtz et al., 2009; Rosemann et al., 2016; Lim, 2018). With note index, EHS can vary depending on the type of music and the skill of sight-reader (Chang, 1993; Furneaux and Land, 1999; Gilman and Underwood, 2003). For example, according to a study by Weaver (1943), EHS for a four-voice chorale-like music has been reported as 1.5 notes, that for a homophonic music (i.e., a melody with its accompaniment) as 1.9 notes, and that for a two-voice contrapuntal music as 3.1 notes. EHS of good sight-readers can be as long as 6.8 notes while that of poor sight-readers can be only 3.8 notes (Sloboda, 1974).

While sight-readers coordinate between visual and motor domains, they also make actions and generate the intended sound (e.g., move their physical parts on an instrument or use their vocal cords and other related muscles). This is the third phase of sight-reading process, *execution*. An accuracy of execution has been measured by the number of errors, which evaluates a degree of accuracy while executing information transformed from visual to motor domain (Sorel and Diamond, 1968; McPherson, 1994; Gilman and Underwood, 2003; Highben and Palmer, 2004; Gudmundsdottir, 2010; Adachi et al., 2012; Zhukov et al., 2016). The number of errors is often used to differentiate sight-readers between good and poor (Drake and Palmer, 2000; Gilman and Underwood, 2003; Besson et al., 2007). Good sight-readers tend to make fewer errors in execution and have a higher accuracy rate than poor sight-readers. This seems to be because skilled sight-readers are more efficient, they can perform correctly without interruptions and tend to make fewer errors (Drake and Palmer, 2000; Herrero and Carriedo, 2019). Moreover, the number of errors depends on the style of music (Chang, 1993): Sight-readers make more errors in contemporary (13 %) than contrapuntal Baroque music (6%). Moreover, *stuttering*—trying to correct mistakes by playing

more than once—can be an index for flow of execution that may relate to one's confidence in sight-reading. For example, the beginners make more stuttering than the advanced sight-readers; moreover, the advanced sight-readers stutter more often in sight-reading a score with complex meter (Adachi et al., 2012).

Thus, previous research on sight-reading has provided us with various measures that can evaluate the accuracy and the efficiency of input and visuo-motor coordination as well as the accuracy and the flow of execution. Any of these individual measures could highlight what differentiates between good and poor sight-readers; however, it is not fully understood how different abilities across the three phases relate to each other. In fact, such information is scarcely explored except in a few studies. For example, EHS with note index is correlated negatively with the number of errors (Sloboda, 1974; Gilman and Underwood, 2003; Rosemann et al., 2016; Cara, 2018), which implies that the efficiency of visuo-motor coordination may be responsible for the accuracy of execution. It may be vague just to show that the number of errors or stuttering decreases as the level of expertise (or musical training) increases (e.g., Penttinen and Huovinen, 2009; Adachi et al., 2012; Zhukov, 2014a,b; Zhukov et al., 2016), but this information should become noteworthy if one can demonstrate the origins of errors or stuttering to be different between expertise (or training) levels. For example, the number of the beginner's stuttering is correlated negatively with the proportion of fixation (implying its origin to be an inefficiency in input), whereas that of the advanced pianist's is correlated positively with the numbers of pitch and rhythm errors (implying its origin to be a failure in execution) (Adachi et al., 2012). Thorough examinations of relations between measures across input, visuo-motor coordination, and execution will fill in the void in our knowledge of mechanisms of music sight-reading. Moreover, we found that most past studies on sight-reading were performed under restricted rhythmic conditions. In reality, however, sight-reading is not usually performed under restricted rhythms. This finding made us realize that the efficiency of information processing is likely to be affected when sight-reading is performed under rhythm-constrained conditions. Therefore, allowing the sight-reader to perform sight-reading at a natural, unrestricted tempo can maximize the recovery of the sight-reading information processes.

In addition, in the same composition, the minor mode passage is played more slowly than the major mode passage (Post and Huron, 2009). This is probably because the performers have to play at a slower tempo due to less efficient processing of information when playing a minor mode passage. However, there does not seem to be a difference in the proportion of errors between major and minor modes (Lewandowska and Schmuckler, 2020). We suggest that this may be because the reduction in performance speed relieves the cognitive load on the sight-reader and improves the accuracy of the performance. Our review of 47 music sight-reading studies from 1968 to 2018 have revealed that 45 used scores in major while only 14 used those in minor (Qi and Adachi, 2022). Of those, 12 used both major and minor, but none compared multiple dependent variables between these two modes such that their results could capture an overall picture of sight-reading process in tonal music.

The purpose of the present study was two-folds: (1) to investigate effects of modality (major and minor) in three phases of sight-reading process (i.e., input, visuo-motor coordination, and execution) observed on the piano, and (2) to identify directional relations between variables obtained across these phases. In particular, we focused on sight-reading by the advanced pianists (i.e., the population most often studied in the literature), using two-voice contrapuntal music that tends to elicit more efficient visuo-motor coordination than other styles of music (Weaver, 1943; Chang, 1993; Rayner and Pollatsek, 1997). Moreover, we incorporated the complexity of intervallic relations of notes in each voice by preparing for comparable scores between major and minor materials, since the predictability of upcoming intervals would influence the efficiencies of input and visuo-motor coordination as well as the accuracy of execution (Chang, 1993; Ronkainen and Kuusi, 2009).

We predicted that, first, sight-reading a major score would lead to more efficiencies in the process of input and visuo-motor coordination than a minor score, since the latter generally contains more accidentals than the former, but the number of errors in execution would be equivalent between two modes (Post and Huron, 2009). Second, sight-reading a more complex score would result in lower efficiencies in all three phases as well as less accuracy and flow in execution (Chang, 1993; Ronkainen and Kuusi, 2009). Finally, an efficiency in visuo-motor coordination would be correlated negatively with the errors (i.e., higher accuracy and flow) in execution (Sloboda, 1974; Gilman and Underwood, 2003; Rosemann et al., 2016; Cara, 2018). Our analyses of other relations across phases were exploratory without any specific prediction. Together, we hoped not only to verify previous findings but also to touch upon unclear issues that had rarely been discussed in music sight-reading research.

Method

Participants

To gather more participants for the experiment, a request was sent to a piano professor at the School of Music to recommend proficient performers of the piano. Specifically, they are undergraduate piano major students and pianists who have continued their musical activities after graduation, as well as undergraduate students who are not majoring in piano (i.e., majoring in composition, music education, etc.),

who have received systematic piano instruction, participated in piano competitions, and have been judged to have professional performance ability. Finally, 32 advanced pianists with healthy (or corrected) vision participated in this study. The sample consisted of 24 women and eight men, ranging in 18–58 (M = 21.72, SD = 7.60) years of age, with 5–54 (M = 14.11, SD = 8.02) years of formal piano training. Prior to the experiment, each participant signed a consent form explaining its purpose, procedure, and possible risks as well as informing a permission to withdraw anytime as wished. Participants received 3,000 JPY or small gifts upon completion as incentive.

Scores

Two scores (consisting of 2-octave scale, arpeggio, and cadence) were prepared for a warm-up exercise in E major (for those who sight-read major scores) and f minor (for those who sight-read minor scores), which uses four sharps and four flats in their key signatures, respectively. For a practice trial, two unfamiliar scores—G major and c minor—were created, based on unknown fugues by George Frederick Handel (1685–1759). For trials, three unfamiliar scores with different complexities of intervallic relations between notes were created for each modality (three scores for major condition and the other three scores for minor condition), based on unknown pieces by Johann Ernst Bach (1722–1777) and George Frederick Handel. All scores were polyphonic (i.e., two voices) in 4/4 m consisting of 20 measures arranged in four rows in one page, generated on Finale 2014 (version 2014d.v5545, makemusic).

To control the difficulty of scores between major and minor conditions, we calculated the complexity of intervallic progressions per score by applying the concept of melodic expectancy. Music expectancy was first introduced by a music theorist Meyer (1956) as a listener's anticipatory state of mind toward upcoming musical events while music is being played, and its bottom-up mechanism, especially, in melody has been investigated psychologically (Carlsen et al., 1970, 1994; Carlsen, 1981, 1982; Adachi, 1995) and developed into different models (e.g., Krumhansl, 1995; Schellenberg, 1997). We used one of principles in two-factor model by Schellenberg (1997): pitch proximity (PP). The principal PP represents that listener would anticipate (or expect) smaller intervals more than large intervals in upcoming musical events (Schellenberg, 1997), originally deriving from Meyer's theory of melodic expectancy based on Gestalt principle (Meyer, 1956). Musicians' strong expectancies for particular musical events can make them ignore misprints on a score, allowing them to sight-read while self-correcting notes in the way the composer would have intended (Sloboda, 1977, 1985). This suggests that scores consisting of intervals more likely to be anticipated (e.g., smaller intervals) can reduce cognitive load of bottom-up processes, resulting in easier sight-reading than otherwise. Based on this speculation, we developed an index called the intervallic complexity, representing mean expected value of an upcoming interval per score. The following is how to calculate.

First, we calculated the probability of occurrence of interval "E" —P(E)— in the target score as follows:

$$P(E) = \frac{Frequency\ of\ "E"}{Total\ Number\ of\ Intervals}$$

Second, we calculated *entropy*, i.e., a value indicating how uncertain it is for a particular event (or, in this case, a particular interval) to occur (Meyer, 1957; Carlsen et al., 1994). The greater I(E) is, the more uncertain (thus less expected) the upcoming interval would be. The entropy for interval "E" —I(E)—can be defined as:

$$I(E) = \log_2\left(\frac{1}{P(E)}\right) = -P(E)$$

Third, we calculated uncertain value of interval "E" —UV(E)— as an upcoming note while applying I(E) and an index of pitch proximity—PP_E–expressed as the number of semitones between two adjacent notes. Here, 1 is added to PP_E to avoid UV to be 0 when PP_E is 0 (i.e., when the same pitch is repeated in a score).

$$UV(E) = (PP_E + 1) \times I(E)$$

Finally, mean of UV for a particular score was calculated as follows:

$$Mean\ of\ UV = \frac{Total\ of\ UV}{Total\ Number\ of\ Intervals\ used\ in\ the\ target\ score}$$

A larger mean of UV indicates a score to be more complex such that sight-readers cannot anticipate upcoming intervals as easily as those with a smaller mean of UV.

The intervallic complexity (i.e., mean of UV) of each score is shown in Table 1. Bootstrap paired t-tests revealed that three levels of intervallic complexity were significantly different from each other: $t_{obt}(1) = 2.08$, $p = 0.002$, $d = 2.91$ (high vs. medium); t_{obt} (1) = 5.45, $p = 0.002$, $d = 2.47$ (medium vs. low); t_{obt} (1) = 4.10, $p = 0.002$, $d = 5.24$ (high vs. low). Moreover, another bootstrap paired t-test revealed no significant difference in the intervallic complexity between major and minor conditions, t_{obt} (2) = 0.05, $p > 0.05$, $d = 0.02$.

TABLE 1 The intervallic complexity of each score identified with the left letter as the level of complexity and the right letter as modality.

	Intervallic Complexity			
Modality	**High**	**Medium**	**Low**	***M (SD)***
Major	HM (B^b): 3.04	MM (F): 2.48	LM (G): 1.77	2.43 (0.64)
Minor	Hm (a): 3.65	Mm (g): 2.04	Lm (g): 1.55	2.42 (1.10)

Each cell consists of score ID with the tonic in parenthesis, followed by the value of intervallic complexity.
[b]Stands for flat.

Apparatus

Each participant performed sight-reading tasks on an electronic piano (MP-300, Roland) while wearing a baseball-cap type eye-tracking device (EMR-9, Nac) to record eye movements. The sound from the electric piano was recorded directly to the controller of EMR-9 so that its timing was synchronized with the recorded eye movements. The experiment was controlled by a program created on PsyScope X (Cohen et al., 1993) through a laptop computer (MacBook Air, OS10.13, Apple). Verbal instructions and scores were presented on a 19-inch display (L1919C-BFS, LG), positioned at the score stand of the electric piano. An additional digital video camera (HF-R62, Canon) captured each participant's postures and behaviors throughout the experiment.

The recorded eye movements were imported to a laptop computer (MacBook Pro, Windows 7 Ultimate Service Pack 1) where the number of fixations was identified on a software (EMR-dFactory, version 2.71a, Nac). To identify eye-hand span with note index (i.e., N-EHS), the recorded sound was first converted to wave form using Final Cut Pro (version 10.4.1, Apple), and then the wave form of the note being played at the time of each fixation (indicated by dFactory) was identified manually by checking eye movements frame by frame, using iMac (OS High Sierra 10.13.3, Apple) with a 27-inch Retina display (5,120 × 2,880).

Procedure

The experiment was executed in a quiet room. In the beginning, each participant played a well-practiced piece of their choice as a warm-up. Then, an eye tracker was attached and calibrated to each eye. To get used to playing a score while maintaining their head position, participants first played a simple score consisting of ascending and descending scales followed by arpeggios and cadence, and then sight-read either a major or a minor score as a practice trial. Those who were assigned for major condition ($n = 16$) played scores in a major key both for scales and practice trials while others ($n = 16$) played them in a minor key.

For experimental trials, each participant sight-read 3 two-voice scores, written in an assigned mode, presented randomly. Each trial began with presentation of a score followed by 1-min preview during which any preparation except pressing piano keys was allowed (e.g., singing/humming a melody, moving fingers on the lap, tapping beat). A chime sound was presented as a sign of the end of preview. Upon completion of each sight-reading, the participants responded to two questions by 9-point scale (1 as "not at all" to 9 as "completely"): (1) how much they could prepare during 1-min preview and (2) how difficult it was to sight-read. In addition, the participants responded whether they had played the given score before. Each participant's personal information including past musical experiences and training activities during 1 year prior to the experiment was obtained through questionnaire. The entire experiment including a warm-up lasted ≈60 min.

Analysis

In the present study, we analyzed fixations, eye-hand span, duration of sight-reading performance, and errors in performance. Two rows in the middle of each score (i.e., measures 6–15) were the target of analysis due to possible deviations in recorded eye movements near top and bottom edges of the display. Each dependent variable was measured as follows.

Fixation

For the efficiency of input, we analyzed fixation as a measure for the participant's eye movements. Either left or right eye movement (recorded more consistently than the other side) was used in measurements. A fixation was defined as the eye movement staying at the same location equal to or longer than 100.00 ms (see Figure 1). Three dependent variables were obtained: (1) the number of fixations, (2) the mean number of frames per fixation, and (3) the proportion of fixations. The eye movements were identified frame by frame with 1 frame equals to 33.33ms.

Eye-hand span and the duration of performance

The efficiency of visuo-motor coordination was measured by note-index eye-hand span (N-EHS) and beat-index eye-hand span (B-EHS), as well as the duration of sight-reading performance. For N-EHS, we first numbered each note as its numeric ID (e.g., 1, 2, 3) in the targeted portion (6–15 measures) of each score. Second, we identified the beginning and the ending time of each fixation. Finally, we identified a N-EHS by subtracting the numeric ID of a note being played at the time of the target fixation ended from the numeric ID of the target fixation (see Figure 2). For B-EHS, we numbered each beat, based on the thirty-second note (i.e., the shortest note used in the scores used) as the unit, as its numeric ID in the targeted portion of each score. The maximum of 32 beats per measure (4/4) and maximum of 320 beats at the end of the 15th measure. Finally, we identified a B-EHS by subtracting the numeric ID of a beat being played at the time of the target fixation ended from the numeric ID of the target fixation (see Figure 2). If the participant's fixation was located somewhere between two notes, its numeric ID was 0.5 point added to that of the left side. When the eye-tracking mark disappeared from the score (presumably because

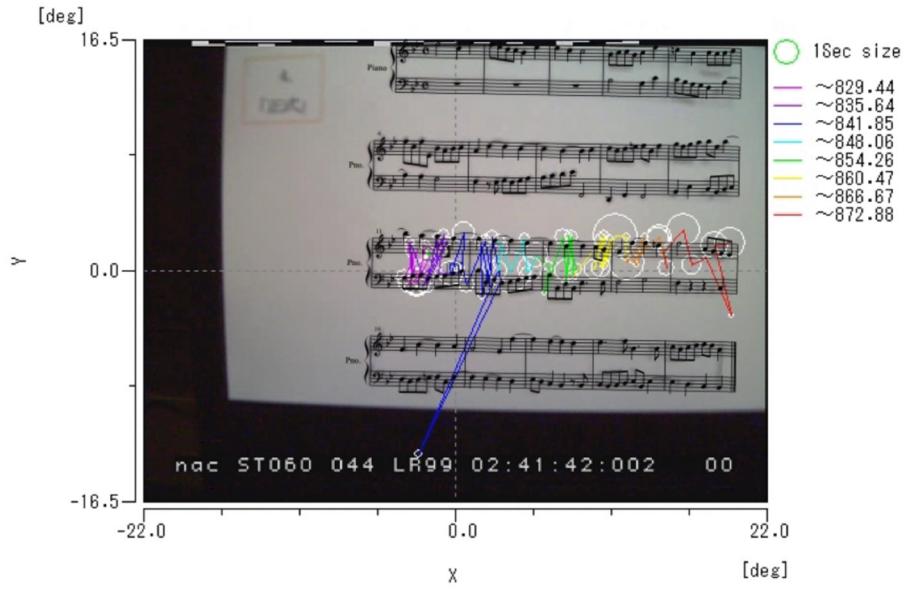


FIGURE 1
An example of visualization of eye tracking while one participant was playing the third row of score HM. The size of white circle represents the duration of each fixation with the size of green circle on the right column as 1 s (i.e., 1,000 ms). Lines with different colors show traces of eye tracking in time lines shown on the right column.

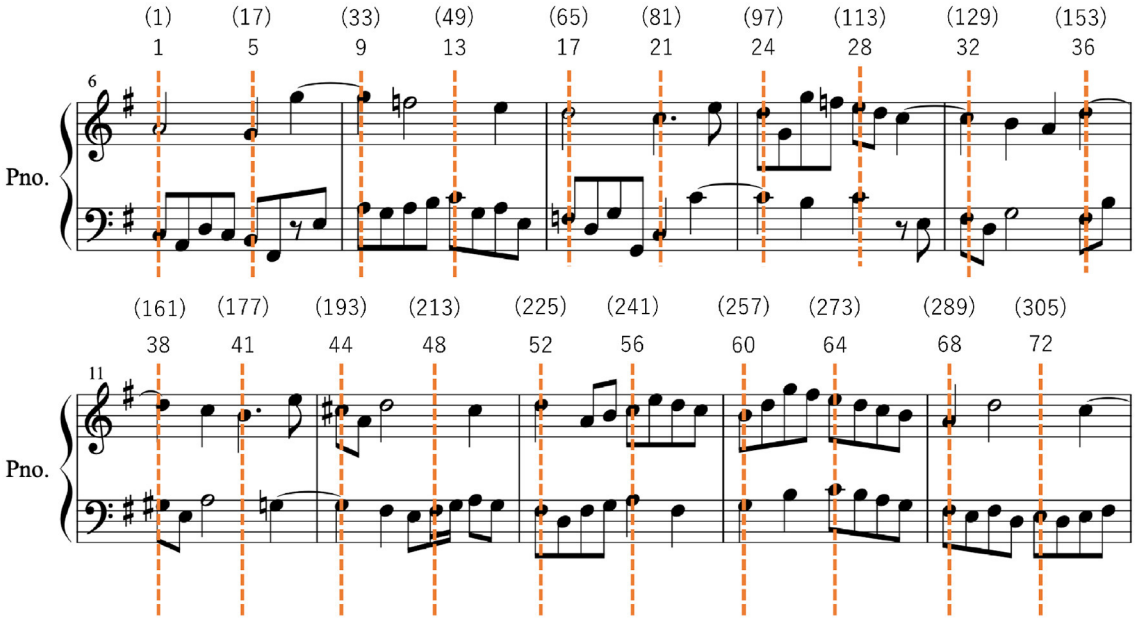


FIGURE 2
An example of numbering notes in the targeted portion (6–15 measures) for N-EHS (without parentheses) and B-EHS (with parentheses), using score LM. If the participant was playing G_4 (in the treble clef) and B_2 (in the bass clef) in measure 6 when her fixation on G_3 (in the bass clef) in measure 7 ended, then N-EHS would be 5 (i.e., 10 − 5) and B-EHS would be 20 [i.e., (37) − (17)].

of the participant's checking of key or hand locations), we skipped measuring EHS until the eye-tracking mark reappeared on the score. For the duration of sight-reading performance (in ms), we calculated the duration between the first note of measure 6 being played and the last note of measure 15 being played.

Errors

The accuracy of execution was measured reversely by the number of errors. The errors were counted in each voice separately and added them together per score. Four types of errors were calculated in this study: the number of pitch errors (i.e., including missed, miss-played, or simultaneously played notes), the number of lengthened rhythm errors (i.e., notes played longer than what it should be), the number of shortened rhythm errors (i.e., notes played shorter than what it should be), and the number of stuttering (i.e., notes repeated unnecessarily).

Statistical analysis

Because most of data were not distributed normally, perhaps due to varying sight-reading skills among individuals as often indicated elsewhere (Sloboda, 1977; Lehmann and Ericsson, 1993; Underwood and Everatt, 1994; Meinz and Hambrick, 2010; Herrero and Carriedo, 2019), we used bootstrap *t*-tests with 1,000 iterations for all comparisons. To maintain the power of analysis, we set the level of significance by applying Bonferroni's correction for each comparison with the overall α for comparison to be 0.10 due to an exploratory nature of the study. In addition, Spearman's correlation coefficients were used to examine relations between dependent variables. All statistics were executed by SPSS (version 22).

Results

Two pianists were invited to evaluate the performance level of the 32 participants, and a *t*-tests confirmed that there was no statistical difference in performance level between participants in the major ($n = 16$) and minor ($n = 16$) groups ($ps > 0.10$, $ds = 0.24$–0.50). Subsequently, we conducted a reliability analysis of the two pianists' evaluations, and the intraclass correlation coefficient confirmed that the evaluations showed reliability ($ICC = 0.76$).

Effect of modality

We conducted bootstrap *t*-tests between major and minor conditions for four levels of intervallic complexity (i.e., low, medium, high, overall, subset $\alpha = 0.025$ with Bonferroni's correction). We describe results according to three sight-reading phases.

Input

Table 2 shows means and standard deviations of three variables for an efficiency of input. The number of frames per fixation was equivalent (ts_{obt} (30) = −0.29 to 1.13, $ps > 0.10$, $ds = 0.10$–0.40) between major ($M = 16.57$, $SD = 6.20$) and minor ($M = 14.84$, $SD = 5.69$) conditions. However, the number of fixations was greater in minor ($M = 126.04$, $SD = 54.19$) than major ($M = 63.38$, $SD = 25.80$) condition, t_{obt} (30) = −4.18, $p = 0.003$, $d = 1.48$). Specifically, participants fixated significantly more in minor than major condition when the intervallic complexity was medium (t_{obt} (30) = −2.58, $p = 0.009$, $d = 0.91$) and low (t_{obt} (30) = −4.77, $p = 0.002$, $d = 1.69$). Even for a score with high intervallic complexity, this tendency appeared to be evident due to its medium effect size ($d = 0.52$). The proportion of fixation tended to be greater in major ($M = 0.85$, $SD = 0.06$) than minor condition ($M = 0.76$, $SD = 0.10$), t_{obt} (30) = 2.81, $p = 0.02$, $d = 1.00$). Specifically, participants fixated proportionately more in major than minor condition when the intervallic complexity was high (t_{obt} (30) = 3.02, $p = 0.009$, $d = 1.07$). Although statistically insignificant, medium to high effect sizes of modality on the proportion of fixation appeared to show the same tendency for medium ($d = 0.66$) and low ($d = 0.89$) intervallic complexities as well. An effect of modality was not observed in the duration of fixation.

Visuo-motor coordination

Table 3 shows means and standard deviations of three variables for an efficiency of visuo-motor coordination. N-EHS was equivalent (ts_{obt} (30) = 0.44–1.27, $ps > 0.10$, $ds = 0.16$–0.45) between major ($M = 3.12$, $SD = 1.33$) and minor ($M = 2.86$, $SD = 1.89$) conditions. However, B-EHS indicated a medium effect size ($d = 0.66$) of modality with major ($M = 13.75$, $SD = 5.81$) appearing to be greater than minor ($M = 9.74$, $SD = 6.30$) condition. This tendency was evident in score of low intervallic complexity: B-EHS was greater in major than minor condition, t_{obt} (30) = 2.61, $p = 0.018$, $d = 0.92$). In addition, the duration of performance revealed less efficiency in minor condition. Participants spent significantly more time in sight-reading minor ($M = 64.94$, $SD = 24.37$) than major ($M = 40.05$, $SD = 18.09$) scores, t_{obt} (30) = −3.28, $p = 0.003$, $d = 1.16$). This difference was evident when the intervallic complexity was high (t_{obt} (30) = −2.32, $p = 0.021$, $d = 0.82$) and low (t_{obt} (30) = −4.32, $p = 0.001$, $d = 1.53$). Even sight-reading a score of medium intervallic complexity, this tendency was approaching significant with high effect size (t_{obt} (30) = −2.26, $p = 0.026$, $d = 0.80$).

Execution

Table 4 shows means and standard deviations of four variables for an accuracy of execution. No significant differences were found in any errors between major and minor conditions. However, medium to high effect sizes of modality were evident in three types of errors. More specifically, pitch errors appeared to be observed more in major than minor scores with high (t_{obt} (30) = 1.60, $p = 0.207$, $d = 0.57$) and medium (t_{obt} (30) = 1.67, $p = 0.186$, $d = 0.59$) intervallic complexities. In contrast,

TABLE 2 Means and standard deviations of three dependent variables for an efficiency of input, as well as results of bootstrap *t*-tests with Bonferroni's correction (*subset* $\alpha = 0.025$) for effects of modality on each measure.

Number of fixations

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	72.81	29.78	88.56	31.00	−1.47	0.158^{+}	0.52
Medium	60.19	30.47	88.88	32.45	−2.58	0.009**	0.91
Low	65.13	25.00	135.94	53.81	−4.77	0.002**	1.69
Overall	63.38	25.80	126.04	54.19	−4.18	0.003**	1.48

Duration of fixation per frame

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	14.60	5.48	15.24	7.09	−0.29	0.781	0.10
Medium	19.68	9.43	15.83	9.83	1.13	0.271	0.40
Low	17.18	7.70	14.66	4.72	1.12	0.327	0.40
Overall	16.57	6.20	14.84	5.69	0.82	0.437	0.29

Proportion of fixation

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	0.84	0.06	0.74	0.12	3.02	0.009**	1.07
Medium	0.84	0.08	0.76	0.16	1.85	0.078^{+}	0.66
Low	0.88	0.14	0.77	0.12	2.52	0.051^{+}	0.89
Overall	0.85	0.06	0.76	0.11	2.81	0.015*	1.00

**p < 0.01, *p < 0.025, $^{+}$p > 0.025 with medium to high effect size.

lengthened rhythm error and stuttering appeared to be observed more in minor than major scores, as evident in a medium effect size ($d = 0.57$) of modality for high intervallic complexity, and its high effect size ($d = 0.87$) for low intervallic complexity, respectively.

Relations among three phases of sight-reading process

Table 5 shows Spearman's correlation coefficients between all dependent variables. We summarize the results first relations between variables of each phase, and then move on to those between phases.

Input

The number of fixations (NF) was correlated negatively with the duration of fixation (DF, $r_s = -0.45$, $p = 0.010$) and the proportion of fixation (PF, $r_s = -0.66$, $p < 0.001$). The proportion of fixation (PF) and the duration of fixation (DF) were positively correlated ($r_s = 0.55$, $p = 0.001$). This indicates that the more the duration of fixation, the fewer number of fixations, and the greater the proportion of fixation.

Visuo-motor coordination

Two indices of EHS were correlated positively ($r_s = 0.91$, $p < 0.001$), and this high correlation demonstrates that both N-EHS and B-EHS measure the same construct. The duration of performance (DP) was correlated negatively with N-EHS ($r_s = -0.39$, $p = 0.029$) and B-EHS ($r_s = -0.50$, $p = 0.004$). These results suggest that the longer the EHS, the shorter the duration of sight-reading performance.

Execution

The analyses confirmed moderate to high correlations between the different types of performance errors. Among them, pitch errors (PE) were correlated positively with both

TABLE 3 Means and standard deviations of three dependent variables for an efficiency of visuo-motor coordination, as well as results of bootstrap *t*-tests with Bonferroni's correction (*subset* $\alpha = 0.025$) for effects of modality on each measure.

N-EHS							
Intervallic complexity	**Major**		**Minor**		***t(30)***	***p***	***d***
	M	***SD***	***M***	***SD***			
High	2.78	1.27	2.18	1.35	1.27	0.205	0.45
Medium	3.35	1.74	2.61	1.78	1.20	0.268	0.42
Low	3.37	1.43	2.89	1.85	0.81	0.409	0.29
Overall	3.12	1.33	2.86	1.89	0.44	0.654	0.16
B-EHS							
Intervallic complexity	**Major**		**Minor**		***t(30)***	***p***	***d***
	M	***SD***	***M***	***SD***			
High	12.95	6.64	10.29	7.02	1.10	0.277	0.39
Medium	13.60	7.61	11.15	8.31	0.87	0.403	0.31
Low	13.68	6.79	7.93	5.63	2.61	0.018*	0.92
Overall	13.75	5.81	9.74	6.30	1.87	0.067^{+}	0.66
Duration of performance							
Intervallic complexity	**Major**		**Minor**		***t(30)***	***p***	***d***
	M	***SD***	***M***	***SD***			
High	39.56	18.98	55.46	19.85	−2.32	0.021*	0.82
Medium	41.15	18.67	55.78	17.94	−2.26	0.026^{+}	0.80
Low	39.43	17.25	83.60	37.07	−4.32	0.001**	1.53
Overall	40.05	18.09	64.94	24.37	−3.28	0.003**	1.16

**$p < 0.01$, *$p < 0.025$, $^{+}p > 0.025$ with medium to high effect size.

shortened (SRE, $r_s = 0.39$, $p = 0.025$) and lengthened (LRE, $r_s = 0.53$, $p = 0.002$) rhythm errors, whereas stuttering (St) was correlated positively only with shortened rhythm error ($r_s = 0.67$, $p < 0.001$). Only moderate positive correlation between two types of rhythm errors ($r_s = 0.43$, $p = 0.014$) indicates that these measures can tap into different aspects of performance errors, which may not be revealed otherwise.

Input vs. visuo-motor coordination

Of those, the duration of performance—representing an inefficiency of visuo-motor coordination—was correlated positively with the number of fixations ($r_s = 0.80$, $p < 0.001$) and negatively with the proportion of fixation ($r_s = -0.55$, $p = 0.001$). B-EHS ($r_s = -0.49$, $p = 0.004$)—representing an efficiency of visuo-motor coordination—was correlated negatively with the number of fixations. These results indicate that inefficiencies during input (i.e., more frequent, or less proportion of, fixations) are related to a slower tempo and shorter EHS during visuo-motor coordination of music sight-reading.

Input vs. Execution

The number of fixations was correlated positively with stuttering ($r_s = 0.42$, $p = 0.016$) and the duration of fixation was correlated negatively with pitch error ($r_s = -0.36$, $p = 0.040$). This indicates that an inefficient input (i.e., more frequent fixations or shorter duration of fixation) is related to a poor execution (i.e., more stuttering or pitch error) in music sight-reading. When the input processing becomes inefficient, the duration of each fixation gets shorter, and less note information can be acquired. To ensure uninterrupted playing, the performance is kept even if there are successive wrong notes, resulting in more pitch errors.

TABLE 4 Means and standard deviations of four dependent variables for an accuracy of execution, as well as results of bootstrap *t*-tests with Bonferroni's correction (*subset* $\alpha = 0.025$) for effects of modality on each measure.

Pitch error

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	10.88	18.90	3.25	2.35	1.60	0.207^{+}	0.57
Medium	9.63	12.39	4.31	2.94	1.67	0.186^{+}	0.59
Low	10.38	12.83	14.00	11.87	−0.83	0.420	0.29
Total	10.29	14.07	7.19	4.58	0.84	0.447	0.30

Lengthened rhythm error

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	0.94	1.29	1.88	1.93	−1.62	0.116^{+}	0.57
Medium	2.19	2.34	1.81	2.20	0.47	0.644	0.17
Low	1.63	1.86	3.06	4.81	−1.12	0.274	0.39
Total	1.58	1.55	2.25	2.68	−0.86	0.396	0.30

Shortened rhythm error

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	1.25	2.21	1.50	1.26	−0.39	0.697	0.14
Medium	1.50	2.94	1.38	1.36	0.15	0.878	0.06
Low	1.13	1.59	1.94	3.23	−0.90	0.374	0.32
Total	1.29	2.16	1.60	1.35	−0.49	0.624	0.17

Stuttering

Intervallic complexity	Major		Minor		*t(30)*	*p*	*d*
	M	*SD*	*M*	*SD*			
High	4.88	7.54	6.00	6.39	−0.46	0.652	0.16
Medium	5.94	7.59	4.94	7.25	0.38	0.706	0.14
Low	4.38	4.53	11.81	11.19	−2.46	0.036^{+}	0.87
Total	5.06	6.05	7.58	7.72	−1.03	0.327	0.36

$^{**}p < 0.01$, $^{*}p < 0.025$, $^{+}p > 0.025$ with medium to high effect size.

Visuo-motor coordination vs. execution

The duration of performance (DP) was correlated positively with shortened rhythm error (SRE, $r_s = 0.38$, $p = 0.030$) and stuttering (St, $r_s = 0.53$, $p = 0.002$) while N-EHS and B-EHS was not correlated with any errors. This indicates that an inefficient visuo-motor coordination measured by the duration of performance (i.e., a slower performance) is related to a shortened rhythm error or stuttering during execution of music sight-reading.

Discussion

The primary goal of this study was to investigate effects of modality in three phases of music sight-reading: input, visuo-motor coordination, and execution. From the literature, skilled sight-reading requires both *accuracy* (Waters et al., 1997; Gudmundsdottir, 2010; Adachi et al., 2012; Herrero and Carriedo, 2019) and *efficiency* (Sloboda, 1974; Goolsby, 1994; Truitt et al., 1997; Madell and Hébert, 2008; Cara, 2018), and

TABLE 5 The Spearman's correlation coefficient among variables of Input, Visuo-motor coordination, and Execution.

		Input		Visuo-motor coordination			Execution			
		DF	PF	N-EHS	B-EHS	DP	PE	LRE	SRE	St
Input	NF	−0.45**	−0.66**	−0.33	−0.49**	0.80**	0.19	0.25	−0.01	0.42*
	DF		0.55**	−0.07	0.07	0.003	−0.36*	0.14	0.01	0.10
	PF			−0.02	0.15	−0.55**	−0.15	−0.02	−0.05	−0.10
Visuo-motor coordination	N-EHS				0.91**	−0.39*	−0.03	0.06	0.29	−0.07
	B-EHS					−0.50**	−0.11	−0.03	−0.20	−0.19
	DP						0.14	0.38*	0.10	0.53**
Execution	PE							0.53**	0.39*	0.34
	LRE								0.43*	0.33
	SRE									0.67**

*p < 0.05, **p < 0.01.
NF, Number of fixations; DF, Duration of fixation per frame; PF, Proportion of fixation; N-EHS, Note-index eye-hand span; B-EHS, Beat-index eye-hand span; DP, Duration of performance; PE, Pitch error; LRE, Lengthened rhythm error; SRE, Shortened rhythm error; St, Stuttering.

these key concepts need to be considered in discussing what is going on during each phase of sight-reading process. In reality, however, the accuracy is observable only during execution even though we are aware that inaccurate input or missed visual-to-motor conversion is also possible. The present study is not free from this dilemma; we will primarily discuss efficiency regarding input and visuo-motor coordination while discussing accuracy regarding execution. At least, correlational analyses between variables across phases allow us to discuss relations between accuracy and efficiency.

Modality and intervallic complexity in accuracy and efficiency of music sight-reading

Overall, modality influenced input in the way we predicted. During input, sight-readers fixated more frequently (i.e., encoded information more inefficiently) for minor than major scores. The greater proportion of fixation for major than minor scores means that sight-readers spent more time looking at notes and less time looking down at the keyboard for major scores. Even though this tendency was apparent in sight-reading a score with the high intervallic complexity, similar tendencies were observed also for other scores, which appears to imply that features unique to a minor score (e.g., embedded accidentals) may be more responsible for inefficiency than its intervallic complexity.

During visuo-motor coordination, on the other hand, a significant interaction between modality and intervallic complexity was observed: B-EHS was greater in sight-reading a major than minor score only with low intervallic complexity. This appears to have derived from much smaller B-EHS in sight-reading a minor score with low intervallic complexity (i.e., 7.93) relative to the rest of scores (i.e., 10.29–13.68, see Table 3). This contradicts our prediction that a higher intervallic complexity would result in lower efficiency during visuo-motor coordination. In addition, a slower performance (i.e., inefficient visual-to-motor conversion of information) was evident in sight-reading minor than major scores regardless of their intervallic complexities, again, contradicting our prediction. How did this happen?

One obvious explanation is that we did not control *tempo* (or speed) of performance. Slowing down for minor scores would have helped sight-readers maintain their efficiencies for a more difficult task (Truitt et al., 1997; Furneaux and Land, 1999; Wurtz et al., 2009; Lewandowska and Schmuckler, 2020), reflected in equivalent sizes of N-EHS among all scores (i.e., 2.18–3.37, see Table 3). Based on the collected analyses of the sight-reader's assessment of the score, we found that modality did not appear to influence the sight-reader's assessment of the score (t_{obt} (30) = −1.79, $p = 0.088$, $d = 0.63$). That is, the sight-reader seemed to perceive no difficulty in sight-reading scores in either major ($M = 4.46$, $SD = 1.45$) or minor ($M = 5.42$, $SD = 1.58$). Such results confirm the above explanation that when the efficiency is reduced, the sight-reader performs relatively difficult tasks more easily by lowering their tempo. This rationale can also explain equivalent sizes of B-EHS between scores of medium and high intervallic complexities, but we still need an alternative explanation for the smaller B-EHS of minor score with low intervallic complexity.

In the present study, we controlled various factors of sight-reading materials such as intervallic complexities, meter, and the total number of measures, but we overlooked density of notes within a measure. The minor score with low intervallic complexity consisted of many more 16th notes than its major counterpart. This unbalanced density may have served as a confounding variable for the paired scores of low intervallic

complexities. The higher note density (or many more 16th notes) of the minor score with low intervallic complexity can also explain its extremely greater number of fixations (i.e., 135.94) relative to those for other scores (i.e., 60.19–88.88) during input, and that of stuttering (i.e., 11.81) relative to other scores (i.e., 4.38–6.00) during execution.

Furthermore, as predicted, the modality did not have any effect on the accuracy and flow of the execution. There were no significant differences between major and minor scores for any performance error, although the modality influenced the input. This implies that, even though the sight-reader's input was less efficient in identifying the minor score, they improved psychological stability and reduced pitch errors by slowing down the tempo without being controlled (Lewandowska and Schmuckler, 2020).

It is noteworthy that those sight-readers who played faster seemed to make more pitch errors. Why does this occur? One plausible explanation is that the faster tempo leaves the sight-reader with no more response time and is more likely to make pitch errors. In order to keep the performing intact, sight-reader does not make error corrections, and usually deviations in one note lead to pitch errors in several consecutive notes (and possibly several phrases or measures) that follow. This seems to indicate that a sight-reader who plays fast is not necessarily an accurate sight-reader (Cara, 2018).

However, the complexity of interval did not seem to affect the accuracy and flow during the sight-reading as we predicted, only showing some trends. We observed a tendency to show fewer pitch errors when sight-reading minor scores with high and medium intervallic complexity (i.e., 3.25–4.31, see Table 4) than major (i.e., 9.63–10.88, see Table 4). In high intervallic complexity, major (i.e., 0.94, see Table 4) showed a tendency to make fewer lengthened rhythm errors than minor (i.e., 1.88, see Table 4). As previously mentioned, these trends seem to imply that tempo may be more influential on performance accuracy than the complexity of the interval.

Correlation of efficiency with accuracy and flow of music sight-reading

In general, the results of the analysis were in line with our predictions. That means, the shorter the performing duration, the less the lengthened rhythm error and stuttering. This suggests that efficient visuo-motor coordination ensure accuracy and flow of execution. It should be noted that although we obtained a positive correlation (i.e., $r_s = 0.38–0.53$), this does not contradict our prediction (i.e., efficiency is negatively correlated with accuracy and flow). This is because when the visuo-motor coordination is inefficient, the sight-reader cannot mobilize the fingers to play the corresponding keys accurately, they try to obtain the latency time by reducing the tempo. This leads to longer duration of performance and less accuracy and flow.

Unfortunately, however, although our predictions were confirmed, we did not see a correlation between accuracy and flow of execution and EHS. However, the significant negative correlation between EHS and performance duration indicated that the longer the duration of the performance, the shorter the EHS. We can explain this by the fact that the sight-reader expects to look forward to getting more musical information, but the present study did not control the tempo for as close to natural sight-reading as possible, and the sight-reader could perform at a tempo that suited them. That means, when visual-motor coordination is inefficient, sight readers are unable to successfully motivate finger movements through visual information and can only adjust to their sight-reading by slowing down the tempo, which led us to find no correlation between performance errors and EHS. This seems to indicate that when visual-motor coordination processing is inefficient, the sight-reader tries to balance the efficiency of information conversion and accuracy of execution by slowing down the tempo and narrowing the EHS (Rosemann et al., 2016).

On the other hand, the significant correlation between input and visuo-motor coordination showed that by spending more time looking at the notes (i.e., an increased proportion of fixation) and using less fixation, the sight-reader increased the efficiency of musical information input, increased the B-EHS, converted visual information into finger movement in a timely manner, enabling perform fluency even with faster tempo, reduced performance duration, and improved visuo-motor coordination efficiency. Sight-reading is primarily determined by effective visual input and the process of visual-to-motor conversion of musical notation information (Waters et al., 1998). For advanced pianists, an increase of fixations is accompanied by an increase of performing time (Chang, 1993). This suggests that inefficient input leads to a failure of visuo-motor coordination. Because the sight-reader cannot input musical information efficiently enough to convert visual information into finger movements smoothly but must slow down the tempo. Sight-reading requires playing the right rhythmic structure at the right time (Drake and Palmer, 2000). The correlation between the variables of input processing supports that when there are no rhythmic constraints, sight-readers can play at a tempo that suits them, without having to rush to expect musical information too far ahead of the playing position. The low load during information input allows the sight-reader to reduce unnecessary eye movements by holding fixations for long periods of time to ensure that more musical information is available with each fixation, such as by reducing the number of fixations that must be paused to gaze at the score in order to check the keyboard position with the head down (as reflected in the increased proportion of fixation).

Moreover, the significant correlation between input and execution showed that the more fixations and the shorter the

duration of per fixation, the more likely it was to produce pitch errors and stuttering. This suggests that more frequent eye movements lead to inefficient input, as well as low accuracy and stuttering of execution.

In addition, we noticed a significant positive correlation between accuracy (i.e., error) and fluency (i.e., stuttering) of the performance. This may be due to the sight-reader's perception that the score is a little difficult or a lack of confidence in the performance (Adachi et al., 2012). This suggests that when sight-readers realize that a performance error has occurred, they tend to correct it repeatedly starting from the neighboring note where the performance error occurred. Sometimes, in order to achieve a more perfect sight-reading, sight-reader will also correct from the first note of the measure where the performance error occurred until they are satisfied (McPherson, 1994). Furthermore, we found that sight-players were more likely to make pitch errors rather than rhythm errors. This may be because the sight-reader tries to play the notes at the correct time, rather than playing each note correctly. Sight-players consider that playing notes fluently is more important than playing notes accurately from the score (Drake and Palmer, 2000; Lehmann and McArthur, 2002).

Conclusion

This article evaluated the modality of music material (major mode and minor mode) would affect the input processing, the visuo-motor coordination processing, and the execution during sight-reading, as well as the effect of interval complexity on the three phases of sight-reading. In addition, the correlation among these three phases of processes is explored. Thirty-two advanced pianists sight-read three two-voice Baroque pieces in either major mode or minor mode and recorded their eye movements by an eye tracker. The results showed that modality of music material have an impact on the efficiency of input processing and visuo-motor coordination processing in the sight-reading. Sight-readers used more fixation in minor scores than in major scores and tended to sight-read minor scores longer. Moreover, the higher the interval complexity, the less efficient the information processing during sight-reading. In addition, because it is demonstrated that there is a correlation among these three phases of information processes, indicated that an efficient input processing and an efficient visuo-motor coordination processing would represent an accurate execution in sight-reading.

The current study makes the relation between the series of information processing in sight-reading more clearly and confirmed that the modality of music could affect the efficiency of information processing during sight-reading. There was no other study has considered in the experiment before. It should be noted that this study was implemented under the premise of uncontrolled tempo, thus the sight-reader could play with their own tempo. If the tempo is under controlled, how the modality of score affects these three phases of information processing in sight-reading should be explored in future research. In addition, this study only used Baroque music materials as the stimulus, however, whether the modality influence other types of music (e.g., the Classical music; the Romantic music, the 20th century music) has not studied yet and undoubtedly requires further research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Hokkaido University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JQ and MA contributed to conception and design of the study. JQ performed experiment, organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. MA wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Factors affecting expert performance in bid evaluation: An integrated approach

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Experts play a crucial role in underpinning decision-making in most management situations. While recent studies have disclosed the impacts of individuals' inherent cognition and the external environment on expert performance, these two-dimensional mechanisms remain poorly understood. In this study, we identified 14 factors that influence expert performance in a bid evaluation and applied cross-impact matrix multiplication to examine the interdependence of the factors. The results indicate that the two dimension-related factors affect each other within a person–environment system, and a poor situation perception gives rise to the deviation of expert performance. Expert performance can be improved if external supervision and expertise are strengthened through deliberate practices. The study proposes a new expert performance research tool, elucidates its mechanism in bid evaluation from a cognitive psychology perspective, and provides guidelines for its improvement in workplace contexts.

KEYWORDS

expert performance, cognitive psychology, situation perception, supervision, MICMAC-ISM approach

Introduction

One of the most heated research issues in management science is decision-making, which is strongly associated with experts' scientific and accurate judgment (Bolger, 1996). Prior research has affirmed that the advice and judgment of experts are prominent in situations with limited data, enormous uncertainty, timely solutions, and unpredictable trends (Burgman et al., 2011). For example, there is a need for expert-aided decision-making in natural resource management to assess hazards (Victoria et al., 2018). In this sense, expert performance is highlighted to describe the process of providing quality services to meet societal demands. An expert's satisfactory performance depends on whether the expert has sufficient expertise, qualifications, professional morality, and experience. For simplicity, Mcpherson and Kernodle (2007) called these factors "inherent cognition."

However, given inherent cognition, experts may not provide quality judgments. Havers et al. (2019) suggested that the reason could be the conflicts of stakeholders' interests and relationships. As a result, the expert is intended to make a biased decision and causes poor

performance. Recent studies have further argued that personal reputation and fatigue deserve closer attention as they misguide experts to make incomplete decisions in the peer review process (Rodriguez et al., 2007; Burgman et al., 2011). Experts advocate balancing motivational and external constraints (e.g., external pressure, scenario perception, institutional systems; Ericsson et al., 1993). Thereby, expert performance can be improved. According to Araújo et al. (2006), such factors are external and related to material and social environments.

The synthesis of inherent cognition and external environmental factors suggests that expert performance is dynamic, systematic, interactive, and characterized by multiple feedbacks. As ecological cognition theory elaborates, experts prefer to build their decisions on the interaction between inherent cognition and external environmental factors (Vanda et al., 2013). Victoria et al. (2018) argued the protocol for structured expert elicitation is more conducive to coping with external impacts on inherent cognition than randomly capturing changes in dynamic environments. Therefore, attempts to promote expert performance should consider the interaction between inherent cognition and the external environment.

The enhancement of expert performance is fueled by an increase in inherent cognition and the ability to adapt to the external environment. However, there is scant research on the interaction between inherent cognition and the external environment (Ericsson, 2007; Baker et al., 2010; Li et al., 2014; Helfrich et al., 2018). It is also unsure about how inherent cognition and external environmental factors advance expert performance and how these factors drive one another in an industrial setting. This study aims to bridge this knowledge gap by examining expert performance-related factors. The research objectives are to identify the key factors of expert performance in bid evaluation and evaluate the interrelationships between the identified factors using a driving/dependence power graph. Our findings shed some light on a shift of expert performance concepts from cognitive to management science. Furthermore, we laid a foundation for future studies to generalize expert performance determinants, considering the uncertainty of environmental factors rather than merely psychological representations and cognitive scientific calculations.

Literature review

Rethinking expert performance definitions

Expert performance was coined as a key construct for theorizing expert performance (Ericsson, 2007; Debarnot et al., 2014; Hashimoto et al., 2015). Experts are engaged in providing knowledge-intensive professional services for complex questions. Traditionally, a closed system perspective is adopted to interpret experts' long-time superior performance (Ericsson, 2008; Ericsson and Harwell, 2019). The long-time superior performance is tied to the accumulation of deliberate practices and feedback that they encode and the refinery of inherent representations memorized for effective use in a determinate world (Ericsson and Kintsch, 1995). Similarly, novices may be likely to produce opinions and judgments as experts do for the same matters if they have enough knowledge and experience (Spence, 1993). As revealed in scientific judgment and the improvement of learning patterns (Krueger et al., 2012; Campitelli et al., 2015; Friedman and Korman, 2019), inherent cognition, including knowledge and experience, pertains to the generation of expert performance. In a closed system, experts' performances are evaluated without considering the fluctuations in situations they are working with. Unexpected emergencies are precluded in the determination of expert performance.

However, the "closed system" perspective is subject to considerable flaws, as indicated by quantum physics and social and psychological science (Glimcher, 2005). Researchers have thus claimed to advance the closed system to embrace indeterminacy in the research area of brain and behavior (Gigerenzer et al., 2000; Hastie, 2001; Schall, 2004). An open system is consequently framed. Based on the tenet of the open-system philosophy, the determinants of expert performance are beyond the boundary of inherent cognition. For example, an expert's performance does not necessarily exceed that of a novice, regardless of whether the problem is relatively simple or complicated. Chi (2006) and Spence (1993) indicated that inherent cognition might not realize better performance in judgment and decision making as experts must adapt to a new environment. Over the years, with the development of ecological cognitive science, Araújo et al. (2006) proposed an effective way to obtain superior expert performance by capturing specific environmental and perceptual information. Therefore, improving perceptions about environmental factors and owning privileged access to refined inherent representations are crucial to expert performance (Ericsson and Kintsch, 1995).

Expert performance in bid evaluation

When decision-making time and support resources are stretched, the external environment becomes a predominant factor in the formation of expert performance. This is the case in competitive bidding in the construction sector, where experts are highly involved in evaluating submitted bids. As a result, experts must produce professional services to underpin the determination of winners in competitive bid evaluations. To address the issue, previous studies have proposed approaches and models to aid experts in evaluating bids (Liu et al., 2017; Semaan and Salem, 2017). However, they often face inadequate information and uncertain circumstances (Zhen-Song et al., 2021), suggesting that the interaction between inherent cognition and the external environment is not monotonic.

Previous studies have offered a few approaches to examining the links between inherent cognition and the external environment, such as measuring eye movements and verbal reports (Macmahon and McPherson, 2009; Afonso et al., 2012). The approaches address bid evaluation task constraints and behavior settings in experimental. However, laboratory-based simulations represent a real-life situation where experts are vulnerable to biases in decision-making (Araújo et al., 2006). Notwithstanding the complex factors of bid evaluation, expert performance has been paid extensive attention, Kardes (2006), Burgman et al. (2011), and Connor et al. (2020) proposed that it was better to redefine expert performance to account for those contextual and relational factors of expert performance.

A conceptual framework

Person–environment system

According to the open-system concept, we outlined two dimensions of expert performance: inherent cognition and the external environment. A conceptual framework is proposed below to describe the mechanism of expert performance (Figure 1).

As Figure 1 tells, the formation mechanism of expert performance contains two parts: memory and ecological psychology. Inherent cognition is grounded on theories of memory, of which the main components are knowledge, experience, and qualifications (Ericsson, 2003). The formation of inherent cognition contains a loop in which knowledge, experience, and qualifications give a stimulus to memory. A changed memory enlarges the packet of knowledge, experience, and qualifications. This loop mirrors the formation of inherent cognition (Ericsson, 2007). To align with the enlargement, deliberate practice, encoding, and transformation transform external stimuli into meaningful representations (Kording and Wolpert, 2006). Meanwhile, ecological psychology is referred to explain the impacts of the external environment on expert performance, assuming a person–environment system (PES; Araújo et al., 2006). As Turvey et al. (1981) pointed out, actions, judgment, and performance are based on the lawful connections between individuals and the environment in which they act. Therefore, experts are engaged in social culture, rules, and regulations belonging to the external environment.

Experts utilize external environmental factors to avoid biased decisions (Fischhoff et al., 1982; Ludger and Erik, 2016; Contreras-Pacheco et al., 2020). However, the factors also pose physical, goal-related, and task-related constraints to expert performance (Araújo et al., 2006). These constraints cause experts to feel physical discomfort (Liu et al., 2015), peer pressure (Bohannon, 2013), motivation deviation (Ericsson et al., 2009), loose supervision (Gonsalvez et al., 2017), and weak feedback (Kardes, 2006). Furthermore, given a specific external environment, expert performance may combine inherent cognition with the external environment to present a holistic "person–environment system." Expert performance results from dynamic, continuous interaction within the PES, which is influenced by inherent cognition and external environmental perceptions.

Interaction between PES and expert performance in bid evaluation

According to ecological psychology theory, bid-evaluation experts' inherent cognition and perception of the external environment are embedded in each other, emphasizing that the interaction between experts and the environment is an important motivation for expert performance. In the PES, bid-evaluation experts have many opportunities to address the opportunities or possibilities for actions, known as *affordances,* and seize a set of objective and physical external environmental factors to improve their performance (Costall, 1984). Regarding bid-evaluation experts, perceiving an "*affordance*" means perceiving how one can make decisions under specific bid evaluation conditions (Araújo et al., 2019).

In the bid evaluation process, experts are supposed to integrate multiple attributes into the overall description of bidders. This is a perceptual process in which bidders' redundant and irrelevant attributes are removed, and their core attributes are framed. Finally, the experts form inherent cognitive "representations" of the bidders. Interweaving in the environment and perceptual processes (from reactions to relevant external objects and events), this cognitive process is dynamic. Therefore, a bid evaluation task is one in which "*affordance*" captures the interaction between experts and the environment (e.g., peer pressure, time pressure, supervision system, and opportunity cost) with a concatenation of interdependent decisions over time. At the end of bid evaluations, experts provide feedback by reflecting on or summarizing the results from the external environment to change inherent cognition. For example, whether a bid award decision is passable is determined not by its absolute attribution representation (whether measured in performance, qualification, or scale) but rather by how it relates to the substantive responses of an individual bidder to the rules, including technical requirements, economic indicators, and commitments.

Research methods

Expert performance impacts have been examined by exploratory research, including conceptual research (Ericsson and Ward, 2007) and case analysis (Araújo et al., 2006), with a focus on the influence of inherent cognitive or external environmental factors. However, based on experimental research methods, most quantitative research designs lead to the emergence of artificial decisions and behaviors (Sozzo, 2020). Therefore, we adopted a new perspective by investigating the determinants of on-the-job performance of experts within

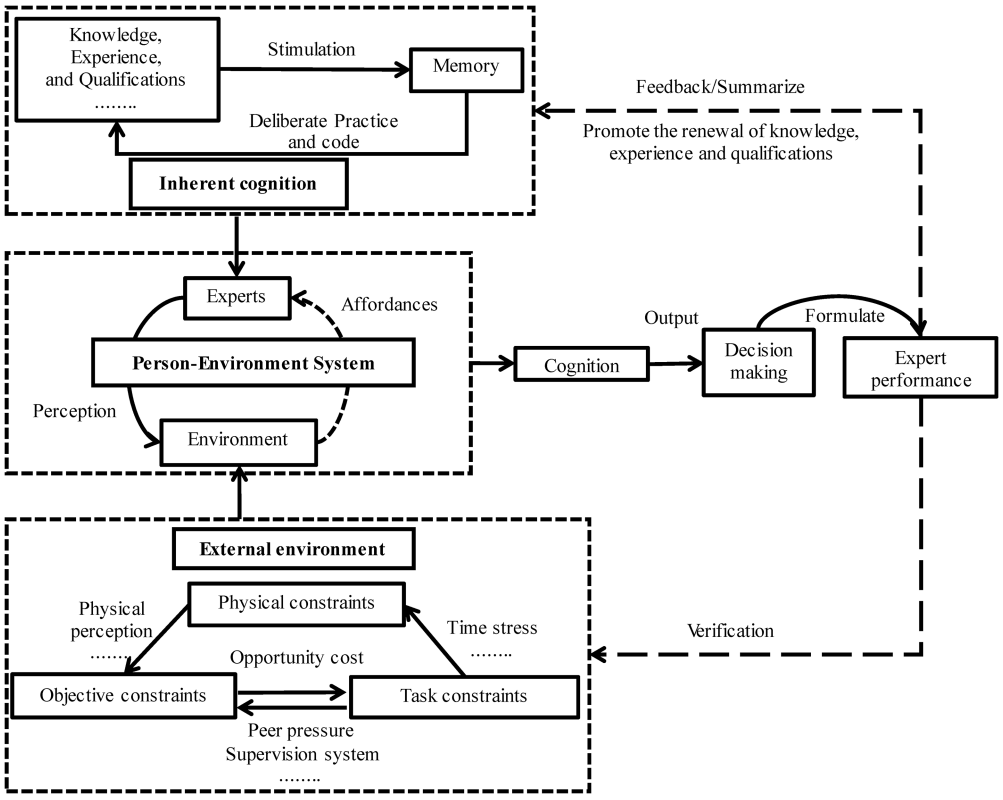


FIGURE 1
The formation mechanism model of expert performance in bid evaluation.

specialist domains in the workplace. First, two-dimensional factors: inherent cognition and the external environment, were identified. Second, we detected expert performance factors through a literature review. Third, in-depth interviews with experts were implemented to confirm the reliability of the factors. Fourth, factors were refined based on the experts' evaluations of the similarity and necessity of the factors. Finally, we compiled a list of bid-evaluation expert performance factors. Consequently, the applicability and usefulness of the factors to attain a hierarchical structural framework were confirmed.

Interpretative structural modeling

We detected these factors' dependency/driving power using cross-impact matrix multiplication, which is often applied to classification and interpretative structural modeling (MICMAC-ISM). Warfield (1974) established a computer-assisted learning process called interpretive structural modeling (ISM) to transform unclear and poorly articulated mental models into well-defined multi-level structural models through experts' practical experience and knowledge. As many interrelated factors affect expert performance in bid evaluation, we selected ISM for our research methodology. The reason not only goes to a well-established methodology for identifying relationships among specific items but also to providing a fundamental understanding of complex situations. Therefore, this study established an ISM-based hierarchical structure model to clarify the dynamics of relationships among expert performance factors encountered in the bid evaluation practices. The technical route of the ISM is shown in Figure 2.

Expert performance factors in bid evaluation

Following the literature review, we categorized expert performance dimensions into 16 factors. A questionnaire was designed, and 34 experts (from construction, design, cost consulting enterprises, research institutions, and government departments) were interviewed to test the reliability of these dimensions and factors. The interviewees were selected based on their bid-evaluation qualifications and experience, and a deep understanding of construction contracts. The profiles of the interviewees are given in Table 1. To allow them to understand the relationships among the factors, we conducted face-to-face interviews with all the experts. As a result, three factors were removed, and a new one was added. Finally, the remaining 14 bid-evaluation expert performance factors were compiled. A summary of these factors is presented in Table 2.

Generation of the adjacency matrix A

The relationships among the 14 factors were confirmed *via* interviews with 34 experts. Using ISM, a "leads to" (one factor leading to another) contextual-type relationship was chosen to identify the interacting position of each factor for analysis. An adjacency 14*14 matrices of the identified impact factor elements (1 = Yes; 0 = No) was developed as an option for paired comparison between elements. The presence or absence of a relationship directed from element *i* to *j* was indicated by placing "1" or "0," respectively, in the corresponding intersection of row *i* and column *j*. After that, information was sent to experts for comments. Based on their responses, we used the Delphi technique to obtain common views from the participants. When 80% of the interviewees agreed upon the relation, it was thought to have a consensus. The threshold value for the reliability of factors was 0.80. Adjacency reachability matrix A, indicating the relationship between elements, is presented in Table 3.

Reachability matrix calculation

From the adjacency reachability matrix A, redundant relationships between elements were eliminated through an iterative process. A diagram established the final relationship level between elements in a hierarchical form. As the adjacency reachability matrix A is a Boolean matrix, we calculated it by applying the following Boolean algorithm:

$$\text{let } I(n\times n)=\begin{bmatrix}1 & 0 & \cdots & 0\\ 0 & 1 & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & 1.\end{bmatrix}$$

$$\mathrm{R}=(\mathrm{A}+\mathrm{I})^{(\mathrm{n}+1)}=(\mathrm{A}+\mathrm{I})^{\mathrm{n}}\neq\cdots\neq(\mathrm{A}+\mathrm{I})^{2}\neq(\mathrm{A}+\mathrm{I}) \quad (1)$$

where $\mathrm{R}=(\mathrm{A}+\mathrm{I})^{n}$ is the reachability matrix R of matrix A.

According to adjacency reachability matrix I of the bid-evaluation expert performance, the calculation process was implemented in MATLAB (Lindfield and Penny, 2012). When $n=5$, the equation $\mathrm{M}=(\mathrm{A}+\mathrm{I})^{(n+1)}=(\mathrm{A}+\mathrm{I})^{n}\neq\cdots\neq(\mathrm{A}+\mathrm{I})^{2}\neq(\mathrm{A}+\mathrm{I})$ held. The derived result and the reachability matrix are shown in Table 4.

Reachability matrix R analysis

The reachability matrix obtained above was partitioned by deriving the reachability set and the antecedent set to establish the hierarchy model of the ISM. The reachability set for each element represented a set of elements (i.e., several risk elements, including itself) upon which the current element had an impact. For example, in the ith horizontal row *Si* of reachability matrix R, if $S_{ij}=1(j=1,2,\cdots,n)$, the element S*ij* is placed in the reachability set, expressed as S*i*. The antecedent set reflects a set of elements that affected the current element. Along the same lines, in the jth column S*j* of reachability matrix R, if $R_{ij}=1(\mathrm{i}=1,2,\rightleftarrows\cdots,n)$, the element R*ij* is placed in the antecedent set, expressed as A*j*. The intersection of these sets $\mathrm{S}_i\cap\mathrm{A}_j$ was derived for all elements. If S*i* is a complete subset of A*j*, the element or elements were moved from the reachability matrix and assigned a specific level.

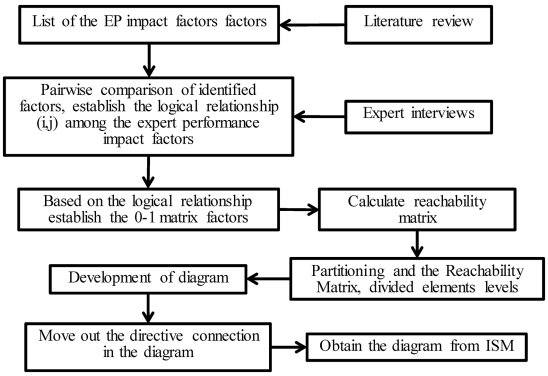


FIGURE 2
The technical route of interpretive structural modeling.

After the iteration, the reachability set for the elements Expertise (S1) and Number of bid evaluations (S5) was a complete subset of the antecedent set; therefore, it was considered the highest level of the elements removed from the reachability matrix. On the other hand, the elements Stress situations (S10), Natural Environment (S11), and Distance (S12) occupied the reachability sets and the antecedent sets on their own, which implies that these factors were isolated from other elements. They were, therefore, removed from the reachability matrix and placed on the first level. The iterative processes were continued in this manner to identify the different levels. Consequently, the hierarchy model of the ISM consisted of all these levels. The results of the final iteration are given in Table 5.

Development of a diagram

A diagram explains the contextual relationship between an impact factor element and its hierarchy. First, as shown in Table 5, the elements taken from the reachability matrix in the previous step were placed at the highest level of the hierarchy. Thus, Expertise (S1), Number of bid evaluations (S5), Stress situations (S10), Natural environment (S11), and Distance (S12) appeared at the top. Next, the elements of Academic ability (S2), Motivation preference (S3), Years qualified as an expert (S4), and Rewards (S14) were removed before the next

TABLE 1 Identification of expert performance factors per dimension.

	Code	Factors	Definitions	References
Inherent cognition	S_1	Expertise of bid evaluation	The expertise is the education background and major of bid evaluation experts	Thompson et al., 2013; Hambrick et al., 2014
	S_2	Academic ability of the bid evaluation experts	The ability to solve practical bid evaluation problems with the knowledge learned, the reaction speed, learning ability and observation ability when encountering the related cases, etc.	Ericsson, 2014; Hamdi et al., 2017
	S_3	Motivation preference	Theoretical research or social practice	Ericsson et al., 2009; Hannele et al., 2016
	S_4	Years qualified as a bid evaluation expert	Proficiency of practice and experience of bid evaluation experts'	Lund et al., 2017; Erturan et al., 2018
	S_5	The number of bid evaluations	Practical experience	Fabian et al., 2016
	S_6	Morality of bid evaluation experts	Is there any record of bid evaluation violation due to behavior bias	Lee and Ryzin, 2019
	S_7	Objectivity of bid evaluation experts	Bidding documents and understanding thereof	Wang et al., 2013; Wei et al., 2019
External environment	S_8	Situation perception of bid evaluation expert in the workplace	Physical environment in the bid evaluation workplace (sitting comfort, air humidity, seat position, physical comfort)	Foglia and Wilson, 2013; Liu et al., 2015
	S_9	Supervision system of bid evaluation	Politics, Laws, Regulations of bid evaluation	Gonsalvez et al., 2017
	S_{10}	Stress situation of bid evaluation expert	Responsibilities and Task-related constraints of bid evaluation experts From peer pressure or Coercion	Michaels, 2000; Whitehead et al., 2016
	S_{11}	Natural environment of bid evaluation	Season (seasonal characteristics can cause mood changes among bid evaluation experts), Climate (storms, snow, heat, typhoons, and other extreme weather), etc.	Heyden, 2013; Hambrick and Tucker-Drob, 2015
	S_{12}	Distance of bid evaluation	Distance from bid evaluation site	Caset et al., 2019; Jo et al., 2019
	S_{13}	Strength of bid evaluation	Bid evaluation rounds Responsibility Target Time constrained	Michaels, 2000; Lindfield and Penny, 2012
	S_{14}	Rewards of bid evaluation	Goal-related constrains (charge, honors for bid evaluation experts, etc.)	Fuller et al., 2013; Korhonen-Sande and Sande, 2016

partition at the second level and placed below the top level. This process was repeated until all the elements were rearranged, creating a four-layer hierarchical structural diagram of the expert performance factors in bid evaluation (Figure 3).

Using MICMAC analysis, it is necessary to prove the relationships among impact factor elements based on the attained diagram. We used this approach to analyze a factor's dependency and driving power. The analysis complements experienced users' impressions drawn from the visual analysis of influence structures. To better understand the significance of certain elements and their influence on others, we used the MICMAC to classify the factors into four clusters (autonomous, dependent, linkage, and independent) according to their driving and dependence power. The driving-and-dependence power of an element was computed *via* the summation of the corresponding rows. Similarly, the dependence power was computed *via* the summation of the corresponding rows and columns, respectively.

TABLE 2 Background profiles of interviewed experts.

Category	Classification	Number of experts	%
Education background	Bachelor's Degree	19	56%
	Master's Degree	9	26%
	PhD	4	12%
	Others	2	6%
Job profile/ department	Construction enterprise	12	35%
	Design enterprise	3	9%
	Cost consulting enterprise	4	12%
	Research institution	9	26%
	Government departments	3	9%
	Others	3	9%
Years of expert qualification (experience)	1 ~ 5 years	10	29%
	6 ~ 10 years	6	18%
	Over 10 years	18	53%

TABLE 3 Adjacency reachability matrix A of expert performance factors.

Code	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}
S_1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S_2	1	0	0	1	0	0	0	0	0	0	0	0	0	0
S_3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
S_4	1	0	1	0	1	0	0	0	0	0	0	0	0	0
S_5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S_6	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S_7	1	0	1	0	0	0	0	0	0	0	0	0	0	0
S_8	0	0	1	0	1	0	0	0	0	0	0	0	1	0
S_9	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S_{14}	0	0	0	0	1	0	0	0	0	0	0	0	0	0

TABLE 4 Reachability matrix of expert performance factors.

Elements $S(i/j)$	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	Driving power
S_1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2
S_2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	5
S_3	1	1	1	1	1	0	0	0	0	0	0	0	0	0	5
S_4	1	1	1	1	1	0	0	0	0	0	0	0	0	0	5
S_5	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2
S_6	1	1	1	1	1	1	0	0	0	0	0	0	0	0	6
S_7	1	1	1	1	1	0	1	0	0	0	0	0	0	0	6
S_8	1	1	1	1	1	0	0	1	0	0	0	0	1	1	8
S_9	1	1	1	1	1	1	0	0	1	0	0	0	0	0	7
S_{10}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
S_{11}	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
S_{12}	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
S_{13}	1	0	0	0	1	0	0	0	0	0	0	0	1	1	4
S_{14}	1	0	0	0	1	0	0	0	0	0	0	0	0	1	3
Dependence power	11	7	7	7	11	2	1	1	1	1	1	1	2	3	56

Finally, each element was plotted on the driving-dependence power matrix (Figure 4).

The first cluster represents "autonomous factors" (weak driving and dependence power). It includes Stress situations (S10), Natural environment (S11), Distance (S12), Strength (S13), Rewards (S14), Academic ability (S2), Motivation preference (S3), Years qualified as an expert (S4), Morality (S6), and Objective (S7). This set of factors reflects complicated situations. The "dependent factors" belonged to the second cluster (weak driving, strong dependence power) and ranked highest in the importance levels of the ISM-based hierarchical model. Two factors were assigned: Expertise (S1) and the number of bid evaluations (S5). Their dependence indicates that they depended on other factors to be resolved during the bid-evaluation expert performance. Therefore, bid-evaluation experts should consider all other factors to achieve the dependent factors and retain superior expert performance. The third cluster specifies the "linkage factors" (strong driving and dependence power). Any change occurring to these factors would significantly impact other factors in return. No factors correlated with this category in our study, implying that none of them had strong driving and dependence power. The "independent factors" (strong driving, weak dependence power) in the fourth cluster formed the foundation of the ISM hierarchical model and should be given priority. The two factors in this set, Situation perception (S8) and Supervision system (S9), are vital, and bid-evaluation experts and policymakers should focus on them for superior bid-evaluation expert performance.

TABLE 5 Level partition of reachability matrix.

Elements $S_{(i/j)}$	Reachability set:R(Si)	Antecedent set:A(Si)	Intersection R(Si)∩A(Si)
Level I = {S_1, S_5, S_{10}, S_{11}, S_{12}}			
S_1	1, 5	1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 14	1, 5
S_2	1, 2, 3, 4,5	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_3	1, 2, 3, 4, 5	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_4	1, 2, 3, 4,5	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_5	1, 5	1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 14	1, 5
S_6	1, 2, 3, 4, 5, 6	6, 9	6
S_7	1, 2, 3, 4, 5, 7	7	7
S_8	1, 2, 3, 4, 5, 8, 13, 14	8	8
S_9	1, 2, 3, 4, 5, 6, 9	9	9
S_{10}	10	10	10
S_{11}	11	11	11
S_{12}	12	12	12
S_{13}	1, 5, 13, 14	8, 13	13
S_{14}	1, 5, 14	8, 13, 14	14
Level II = {S_2, S_3, S_4, S_{14}}			
S_2	2, 3, 4	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_3	2, 3, 4	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_4	2, 3, 4	2, 3, 4, 6, 7, 8, 9	2, 3, 4
S_6	2, 3, 4, 6	6, 9	6
S_7	2, 3, 4, 7	7	7
S_8	2, 3, 4, 8, 13	8	8
S_9	2, 3, 4, 6, 9	9	9
S_{13}	13, 14	8, 13	13
S_{14}	14	8, 13, 14	14
Level III = {S_6, S_7, S_{13}}			
S_6	6	6, 9	6
S_7	7	7	7
S_8	8, 13	8	8
S_9	6, 9	9	9
S_{13}	13	8, 13	13
Level IV = {S_8, S_9}			
S_8	8	8	8
S_9	9	9	9

Findings and discussion

It is important to enhance expert performance in bid evaluation. The derived model reflects the relationships among expert performance factors in bid evaluation practices.

A holistic picture of expert performance factors

The two dimensions of internal cognition and the external environment were independent through theoretical deduction. In the PES, the interaction between the "perceptions" and "affordance" of experts is manifested as expert performance, which feeds back or verifies internal cognition and external environment, forming a "closed system" (Figure 1). However, in the context of engineering, 14 factors affect expert performance, seven of which are from the internal cognitive dimension and seven from the external environmental dimension. We could observe that the two-dimensional factors were scattered on four levels (Figure 3). Inherent cognitive factors influenced each other and were scattered at the 1–3 level. Most of them had strong dependence and were driven and influenced by external environmental dimension factors. Level 2–4 was PES, with perception (e.g., body perception) and supply (e.g., the regulatory system) at the lowest end, the most important driving force in the structural system that influences other factors to work together.

The three factors under the heading of the external environment, namely pressure, natural environment, and working distance, together with expertise and bid evaluation times

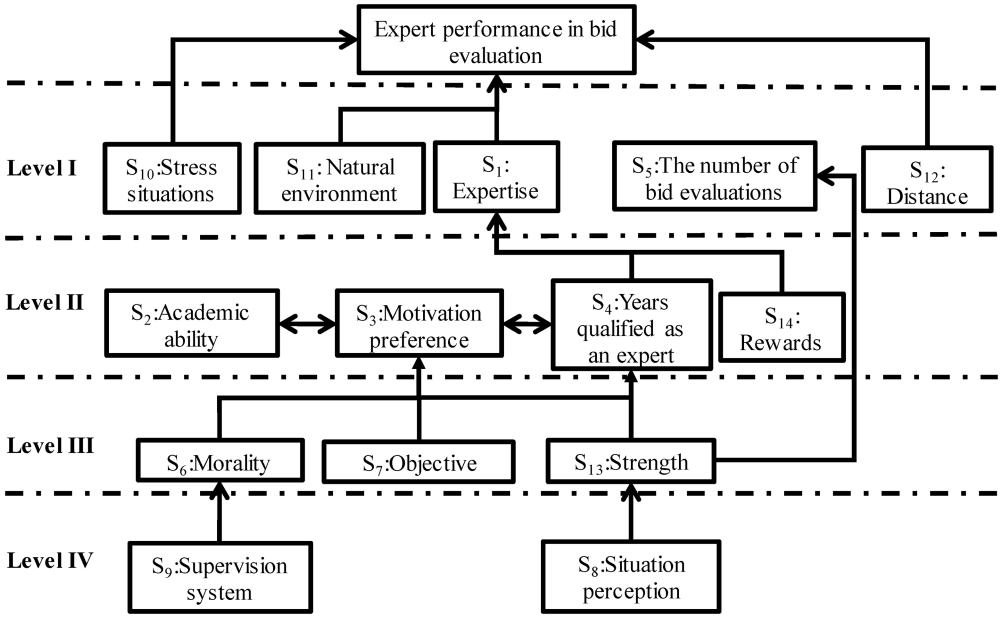


FIGURE 3
Diagram of expert performance factors in bid evaluation.

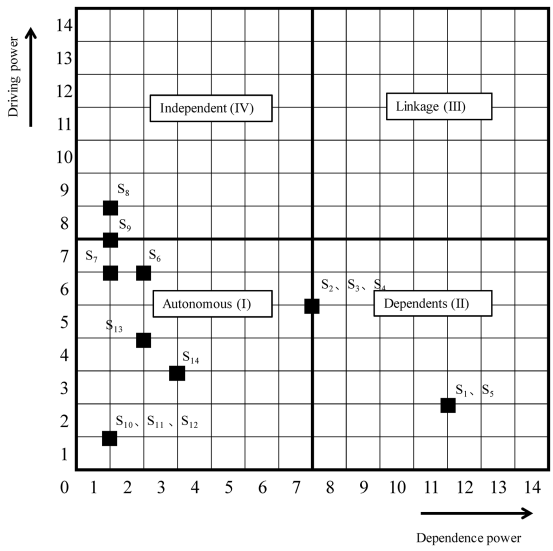


FIGURE 4
Classification of factors.

(internal cognitive dimensions), were at the first level of the hierarchical structure system and were the most direct influencing factors. However, the three factors of the environmental dimension existed independently of any other factors, leaving the structure in an open form. These phenomena reflect the organic integration of memory and ecological cognition theories and completely describe the factors affecting expert performance in engineering. These influencing factors differ from the characteristic cognitive ability mentioned in the ecological dynamics theory of sports decision-making with the help of regularity and universality (Araújo et al., 2006). For expert-performance factors with engineering characteristics, inherent cognition has a dynamic influence on expert performance under the constraint of a unique external environment. In contrast, the external environmental factors are more strongly driven or have a direct and independent influence.

Hierarchy of expert performance factors

In the bid evaluation, considering independent factors (strong driving and weak dependence power from cluster four), situation perception reflects the experts' feelings regarding the environmental properties, including seating, air humidity, and physical comfort. Negative feelings will hinder expert performance as perception, cognition, and behavior are integrated processes. The nature and type of cognition are influenced by the interaction between the body and the external environment. For example, situation perception, relating to concepts such as fatigue (Orazbayev, 2017), is a hidden expert-performance-influencing factor that few researchers focus on. The perception of "affordance" has a dynamic quality and can change (Fajen et al., 2009). Improved working conditions can maintain enhanced situation perceptions and effectively obtain sustainable and superior expert performance. The other independent factor with strong driving power, a sustainable supervision system rather than self-restriction, is also confirmed to improve expert performance. Environmental properties directly inform experts about what they can and cannot do in a performance context (Michaels, 2000). In

essence, the confluence of constraints and perception determines the stability and instability of expert performance.

At level III of the ISM, the factors of morality, objective, and strength precede motivation preference (Figure 3, Level II), while motivation preference, academic ability, and years qualified as an expert (all level II) affect each other bilaterally. Regarding the level II factor, rewards are influenced by the factor of strength. Therefore, these factors with higher driving power in the autonomous cluster (such as Strength) can impact each other. Therefore, their promotion should be given priority in attaining superior expert performance. In contrast, the factors with higher dependence on power are influenced by other factors. Consistent with current studies, academic ability, motivation preference, and years qualified as an expert (Figure 3, Level III) are key factors determining expert performance as acquired skills and experience in bid evaluation.

More factors from inherent cognition and the external environment are plotted at the top of the four-level diagram (Figure 3, Level IV), indicating that factors from the two dimensions collectively determine expert performance. These factors include the inherent cognition dimension (expertise, number of bid evaluations) and the external environment dimension (stress situations, natural environment, and distance).

Previous studies have demonstrated that expertise and exceptional performance are highly reproducible regarding inherent cognition. There is no doubt that unfailed successful learning is necessary for experts to achieve an improved or higher level of performance (Ericsson and Lehmann, 1996). In this regard, of all the factors at the top level, expertise and the number of bid evaluations, both belonging to the inherent cognition dimension, are viewed as the most natural elements influencing expert performance. The other factors: stress situations, natural environment, and distance, which belong to the external environment, are isolated and have no relationship with other factors. This phenomenon shows that the factors affecting experts' performance are in an open system, and some external environmental factors will directly impact them in some situations. Especially in the bid evaluation process, the pressure from peers or the physical impact of the natural environment on experts (e.g., fatigue caused by long-distance travel to the workplace or bad weather) will make expert performances deviate.

Key expert performance factors

The situation perception and supervision system factors (Figure 3, Level IV) may forego morality, objective, and strength (Figure 3, Level III), determining expert performance in the bid evaluation. These are key issues to be addressed to realize superior expert performance. Moreover, Ericsson and Lehmann (1996) showed that situation perception affects labor intensity, whereas a strict supervision system initiates moral restraint. Thus, morality and some other factors (including procedural fairness, technical competence, and general reputation) impact and interact with expert performance. Still, illegalities often occur despite the vital importance of limiting moral deviation during expert behavior. For instance, bid-evaluation experts and bidders collude to manipulate the bidding of private customers (forcing the client to pay high prices). In addition, they colluded on certain municipal contracts, causing huge economic losses to New York taxpayers (TargetedNewsService, 2018). It has been reported that experts' antagonistic feelings may hinder objectivity and obscure experts' fairness (Lindfield and Penny, 2012).

In particular, three environmental constraint factors (stress situation, natural environment, and distance), located in the top layer, are mainly manifested as physical perception in the natural environment. They do not participate in the PES due to no correlation with any factor in internal cognition and other factors in the external environmental dimension. They make the system open, and these factors show that they directly, solely, and openly affect expert performance in engineering. This contrasts with the traditional information processing methods for decision-making in the "open system." When decision-makers calculate and select options in the psychological or neural model, the influence of more uncertain external environment factors should be considered to maximize performance effectiveness.

Implications

Our results show that inherent cognitive and external environmental factors are characterized by high dependence and strong driving power, respectively (Figure 4). For example, Figure 3 Level IV shows that situation perception and supervision system (external environment dimension) are antecedent variables driving expert performance factors and should not be precluded first. However, the classification of factors (Figure 4) shows that morality and objective (internal cognitive dimension) also have higher driving and lower dependence power. This finding suggests that these two special factors bridge the inherent cognitive and external environmental dimensions. Moreover, morality and objectivity (Figure 3, Level III), controlled by the supervision mechanism (Figure 3, Level IV), influence inherent cognition dimension factors.

We confirmed the relationship and hierarchical structure of the two dimensions, suggesting that environmental constraint factors other than inherent cognition contribute to individual expert performance differences in bid evaluation. Furthermore, they show that external environmental factors strongly influence the externalization of inherent cognition. At a practical level, our findings on the two dimensions affirm existing research, supporting the notion that expert performance depends on professional knowledge and the environment in engineering. Furthermore, the findings also provide a basis for exploring ecological cognition based on the idea that the "brain–body-environment system is embedded and embodied."

Conclusion

Several uncertainties and factors of expert performance in bid evaluation make its improvement to be a complicated matter. An individual's performance in a domain is determined by multiple interactions between experience, training, and biological factors. This study produced a comprehensive list of expert performance factors. It identified and examined two dimensions of factors occurring in bid evaluation, and the results indicated that external environmental factors are prominent for expert performance. Furthermore, we also found evidence of cognition-environment interactions, which revealed environmental effects as the most important driving factors of expert performance in bid evaluation. The suggestion is that external environmental factors drive expert performance to change through the role of practice. Thus, poor expert performance can be resolved by fostering a friendly work environment for bid evaluation experts.

Morality and objective can be ranked as factors of ensuring expert performance in bid evaluation. Expert performance should be promoted by driving power factors such as academic ability, motivation preference, and years of qualification. Meanwhile, situation perception and supervision systems are deemed to form the hierarchical foundation, suggesting the need for an eco-friendly environment and enhancement of supervision intensity for good situation perception to support expert performance. In summary, the study sheds some light on the influence relationship and driving relationship among the factors of expert performance to reveal the interaction mechanism between inherent cognition and the external environment. It also extends the concept of expert performance from cognitive science to management science.

Although the study obtained findings on expert performance in bid evaluation, more factors related to the bid evaluation context should be detected to prevent deviations. Furthermore, our research was based on the experience and opinions of interviewees, of which bias and prejudice are unavoidable. Besides, the factors' interactive relationships have not been quantitatively examined and can be further investigated in future research. Finally, expert performance involves many cognitive–psychological activities. Therefore, it is expected to investigate these activities in future studies to promote expert performance in the engineering context.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KY and LW: conceptualization. WW: supervision. LW: writing–original draft preparation. KY and YL: writing–review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Social contact, practice, organization and technical knowledge: Experiences of music students in the course of the COVID-19 pandemic

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For music students, the COVID-19 pandemic has had a great impact, forcing them to adapt to certain coronavirus regulations laid down by the state. In this study, the experiences of music students in three consecutive semesters under different coronavirus-related conditions are investigated. At the end of three semesters, the lockdown semester [SS (Summer Semester) 2020: April – July], a partially opened semester [WS (Winter Semester) 2020/21: October – February] and a mostly opened semester (SS 2021), a total of 152 music students at the University of Music Freiburg were asked to fill in an online survey. A mixed-methods approach was used, with results showing that the qualitative statements of the students support the quantitative data. The results of the cross-sectional study demonstrate that self-regulated learning improved during the lockdown semester, through new time management and focused practice with regular breaks. During the partially opened semester, the use of blended learning formats led to organizational problems, such as travel time and change of locations. Furthermore, music students were challenged by the social distancing, which improved during the partially opened, and mostly opened semester. New technologies regarding digital communication formats were emerged, which have evolved over the course of the three semesters. Concerning the overall experience, students stated that the partially-opened semester was most challenging, since distances and change of locations had to be combined with quickly changing public COVID-19-regulations. These findings during different stages of the COVID-19 pandemic provide constructive starting points for future teaching.

KEYWORDS

personal experiences, social contact, organization, technical knowledge, music students, coronavirus pandemic

Introduction

Since the Summer Semester (SS) 2020, the situation at universities has been markedly affected by the COVID-19 pandemic. During that semester and the following two, certain coronavirus-related rules had to be followed (e.g., regular ventilation, wearing of facemasks, distancing, restrictions in using the university buildings) and teaching at universities changed significantly, too. For music students, the situation largely concerned the use of practice rooms and the instrumental and vocal lessons.

Recent studies show that students, in general, have developed a range of approaches to meet the different conditions of the coronavirus pandemic (Biasutti et al., 2021; Habe et al., 2021; Holm-Hadulla et al., 2021; Martinek et al., 2021; Nusseck and Spahn, 2021; Rosset et al., 2021; Schiavio et al., 2021; Tejedor et al., 2021).

One topic, that students of all disciplines had to find ways to deal with, are online courses. Universities of Music have had less experience in online teaching, compared to the long-standing tradition of face-to-face artistic instruction, which clearly requires a certain interaction between teacher and learner (de Bruin, 2021; Güsewell and Terrien, 2021; Vladova et al., 2021). Organizational aspects were found to be problematic, whereas acceptance of technical requirements (such as programs for online course) on the part of both teachers and learners was mostly high. Li et al. (2021) observed the use of online courses at a Chinese performing arts university during times of social isolation, specifically, hybrid teaching formats such as blended learning, mixed teaching methods, and flipped classrooms, in combination with outcome-based and student-oriented learning. It was shown that these formats if employed in a professional way can lead to rich and meaningful teaching and learning. Güsewell and Terrien (2021) observed the relationship, challenges and chances of one-on-one teaching in musical higher education in Switzerland and France, looking mainly at the year of 2020. They did an online survey ($N = 56$), as well as semi-structured interviews with 3 teachers. Difficulties that were mentioned were connection problems with students, poor network, unsuitable or missing tools, poor sound quality, high levels of stress and discomfort, and a very time-consuming nature of online courses. On the other side, they also found positive effects, such as an increase in the pedagogy level, as well as interesting spill-overs for their teaching. The study of Ozer and Ustun (2020) took place in the beginning of the COVID-19 pandemic in 2019/2020, focusing on students' experiences with the lockdown semester, and especially distance education in the Music and Performing Arts at Nevsehir Hacı Bektas Veli University, Turkey. The students reported mainly difficulties with distance education, with the exception of music students, who found that they were able to self-improve in individual courses and were able to work more efficiently, while having more time alone. Rucsanda et al. (2021) observed the attitude towards online lessons in individual courses of music students at a University of Music in Romania during the lockdown semester. They found that by the compulsion of using e-learning tools, the attitude towards them changed and led to more satisfaction.

Holm-Hadulla et al. (2021) investigated the personal experiences of students at the University of Heidelberg during the COVID-19 pandemic. They found that loneliness and social isolation were the main reasons for a decrease in students' well-being, along with a loss of motivation.

A study of 310 sports and music students was conducted by Habe et al. (2021), in which lockdown conditions were compared with those pre-coronavirus. Researchers found that sport students experienced predominantly positive effects compared to music students. At the same time, they advance the hypothesis that music students were able to deal with the lockdown and the accompanying social isolation more effectively especially since they are used to being alone when practicing.

In their qualitative study, Schiavio et al. (2021) addressed the special situation in music studies. Questioning music students at an Italian conservatory, they found that approaches to practicing and time management have improved during the COVID-19 pandemic. In particular, prioritizing short-and long-term goals, enhancing creative potential and building interactions with peers were found to be core themes. A further related issue that music students faced during the pandemic is the development of certain self-regulated learning skills (McPherson et al., 2017; Nusseck and Spahn, 2021). In this context, Nusseck and Spahn (2021) observed that students spent less time practicing during the lockdown semester, but they also developed new, more self-regulated practicing methods, which led to greater efficiency.

For music students in particular the relationship to their teachers is of especial importance, since it is mainly one-on-one teaching. The lockdown semester brought changes to this interpersonal relationship (Antonini Philippe et al., 2020) in terms of social distancing. The music students began to rethink the relative importance of this relationship, developing more self-regulated practicing behaviors, resulting in a better understanding of their own learning and practicing. Rosset et al. (2021) also investigated the impact of the coronavirus pandemic on the practice behavior of music students during the lockdown semester of summer 2020. They found that music students practiced less hours with a perceived increase in stressful thoughts and feelings.

Summarizing the studies mentioned above, it becomes clear that they either examine solely the lockdown semester, or compare different regulations and their impacts on students to a time before these conditions. Therefore, they offer insight into students' overall experiences and practice behaviors during this specific period, but deal with a potentially unreliable retrospective recall bias. Our more differentiated study aims to investigate the personal experiences and practice behaviors of music students, under varying coronavirus-related conditions, comparing three points in time: full lockdown (SS 2020), hybrid/ partially open (WS 2020/21) and mostly open (SS 2021). During each of these time frames, different social, coronavirus-related regulations prevailed, leading to different underlying conditions at the University of Music Freiburg for both students and teaching faculty.

Materials and methods

Design

Conceived as cross-sectional, the study contains three surveys carried out in consecutive semesters during the coronavirus pandemic, the results of which are compared with each other. The study follows a mixed-methods approach in which quantitatively evaluable items and free text answers in a questionnaire were filled out by music students (Flick, 2019). In the analyses, quantitative and qualitative data were considered jointly.

At the University of Music Freiburg, the regulations and measures (Spahn and Richter, 2021) changed drastically between the first three semesters during the COVID-19 pandemic according to the respective stage of said regulations. We chose to collect the data at the end of each semester to better control the recall bias. The question of how students are faring under these differing coronavirus-related conditions drove the study, with three points in time compared (Figure 1): (1) July 2020: looking back on the lockdown semester (2) February 2021: looking back on partially re-opening and so-called hybrid conditions, and (3) July 2021: looking back on a mostly opened semester.

1. The first survey was carried out in July 2020, at the end of the 2020 summer semester, reviewing the lockdown semester just past. During this semester, students had nearly no courses in which their physical presence was required. It was stipulated that the courses, both theoretical and practical, be conducted in digital format. During most of the semester, the University of Music was closed. The administration and technical support staff were allowed to enter the building, with practice rooms kept open for students who were unable to practice at home. Students needed to apply for admittance to the building and had to make appointments to use a practice room. Some instrumental and vocal lessons were held in the concert halls. No gatherings at all were allowed in the building.
2. The second survey took place in February 2021, at the end of the 2020/2021 winter semester, looking back on the partially opened semester. At the University of Music Freiburg this semester was conducted in a semi-open manner. Based on the frequently updated "risk assessment of a coronavirus infection in the field of music" (last update: January 13, 2022) of the Freiburg Institute for Musicians' Medicine, hygiene and safety measures were evaluated, which led to regulations that allowed a partial reopening of the university. Empirically verified ventilation measures plus compliance with the particular instrumental and singing-specific distancing, masking, and hand and surface cleaning rules formed the prescribed measures for teachers, students and the whole staff of the University of Music Freiburg. On this basis, lessons could be held in large rooms of the University. Especially one-on-one voice and instrumental lessons, as well as small ensembles and chamber music groups with students and their teachers, were allowed to take place. Furthermore, the students had access to the University building again, and were allowed to use practice rooms. Theoretical courses were still conducted in digital format.
3. The third survey was performed in July 2021, at the end of the 2021 summer semester, looking back on the mostly open semester. This was the first semester that allowed almost normal scenarios of practicing, lessons, rehearsals and concerts with a limited number of viewers for large ensembles, choirs and orchestras, too, again drawing on empirically verified measures of ventilation, distancing, masking, and hand and surface cleaning; the increasing rates of vaccinations also played a role in this relative loosening of rules. The University of Music Freiburg enabled vaccinations for students, teachers and staff members of the university, from early 2021 on. On the basis of a survey with voluntary responses given at the end of summer semester 2021, it was found that 92% of all university members had had their first vaccination (Spahn and Richter, 2021).

For a general comparison of the three time points of the surveys, the Oxford COVID-19 Stringency Index (Ritchie et al., 2020; Hale et al., 2021) considering the degree of governmental regulations were taken into account. The value of the index ranges between zero (no regulations) and 100. In Germany, the value was in the SS 2020 between 77 in April 2020 and 55 in July 2020. At the time of the first survey, the index was at 63. In the WS 20/21, the value ranged between 50 in October 2020 and 85 in January 2021. At the time of the second survey in February 2021, the value

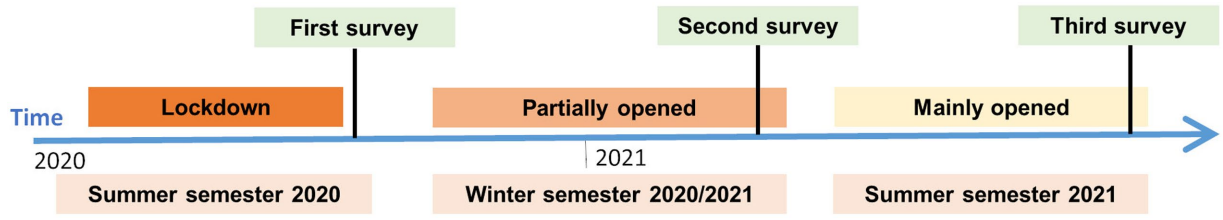


FIGURE 1
Overview of the conducted surveys on a time line.

was 83. At the beginning of the SS 2021 in April, the index was at 75 and reduced to 68 at the third survey in July 2021.

The study was performed in online surveys using the platform SoSciSurvey. The participation in the surveys was purely voluntary and music students had to affirm their participation on the first page of the survey. The data was collected anonymously and the procedure was approved by the Ethics Committee of the Medical Center of the University of Freiburg.

Participants

For the surveys, music students of different theory practice seminars at the University of Music Freiburg were asked in the last session at the end of the semester to participate in the survey as part of an evaluation of these courses. The seminars were regular common courses in the area of music physiology offered for all students across all study areas. Therefore, the samples of this study are representative of the full spectrum of music students at the University of Music.

A total of 152 music students took part in the three surveys at the University of Music Freiburg. 56% of the 152 students were in the Bachelor of Music cohort, 40% in the Master of Music and 4% in other study profiles cohort; 73% were female students. The mean number of semesters across the 152 students was 3.8 semesters (SD = 1.9 semesters).

The characteristics of the participants in each of the three surveys can be seen in Table 1. In the first survey in SS 2020, 68 students participated, the second survey in WS 2020/2021 contained 56 students and the third survey in SS 2021 had a smaller sample size of 28 students. The distributions of gender and study profile did not significantly differ between the surveys [Gender: $\chi^2(2) = 0.49$, n.s.; Study profile: $\chi^2(4) = 6.0$, n.s.]. There was also no significant difference in the number of semesters between the surveys [$F(2,140) = 1.94$, n.s.].

The instruments were distributed as follows: 23% piano, 14% vocals, 33% strings, 8% brass, 15% woodwind and 7% other instruments in the total sample ($N = 152$). The distribution of the instrumental groups did not significantly differ between the surveys [$\chi^2(8) = 8.5$, n.s.].

TABLE 1 Characteristics of the student samples in the surveys.

	Survey 1 SS 2020 $N = 68$	Survey 2 WS 20/21 $N = 56$	Survey 3 SS 2021 $N = 28$
Age (years) Mean (SD)	23.8 (3.6)	22.5 (2.6)	24.8 (4.5)
Gender (female)	74% ($N = 50$)	75% ($N = 42$)	68% ($N = 19$)
Number of semesters Mean (SD)	4.1 (2.0)	3.4 (1.6)	4.0 (1.9)
Study profile			
Bachelor of Music	60% ($N = 41$)	59% ($N = 33$)	39% ($N = 11$)
Master of Music	35% ($N = 24$)	39% ($N = 22$)	50% ($N = 14$)
not specified	5% ($N = 3$)	2% ($N = 1$)	11% ($N = 3$)

Questionnaire

The questionnaire contains sociodemographic data such as age, gender, number of semesters, study profile and main instrument/voice. The questionnaire was conducted in German and the students' statements were translated into English, after the analysis.

Practice time

The participants were asked to estimate in minutes the amount of time spent practicing daily over the past semester. Additionally, they were asked to compare this practice time to the usual practice time in a non-coronavirus semester on a scale from 1: much less to 5: much more.

Practice behavior

Participants were asked to indicate whether their practice behavior had changed in the past semester compared to the previous semester and if yes, to describe in a freely formulated text how such practice behavior had changed.

Rating of overall experience

Students were asked to evaluate their experience of that semester compared to semesters prior to the coronavirus pandemic. The question was "How did you experience this semester compared to your studies before the Corona pandemic?" Students who started their study during the pandemic were told to skip this question. Answers were possible on a 100-point analog scale (1: negative to 100: positive). The scale allowed that a response of 50 implies a neutral value regarding a similar experience in comparison to other semesters. Moreover, students were asked to compare their overall experience of a semester with that of the previous one. The same question and scale were used, but the reference of comparison was the last semester. In the first survey, there was only one question, since the semester fell together with the earlier semester unaffected by coronavirus.

Open experience responses

Students were asked to give a personal statement in an open text field, about what they enjoyed most, and what they liked less about the past semester.

Evaluation methods and statistics

Quantitative data

All parametric values were reported descriptively with mean and standard deviation of the mean (SD). For the analysis of main effects between the surveys, an analysis of variance (ANOVA) was used. A post-hoc analysis was performed with the Tukey-HSD correction. Nonparametric comparisons made use of cross-tables; Pearson's χ^2 was reported. The statistical analyses were conducted with SPSS

(Version 28, Armonk, NY: IBM Corp.). The level of significance was set to $p = 0.05$.

Qualitative data

All open-text answers of the questionnaire were analyzed with the qualitative content analysis according to Mayring (2010). First, transparency was created by describing the sample in detail. Then, a category system was developed bottom up on the basis of the music students' answers. This served as a guideline in the course of further interpretation. Through this procedure and by working jointly in a research team, reproducibility and objectivity were guaranteed.

The qualitative content analysis was used to analyze the students' text-based statements in order to find out reasons for the students' behavior during the three semesters examined. With the help of the summary content analysis, an inductive category system was designed, which forms the basis of the coding (see Figure 2), and led to the following interpretation.

Results

Overall experience of study

By use of the mixed-methods approach, we combined the quantitative and qualitative results. The quantitative data were looking at the individual overall experience of the different semesters, as well as practicing times, whereas the qualitative questions were considering self-regulated learning and self-organizational questions, practicing habits, as well as social and personal aspects. On this base, we developed four main categories: (1) "Organization," (2) "Practicing," (3) "Social Dimension," and (4) "Technical Aspects" (Figure 2). Each of these categories was assigned codes that deepened the category and were based on the thematic aspects that the students were engaged in during the three semesters examined.

Overall experience

The responses to the question of how the students experienced the semester compared to a non-coronavirus semester are shown in Figure 3. There was a significant main effect between the surveys [$F(2,135) = 6.3$, $p = 0.002$]. Individual t-tests against the neutral value of 50 yielded a significantly higher mean value in SS 2020 [$t(62) = 2.26$, $p = 0.014$], a significantly lower mean value in WS 20/21 [$t(48) = -2.70$, $p = 0.005$] and no significant difference in SS 2021 [$t(25) < 1.0$, n.s.].

In terms of the experience ratings of the semester compared to the previous semester, students in WS 20/21 rated that semester relative to the SS 2020 with an average of 75.2 (SD 18.1) and the SS 2021 relative to the WS 20/21 with an average of 74.1 (SD 20.7). Both ratings were significantly higher compared to the neutral value of 50 [WS 20/21: $t(51) = 10.03$, $p < 0.001$; SS 2021: $t(25) = 5.93$, $p < 0.001$].

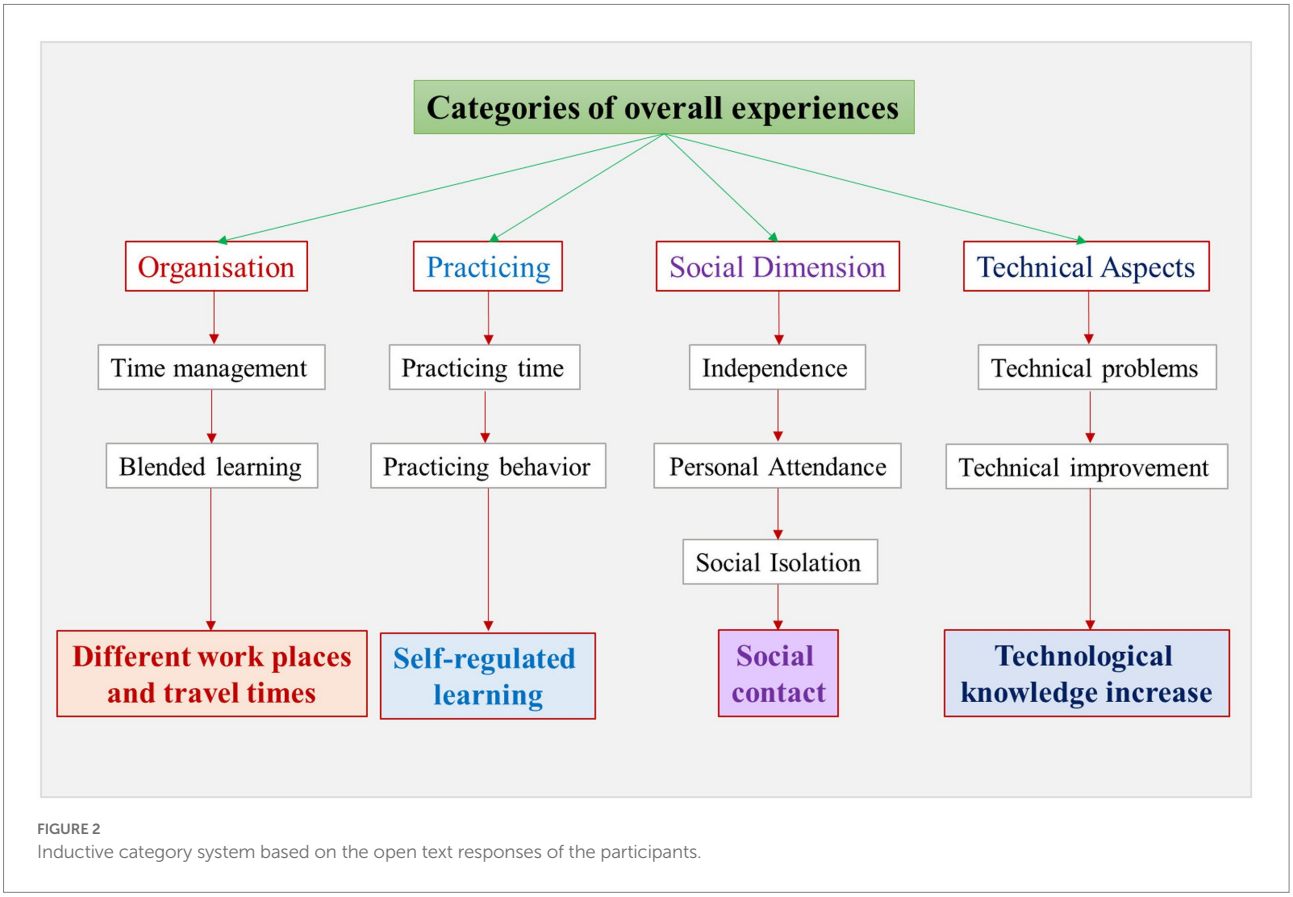


FIGURE 2
Inductive category system based on the open text responses of the participants.

Organization

Category 1, "Organization" arises from our qualitative data and focuses on two topics concerning the organization of student life during the three semesters.

During the lockdown semester of SS 2020, many students described a *self-oriented time management*, which turned out to be a typical feature of this semester. For example, one student commented that the semester had "more flexible scheduling and precise preparation of teachers," referring to the concrete preparation of course contents. Another student wrote: "I found the freedom in my schedule relaxing." Positive experiences with self-oriented time management were not mentioned for the hybrid-semester of WS 2020/21 or for the SS 2021, where all courses could once again be held with students in actual attendance.

A second main topic within this category was the experiences in the context of *blended learning*, focusing on room situations. During SS 2020 students indicated that they had experienced "local flexibility," and the feeling of being "not spatially bound," and that they liked "the flexibility in terms of space and time, so that I could arrange tasks myself and did not have to be constantly on the move between buildings." The positive implications of solely online lessons were no longer reported by respondees for the hybrid semester of WS 2020/21. On the contrary a student wrote that its "organization was more complicated: [we had] new rules all the time." Another student described how "[…] the online classes just do not work as well as face-to-face classes. Especially since I do not live so close to the university, switching between online and face-to-face teaching is very time-consuming." Comparable experiences were not reported for the SS 2021.

The difficulties students experienced in spatial situations, represented in the term *different work places and travel times*, was reported by the students as a typical problem of blended learning, specifically the alternating between online and face-to-face classes.

Practicing

The aspects *Practicing time* and *Practicing behavior* during the three different semesters can be derived from our quantitative and qualitative data (see Category 2 "Practicing" Figure 2). Across the three surveys, the main effect of the mean practice time was significant [Figure 4A, $F(2,128) = 3.1$, $p = 0.049$], showing 45 min more practice time per day in the SS 2021 than in the SS 2020, while the practice time in the WS 20/21 lies in between. The

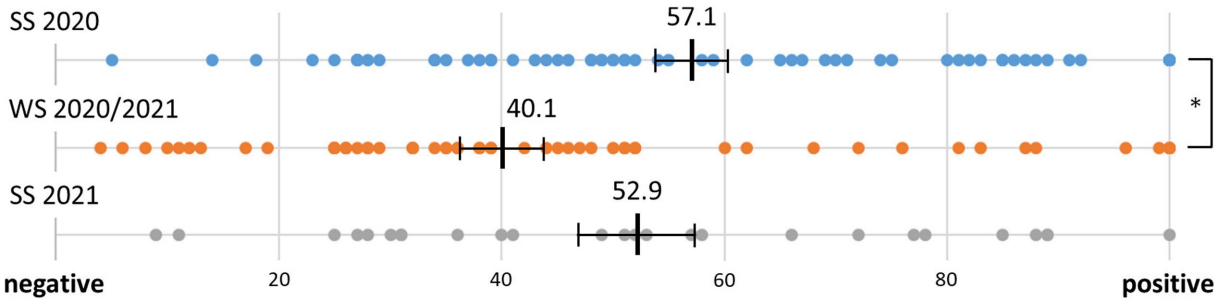


FIGURE 3
Ratings of the student's experiences during each semester (the bold cross lines mark the mean value, the error bars present the standard error of the mean, *p<0.05).

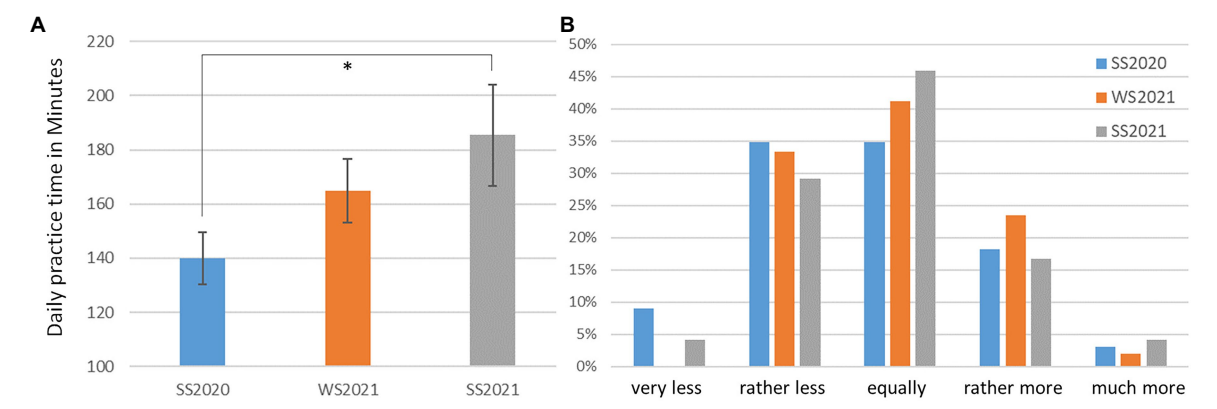


FIGURE 4
(A) Left: the mean daily practice time in each semester (error bars present the standard error of the mean, *p<0.05). **(B)** Right: distribution of the answers to the question of how the practice time differed from usual semesters before the pandemic.

post-hoc analysis showed that the main effect across the three surveys reflected the difference between the SS 2020 and the SS 2021.

The responses to the question of how the practice time differs from usual semesters without coronavirus are also shown in Figure 4B. The average of the ratings was mainly around the answer of equal practice time. There was no significant main effect of the rating distribution between the surveys.

These results were related to those garnered from the personal statements of the students. In comparison to the other two semesters, especially in the SS 2020 students described a predominantly self-regulated practice behavior: One student wrote that during SS 2020: "I learned focused practicing," while another student noted "a higher level of self-regulated working." More than one student wrote about "concentrated self-study" during the lockdown period. "I practice in a more concentrated and constant and focused way." And: "I worked in a concentrated and more organized way. Without pressure," were further statements that described the practice behavior. Other students describe their practicing as follows: "I use body awareness as a tool for better practice. Goal-oriented practicing, with realistic and personal goals. This brings motivation for practice." Or: "It is important to have good balance between practicing and breaks / other activities." In conclusion, one student wrote: "The most important thing is to practice consciously. It does not depend on the amount of time to play better, but on the quality of the practice mainly." Our qualitative data demonstrates an obvious predominance of *self-regulated learning* during the lockdown semester SS 2020.

Social dimension

The "Social Dimension" is an important category deriving from our qualitative data (Figure 2). The content analysis revealed three more aspects which were associated with this topic: *Independence, Personal Attendance* and *Social Isolation*.

Concerning the lockdown semester 2020 students wrote that they had a "high level of independent working," as well as, "more free time," and "free practice time," or "more time to do sports," leading to the code of "independence."

Personal attendance for the SS 2020 was discussed in statements with remarks such as "good support from the teachers," "online-courses were really good," or: "I think that the university did a great job in coordinating online courses. They were solution-oriented and had patience when you had questions."

However, at the end of SS 2020, social isolation was also indicated: "I cannot meet my teacher and colleagues," or: "Contact with fellow students has been lacking." Another one wrote "Above all, the lack of direct social contact in the courses or in the foyer of the university [was lacking]." Concerning the next semester WS 2020/21—where students of the University of Music Freiburg had instrumental lessons again and were allowed to use the university building for practicing—students commented: "You see people in the university again and can at least talk to them. One-to-one lessons can take place again, almost without restrictions." Another socially-related topic during this period that was a source of regret was the fact that "no concerts have been taking place." At the end of SS 2021, in which everything had been open again, students expressed great pleasure about "the possibility to play and go to concerts again," and "that there are more options to meet face-to-face." The statement of one student sums up this observation: "I enjoy my studies much more. It is more communicative and I no longer feel so pressured." Another topic for the students was that they felt "more secure in life." Negative points during this semester related mainly to daily life, such as: "wearing a mask all the time is exhausting," or "it's not all like before," and they did not like "that not everyone follows the rules, e.g., ventilation breaks."

Clearly, as shown by this qualitative data, *social contact* was an important topic for respondees.

Technical aspects

In the qualitative data, "Technical Aspects," divided into *Technical Problems* and *Technical Improvement*, played an important role.

Technical problems were mainly addressed during SS 2020: "I had technical problems, internet problems, and not enough silence at home," or as another student stated: "Online-courses always need a working internet connection." Another student wrote that he had "technical problems, which hinder the learning process." And: [online] "instrumental lessons […] were complicated." During WS 2020/2021 this changed to *technical improvement*. Students wrote: "Technical implementation of teaching has improved" and concerning SS 2021: "Online possibilities became more diverse." Overall, *Technological knowledge increase* emerged over the three semesters as an important topic.

Discussion

In this study, music students were asked at the end of three different coronavirus-impacted semesters to report on their experiences during these semesters. The questions considered their general experiences, with additional focus on aspects of practicing. The mixed-methods approach of this study allowed the quantitative and qualitative data to be related to each other, showing that the qualitative statements of the students enabled a more differentiated interpretation of the quantitative results. This provides a profounder understanding and explanation of the findings.

Comparison of students' experiences under three different coronavirus conditions

A special feature of the present study is that three semesters that differ significantly in terms of their underlying conditions are compared with one another in terms of the personal experiences of the music students. However, it must be clearly stated that this is a comparison of three cross-sectional surveys and not a longitudinal study.

The overall experience of the music students in the three semesters compared to the pre-coronavirus semesters showed that the lockdown semester was rated significantly better than the following semester with blended learning and even better than the semester with full face-to-face teaching. This may seem surprising at first glance, but can be understood and discussed in a more differentiated way based on the qualitative results.

The answers from the students can be summarized in four categories, which crystallize to form important points in the three semesters: Organization, Practice, Social Contact and Technical Aspects.

It is interesting that there is not one theme that stands out at all three points in time. Rather, for each of the three semesters, a different topic is at the forefront for the students, which can only be explained by their personal statements in relation to the respective social and university-related underlying conditions prevailing in each semester concerned.

The lockdown semester – SS 2020

During this semester two topics were at the forefront of the students' experiences: on the one hand they were challenged by social distancing, while on the other hand they had the chance to develop self-regulated learning techniques.

Even if the students suffered from social isolation during the lockdown semester and the music students in particular from the restrictions of one-to-one lessons, they also gained independence overall, saved time by eliminating the need to travel and experienced greater self-determination when practicing. The results of our study confirm the hypothesis of Habe et al. (2021) and Ozer and Ustun (2020) that music students gained constructive experiences during the lockdown. Therefore, we suspect that opportunities for music students also emerged, that can generate positive effects and create benefits, coming from the lockdown semester.

Schiavio et al. (2021) also found in their study of students at an Italian conservatory that distinct approaches to practicing and time management have emerged during the COVID-19 pandemic. Music students have developed more self-regulated practicing behaviors, resulting in a better understanding of their own learning and practicing (Antonini Philippe et al., 2020; Rosset et al., 2021).

Technical problems in the lockdown semester were also mentioned as disruptive in the present study. Students perceived the efforts in dealing with the new media and the commitment and attendance of the teachers as positive, especially in the lockdown semester, a finding that concurs with the research by Vladova et al. (2021).

The hybrid semester – WS 2020/21

The winter semester 2020/21 was characterized by the joy of the individual instrumental and vocal lessons taking place again, but also burdened by the still limited contact with other students. During this semester the question of how to deal with organizational requirements predominated due to the change between online and face-to-face classes. The students were also exposed to fundamental pressures, through strict societal restrictions (Stringency Index: Ritchie et al., 2020; Hale et al., 2021), which have led to additional challenges in the general population in Germany. Social isolation was still a topic for the students, but was not at the forefront of their minds anymore. As the students emphasize, switching between locations was complicated, and not always possible. It was complicated to coordinate online and face-to-face lessons. Even though students appreciated the opportunity to attend at least some courses in person, the hybrid format of the semester led to difficulties and confusion. Even more confusion was experienced by the constantly changing social and organizational conditions imposed from outside to which the University of Music Freiburg had to react in a regular manner.

Looking at all the students' comments, they report less self-determination. However, they state an improvement in the technology of online offerings. In agreement with Li et al. (2021), Rucsanda et al. (2021), as well as Güsewell and Terrien (2021), a variety of learning formats in blended learning were rated positively, provided that the organizational requirements were adequately handled. This appears to be an important finding for future teaching practice.

The mostly opened semester – SS 2021

During this semester students were focused on two topics: the resurgence of social contacts, as well as a better handling with digital communication formats. The 2021 summer semester was mainly characterized by the positive experience of social contacts in the large ensembles and orchestras that were taking place again, as well as meeting fellow students on a regular basis once again. This points to the importance of social contact as an integral part of university life and activity. Added to this was the increase in technological knowledge on the part of students. Practicing approached the pre-coronavirus levels again.

Practice time and behavior

As some studies have already discussed, *practice time* decreased during the lockdown semester. However, Nusseck and Spahn (2021) found that while music students spent less time practicing, some aspects of self-regulated learning increased. The students' statements confirm this observation, noting that "I developed more routines," and "I gained more awareness of my body and was able to practice in a more autonomous way." Another student told us that he found out "that I have to take breaks." Practicing during lockdown was also described as "more focused and concentrated."

The quantitative data show that the majority of the students rate their own practice time—always in relation to the previous semester—as constant. However, if one relates this answer to the stated practice time in hours, it becomes apparent that they did not spend the same amount of time practicing, but rather an increasing number of minutes per day.

While the average number of hours spent practicing in the summer semester 2020 was lower than in the previous semester, the number of hours spent practicing increased somewhat in the

winter semester 2020/21 and continued to increase until the summer semester 2021. If the students' quantitative statements are also taken into account, it can be concluded that although they spent significantly less time practicing during the lockdown semester, they did not notice this and expressed positive opinions about practicing. They were satisfied with the free time they had gained, were able to practice in a self-determined and self-regulated manner, yet also organized all their time themselves. The result was that the students achieved a degree of satisfaction with regard to their self-regulated time management, which they obviously did not have or did not know before in this form.

The self-regulated learning approach (Boekaerts, 1999; Hatfield et al., 2016; McPherson et al., 2017; Schunk and Greene, 2017) is characterized by students determining and monitoring the learning process themselves. The model is primarily based on motivation and the desire to learn. Self-regulated learning contains three different strategies: metacognitive, cognitive, and resource management-related (Boekaerts, 1999; Kopp and Mandl, 2011). Cognitive strategies are concerned with organizing, elaborating, reviewing and repeating what was learned. Metacognitive strategies are designed to guide, control, and regulate the use of appropriate learning strategies. Resource management strategies refer to aspects that can be directed both by the students themselves and by others. In the case of our study, the music students' resource management changed due to the coronavirus, which in turn caused them to reallocate and adapt their own resources to the new situation. According to Hatfield et al. (2016), and based on the students' personal statements, we found that students changed their practice behaviors during the lockdown, adapting them through new goal setting, as well as enhanced self-efficacy.

Practical implications for music education

The results of the cross-sectional study in three semesters with different framework conditions focus on different aspects that can play an important role in music education.

From our point of view, an important result is the confirmation that self-regulated learning can be promoted if music students have more time for self-organization. This complements the results of other studies with the aspect that self-determination can arise through less control and less goal-oriented specifications, without direct instruction for self-regulated learning. At the same time, our results make it clear that external structures can have a decisive influence on practice behavior. In the practical implementation in music education, the frequency of the individual lesson must be reflected precisely against this background. This is often stipulated in the assignment plan, regardless of the individual learning curve of the student. In a more flexible teaching setting, the frequency and duration of teaching could also be more individually regulated and adjusted.

With regard to the combination of courses in online and face-to-face formats, the important result was that new organizational aspects must be taken into account. Since there are not enough computer workstations for students at the University of Music, online formats are usually used by students at home. The transport time, which is necessary when changing between online lessons at the place of residence and face-to-face lessons at the University of Music, must be scheduled in the study plan.

Our results also give clear indications that social contacts during studies, both with teachers and with peers, are a central resource for the students' psychological well-being and their performance. While this finding is by no means new and confirms the role of social support in health, it may raise the question of whether face-to-face arts classes can be replaced by online formats. Our results provide arguments for the fact that face-to-face encounters between students cannot be replaced by online formats.

Limitations of the study

The study is based on a small sample, which, while representative for the University of Music Freiburg, has limitations in transferring to other universities.

Our questionnaire took place at three points in time that were very different, meaning that we were unable to collect the same number of answers for all three times. In particular, our third survey was answered by only a few students.

The design is cross-sectional, not longitudinal. This also has to be taken into account.

The experience rating scales have some methodological issues. The labeling only of the extremes (negative/positive) might have caused some misunderstanding. It would have been better to also label the neutral value in the middle with "equally experienced" to clarify the scale. Since the scale is a relative measure, it was not clear how the students would have responded without pandemic context to provide comparable ratings. It was assumed that the rating would be in the middle for similar semesters as it has been found for the SS 2021.

Conclusion

The semesters impacted by the coronavirus have given students new experiences that can be used in the future. Music students state that they have benefited from online formats outside of the one-to-one lessons. The technological knowledge on the part of students and teachers and their technical equipment have increased and improved, respectively, during the coronavirus semesters. When offering blended learning formats, university educators must take into account organizational aspects such as spatial distances, locations etc. As expected, the great importance of social contact between teachers and peers, and among peers, has been confirmed. At the same time, students show more self-regulatory behavior when they are less controlled by face-to-face formats. Both must be reconciled in the

future. The results of the present study show that the experiences of the students from the semesters during the coronavirus pandemic provide constructive starting points for future teaching.

Data availability statement

The raw data supporting the conclusions of this article will be available from the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. The authors declare that the data collection was conducted within the framework of the "Netzwerk Musikhochschulen," which conducts regular evaluations according to the standards of quality management.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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Validity and reliability of the Musicians' Health Literacy Questionnaire, MHL-Q19

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High prevalence of musicians' physical and mental performance-related health issues (PRHI) has been demonstrated over the last 30 years. To address this, health promotion strategies have been implemented at some post-secondary music institutions around the world, yet the high prevalence of PRHI has persisted. In 2018, an international group of researchers formed the Musicians' Health Literacy Consortium to determine how best to decrease PRHI, and to examine the relationship between PRHI and health literacy. An outcome of the Consortium was the development of a new health literacy tool for musicians, the MHL-Q19, which drew from the theoretical framework of the European health literacy suite of tools, HLS-EU. The aim of the current study was to evaluate the validity and reliability of the MHL-Q19. Participants completed a battery of questionnaires, including the HLS-EU-Q16 for the assessment of general health literacy; the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM); the RAND-12 quality of life questionnaire; and the General Self-Efficacy scale (GSE). We hypothesized that the MHL-Q19 would have a weak correlation with the HLS-EU-Q16; moderate correlation with the physical component scale and weak correlation with the mental component scale of the RAND-12; moderate correlation with the GSE; and finally, moderate correlation with pain interference and weak correlation with pain intensity of the MPIIQM. A total of 549 post-secondary music students from six English-speaking countries completed the battery of questionnaires, and 328 of these participants provided valid responses to the MHL-Q19 alone 2weeks later. The tool showed acceptable internal consistency and test–retest reliability. Three of our hypotheses were supported, although the strength of the correlations varied from what we had predicted. The fourth hypothesis was not supported; our findings indicate that lower health literacy scores were weakly related to higher MPIIQM pain intensity and interference scores. The results of this study support the notion that musicians' health literacy is a

distinct construct that cannot be fully evaluated with existing health literacy tools. Given that this is a new instrument, the evidence presented is positive and promising. Further studies will be needed to refine the tool.

KEYWORDS

health literacy, musicians' health, occupational health, validity, reliability, psychometrics

Introduction

Over 30 years of research has demonstrated that many musicians around the world experience significant performance-related physical and mental health conditions, including repetitive strain; peripheral neuropathy; depression; and generalized and performance anxiety (Fishbein et al., 1988; Zaza, 1998; Guptill et al., 2000; Bragge et al., 2006; Paarup et al., 2011; Ackermann et al., 2012, 2014; Kenny and Ackermann, 2015; Steinmetz et al., 2015; Baadjou et al., 2016; Kenny and Asher, 2017; Fernholz et al., 2019; Stanhope et al., 2019). Poor health-promoting behaviors have long been evident in musicians (Williamon and Thompson, 2006; Kreutz et al., 2008; Ginsborg et al., 2009; Kenny and Ackermann, 2016), and specific risk factors for musicians have been identified, both intrinsic and extrinsic, including social, organizational and cultural factors (Chan and Ackermann, 2014; Vaag et al., 2014; Araújo et al., 2017; Perkins et al., 2017; Waters, 2019, 2020). Health promotion strategies have been initiated, mainly in post-secondary music education programs, but health education is not always successful in changing musicians' health behaviors (Spahn et al., 2017; Baadjou et al., 2018; Matei et al., 2018; Norton, 2020; Baadjou et al., 2021).

The importance of health literacy for improving personal health behaviors and community health has been recognized by the World Health Organization (WHO) and in public health research (WHO, 1998; see also Nutbeam, 1998; Okan et al., 2019). Sørensen et al. (2012) define health literacy as follows: "Health literacy is linked to literacy and entails people's knowledge, motivation and competences to access, understand, appraise, and apply health information in order to make judgments and take decisions in everyday life concerning healthcare, disease prevention and health promotion to maintain or improve quality of life during the life course." (p.3). Research has increasingly recognized the importance of context and relational aspects in determining individuals' health literacy (McKenna et al., 2017; Geboers et al., 2018; Sørensen et al., 2021). Occupational health literacy models that account for the environmental and social determinants of health in workplaces have been developed (Rauscher and Myers, 2014; Jørgensen and Larsen, 2019), as have population-specific health literacy tools designed to address the variability of these contextual and relational aspects in different occupational settings (Shannon and Parker, 2020; Suthakorn et al., 2020).

In 2018, the Musicians Health Literacy Consortium (MHLC) was formed, bringing together a panel of international experts in musicians' health. Our intention was to provide a global perspective on how health education can address the persistence of performance-related health issues (PRHI) among musicians, and the role health literacy may play in influencing their health behaviors (Baadjou et al., 2019). An outcome of the MHLC collaboration was the development of an occupational health literacy tool specifically for musicians to measure their abilities to access, understand, appraise, and apply health information concerning their performance health, the Musicians' Health Literacy Questionnaire (MHL-Q19) (Wijsman et al., forthcoming).[1]

The aim of the current study was to evaluate the validity and reliability of the MHL-Q19 among post-secondary music students.

Materials and methods

The research team

The research team included tertiary music educators RL, BR-S, PV, SW and health professionals specializing in musicians' health, CG, VB, BA, all of whom, like JG, are academic researchers in musicians' health; a senior graduate student research coordinator with expertise in music education and musicians' health research, TS; and an academic researcher with expertise in applied measurement, MRR.

Developing the items

The MHL-Q19 was modeled on the theoretical framework and health literacy matrix of the European Health Literacy Survey, the HLS-EU-Q (Sørensen et al., 2012, 2013, 2015), designed to measure health literacy, in relation to general health, in European populations. The HLS-EU health literacy matrix outlines the interaction of four dimensions of health literacy (accessing, understanding, appraising and applying health information) with three domains of health (Healthcare, Disease Prevention and Health Promotion;

1 Wijsman, S., Baadjou, V., de Lisle, R., Ginsborg, J., Guptill, C., Rennie-Salonen, B., et al. Development of the Musicians' Health Literacy Questionnaire (MHL-Q19) (forthcoming).

Sørensen et al., 2012; Pelikan et al., 2019; see Figures 1, 2). These three domains can be further understood through their relationship with the four dimensions of health in the theoretical framework (Figure 1). In other words, the Healthcare domain can be understood as a person's ability to access, understand, appraise or interpret, and apply information relating to medical or clinical issues and advice. The Disease Prevention domain is concerned with accessing, understanding, appraising or interpreting, and applying information on risk factors for health. Finally, the Health Promotion domain is concerned with accessing, understanding, appraising and applying information related to determinants of health (Sørensen et al., 2012).

The HLS-EU-Q framework was chosen as a model, first, because it incorporates the assessment of health literacy competencies discussed in the published research literature on musicians' health behaviors that the team deemed essential to musicians' health literacy: decision-making, evaluation, responsibility, and self-efficacy (Daykin, 2005; Williamon and Thompson, 2006; Kreutz et al., 2008; Ginsborg et al., 2009; Araújo et al., 2017). Second, the HLS-EU-Q was designed for multi-lingual administration; therefore, deriving items for the MHL-Q19 from the HLS-EU-Q enhances the ability to adapt our new tool for different cultures, which is desirable in a tool designed for use with the global population of musicians.

	Access/obtain information relevant to health	Understand information relevant to health	Appraise/process information relevant to health	Apply/use information relevant to health
Healthcare (HLS-EU-Q)	Ability to access information on medical or clinical issues	Ability to understand medical information and derive meaning	Ability to interpret and evaluate medical information	Ability to make informed decisions on medical issues
Healthcare (MHL-Q19)	Find information about musicians' health issues	Understand the information you obtain about musicians' health issues and what it means for you	Interpret and evaluate the quality of the information you obtain about musicians' health	Make informed decisions about your own health as a musician
Disease prevention (HLS-EU-Q)	Ability to access information on risk factors for health	Ability to understand information on risk factors and derive meaning	Ability to interpret and evaluate information on risk factors for health	Ability to make informed decisions on risk factors for health
Disease prevention (MHL-Q19)	Access information on risk factors for musicians' health	Understand the information you obtain about risk factors for musicians' health and what it means for you	Interpret and evaluate the quality of the information you obtain about risks to musicians' health	Make informed decisions about risk factors you may face as a musician
Health promotion (HLS-EU-Q)	Ability to update oneself on determinants of health in the social and physical environment	Ability to understand information on determinants of health in the social and physical environment and derive meaning	Ability to interpret and evaluate information on health determinants in the social and physical environment	Ability to make informed decisions on health determinants in the social and physical environment
Health promotion (MHL-Q19)	Obtain new information on musicians' health and risk factors	Understand the wider social, educational and environmental determinants of health for musicians and what it means for you	Interpret and evaluate the wider social, educational and environmental determinants of health for musicians	Make informed decision about the wider social, educational and environmental determinants of health for musicians

FIGURE 1
Four dimensions of health literacy across three domains of health: original HLS-EU health literacy matrix (Sørensen et al., 2012; used with permission) and adapted MHL-Q19 matrix (Wijsman et al., forthcoming; see footnote 1).

HLS-EU-Q matrix domain	MHL-Q19 item	On a scale from very easy to very difficult how easy would you say it is to:
HP	1	Find information about healthy performance habits?
HP	2	Find reliable advice for your performance health?
HP	3	Understand how your physical environment contributes to performance health?
HP	4	Understand how your social environment contributes to performance health?
HP	5	Judge how performing affects your health?
HC	6	Judge if information about performance health is reliable?
HC	7	Judge how performance health information applies to you?
HP	8	Make informed decisions to establish and maintain performance health?
DP	9	Find out about risks to your performance health?
DP	10	Understand information about risks to your performance health?
DP	11	Judge which risks relate to your performance health?
DP	12	Decide how to prevent performance health issues?
HC	13	Understand information about healthcare for musicians?
HC	14	Judge when to seek help if you have performance health issues?
HC	15	Judge where to seek help if you have performance health issues?
HC	16	Find treatment for your performance health issues?
HC	17	Judge the advantages and disadvantages of different treatment options for performance health issues?
HC	18	Understand treatment advice if you have performance health issues?
HC	19	Follow treatment advice if you have performance health issues?

Key: HC = Healthcare, HP = Health promotion, DP = Disease prevention

FIGURE 2
Questions from the Musicians' Health Literacy Questionnaire, MHL-Q19, and their corresponding HLS-EU-Q matrix domains.

The MHLC undertook a consensus development process over a 6-month period, adapting the wording of the subscales of HLS-EU matrix to make it more suitable for the musician population, and generating 19 musician-specific items based on questions in the HLS-EU-Q47 (Wijsman et al., forthcoming; see footnote 1). Items specific to musicians' performance-related health were modeled on questions in the HLS-EU-Q, avoiding the use of medical terminology and focusing on context-specific aspects of musicians' health literacy. In addition, questions were worded to be inclusive of singers (in future; the current sample consisted of instrumental musicians only); to be inclusive of all musical genres; and to be easily translated into other languages. For example, Question 17 of the HLS-EU-Q47 reads: "On a scale from very easy to very difficult, how easy would you say it is to: find information about how to manage unhealthy behavior such as smoking, low physical activity and drinking too much?" Question 1 of the MHL-Q19 frames this in terms of musician-specific health concerns, asking: "On a scale from very easy to very difficult, how easy would you say it is to: find information about healthy performance habits?" (Wijsman et al., forthcoming; see footnote 1).

Face validity

The preliminary version of the tool was distributed to a stakeholder network developed by the lead author. This group was comprised of 12 field experts, including administrators of music programs at three Canadian post-secondary institutions; senior leaders of five national-and provincial-level music organizations; one healthcare practitioner specializing in musicians' health; and three musicians' health researchers. These experts assessed the face validity of the questionnaire items and gave open-ended feedback on the content of the tool *via* email and during a teleconference, as described in Wijsman et al. (forthcoming; see footnote 1). Based on the generally positive feedback from the stakeholder network, no changes were made to the tool at this stage.

Construct validity

To assess the construct validity of the new MHL-Q19, we administered it along with four additional validated questionnaires assessing relevant constructs. We also sought

to determine whether there were, indeed, elements of health literacy for musicians that were not sufficiently addressed by the other questionnaire tools. The tools employed were as follows:

a. The HLS-EU-Q16 (a shorter form of the HLS-EU-Q47) is a short-form assessment of general health literacy (Pelikan and Ganahl, 2017). This tool consists of 16 questions. The overarching question is: "On a scale from very easy to very difficult, how easy would you say it is to:" with possible answers of *very easy*, *easy*, *difficult*, *very difficult*, and *don't know*. *Very easy* and *easy* responses are assigned a score of 1, and *difficult* and *very difficult* are assigned a score of 0. *Don't know* is scored as missing data. Total scores of 0–8 are defined as representing inadequate health literacy, 9–12 problematic, and 13–16 adequate. The tool takes about 3 min to complete. Concurrent validity was confirmed by correlations of 76% with the HLS-EU-Q47 and the Newest Vital Sign test (Pelikan and Ganahl, 2017; Bas-Sarmiento et al., 2020). It also demonstrates high internal consistency (Bas-Sarmiento et al., 2020). Reliability was reported to be high in several studies in which the tool was translated into other languages (Bas-Sarmiento et al., 2020; Niedorys et al., 2020; Nolasco et al., 2020).
b. The Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM; Berque, 2014; Berque et al., 2014; Schmidt, 2017) is one of two validated tools purporting to measure musculoskeletal pain in musicians, the other being the Musculoskeletal Pain Questionnaire for Musicians (MPQM; Lamontagne and Bélanger, 2012). This questionnaire asks participants to map the location of symptoms of playing-related musculoskeletal disorders (based on a definition related to that developed by Zaza (1998). Participants use a Likert-type scale to answer a series of questions aiming to determine their level of pain and the degree to which it interferes with their ability to play music at the level to which they are accustomed. We chose the MPIIQM because, at the time that this study was first proposed, the MPQM had only been validated in French on a sample of 31 professional musicians. The MPIIQM validation, by comparison, was conducted with a sample of 37 musicians in English. The two-factor structure (pain intensity and pain interference) was supported by confirmatory factor analysis. The tool had high internal consistency and good test–retest reliability (Berque, 2014).
c. The RAND-12 (Johnson and Maddigan, 2004; Cheak-Zamora et al., 2009) is equivalent to the SF-12, derived from the 116-item Medical Outcomes Study designed to measure physical and mental quality of life (QOL). Both tools have been used for decades in health research around the world and have been shown to have good reliability and validity in adults with musculoskeletal (Mani et al., 2017) and chronic health conditions (Johnson and Maddigan, 2004), and mental illness (Huo et al., 2018). Two summary scores can be calculated using these tools: the physical component score (PCS) and the mental component score (MCS). Unlike the SF-12, the RAND-12 does not require a license or the use of the proprietary scoring algorithm, which assumes that the PCS and MCS are unrelated. Instead, we employed the algorithm developed by Johnson and Maddigan (2004) for use in research on individuals with chronic health conditions.
d. The General Self-Efficacy (GSE) scale (Schwarzer and Jerusalem, 1995; Schwarzer, 2014) was selected because the literature indicates that health literacy and self-efficacy are related (Xu et al., 2018; Beasley et al., 2020; Wayment et al., 2020). In addition, we chose a measure of general self-efficacy rather than specific music-related self-efficacy, as we felt that such an item would be more related to efficacy in music performance activities, and less related to health literacy. The GSE was first developed in 1979, and the current version was reduced to 10 items in 1981 (the version used in this study; Schwarzer and Jerusalem, 1995). While information does not appear to be available for psychometrics of this tool in its initial development, subsequent studies have established that the GSE has high internal consistency ($\alpha = 0.86$; Scholz et al., 2002) and good test–retest reliability (ranging from 0.47 to 0.75 in studies cited by Scholz et al., 2002). With respect to validity, the tool performed as expected in relation to Bandura's theory of behavior change (1997), correlating positively with self-esteem and optimism, and negatively with anxiety, depression and physical symptoms, as would be expected (Schwarzer and Born, 1997; Schwarzer et al., 1999). Finally, the scale was demonstrated to be unidimensional, supporting its use as a single measure of general self-efficacy.

We hypothesized that these constructs would be related to musicians' health literacy and, therefore, that scores on the MHL-Q19 would be positively correlated with those on the four questionnaires. Our hypotheses were as follows:

1. There would be a weak correlation between MHL-Q19 and HLS-EU-Q16 scores because the MHL-Q19 is designed to measure context-specific health literacy in musicians related to their performance-related health, using questions that are similar to those in the HLS-EU-Q47 from which the HLS-EU-Q16 is derived, but that capture a more specific subset of health literacy concerns not addressed in the general health literacy questionnaire (please see Methods – Developing the Items);
2. There would be a moderate correlation between MHL-Q19 and MPIIQM pain interference scores but a weak correlation between MHL-Q19 and MPIIQM pain intensity scores. While there is insufficient evidence about the relationship between health literacy and pain intensity and interference, in the research team's expert opinion, informed by combined clinical, pedagogical and applied research experience, musicians whose symptoms interfere with performance are more motivated to seek care; thus, we postulated that they would also be more motivated to seek information, thereby increasing their music performance-specific health literacy;

3. There would be a moderate correlation between total MHL-Q19 scores and the physical component scores, and a weak correlation between MHL-Q19 scores and mental component scores of the RAND-12. This is because the research literature suggests (Douglas, 2019) that information about physical health is more accessible to music students than information about mental health;
4. There would be a moderate correlation between MHL-Q19 and GSE scores because the literature has demonstrated a relationship between health literacy and self-efficacy (Xu et al., 2018; Beasley et al., 2020; Wayment et al., 2020).

Participants and recruitment

The MHLC panel agreed with other researchers that post-secondary training is an ideal time to deliver health promotion and injury prevention education (Chesky et al., 2006; Ginsborg et al., 2012; Norton, 2016; Salonen, 2018), because music students are at significant risk of PRHI, are highly engaged in educational activities, and are motivated to take actions to safeguard their future careers as musicians. Therefore, this initial validation study was completed with post-secondary music students from 13 institutions worldwide. We excluded singers from the sample, because the MPIIQM has only been validated with instrumental musicians. All recruitment was conducted electronically, by email to students directly and through social media using avenues frequented by post-secondary music students.

To calculate the required sample size, we looked at the total number of music students from available data: in the US, 332,297 post-secondary students in 2011, or ~0.1% of the current US population (College Music Society, 2015), and in Australia, 3,500 students in 2011, or ~0.01% of the current Australian population (Global Access Partners, 2011). We used 0.05% as the estimated percentage of the population in the other countries where data were collected (Canada, New Zealand, South Africa and the United Kingdom), for a total of 421,297 students. The estimated sample size required to achieve 95% confidence with 5% margin of error is 384 students (Qualtrics sample size calculator, https://www.qualtrics.com/blog/calculating-sample-size/).

A total of 549 post-secondary music students completed the battery of questionnaires, including participants from Canada ($n = 253$), the United States ($n = 138$), South Africa ($n = 43$), Australia ($n = 57$), New Zealand ($n = 31$), and the United Kingdom ($n = 27$). See Table 1 for a summary of the demographic characteristics of this sample. Participants were largely in the early-20s age bracket, which was only slightly above our minimum age of inclusion in the research (18 years old). For this reason, the age data were not normally distributed and the measure of central tendency for this variable in Table 1 is expressed as median (interquartile range). The majority of the students at these schools were at the Bachelor's level, and studying Western art (classical) music, although some were also in contemporary or jazz programs. Students could be studying in any musical discipline (e.g., performance, composition and theory).

TABLE 1 Demographics.

		All participants ($N = 549$)	Only those included in factor analysis ($n = 439$)	Only those included in reliability analysis ($n = 328$)
Age		21.00 (4.00)	21.00 (4.00)	21.00 (4.00)
Gender	Female	359 (65.4%)	282 (64.2%)	208 (63.4%)
	Male	178 (32.4%)	146 (33.3%)	110 (33.5%)
	Trans female	2 (0.4%)	2 (0.5%)	2 (0.6%)
	Non-binary	6 (1.1%)	6 (1.4%)	5 (1.5%)
	Missing	4 (0.7%)	3 (0.7%)	3 (0.9%)
Country	Australia	57 (10.4%)	43 (9.8%)	28 (8.5%)
	Canada	253 (46.1%)	200 (45.6%)	164 (50.0%)
	New Zealand	31 (5.6%)	24 (5.5%)	12 (3.7%)
	South Africa	43 (7.8%)	32 (7.3%)	19 (5.8%)
	United Kingdom	27 (4.9%)	24 (5.5%)	17 (5.2%)
	United States of America	138 (25.1%)	116 (26.4%)	88 (26.8%)
Instrument	Brass	108 (19.7%)	97 (22.1%)	72 (22.0%)
	Woodwind	115 (20.9%)	93 (21.2%)	71 (21.6%)
	Percussion	24 (4.4%)	18 (4.1%)	13 (4.0%)
	Upper Strings	86 (15.7%)	79 (18.0%)	61 (18.6%)
	Lower Strings	33 (6.0%)	31 (7.1%)	24 (7.3%)
	Keyboard	115 (20.9%)	98 (22.3%)	68 (20.7%)
	Voice	41 (7.5%)		
	Plucked Strings	21 (3.8%)	18 (4.1%)	15 (4.6%)
	Other	4 (0.7%)	4 (0.9%)	3 (0.9%)
	Missing	2 (0.4%)	1 (0.2%)	1 (0.3%)
Degree Program	Bachelor/ undergraduate level	261 (47.5%)	216 (49.2%)	157 (47.9%)
	Masters	39 (7.1%)	32 (7.3%)	25 (7.6%)
	Doctoral/ post-doctoral	3 (0.5%)	3 (0.7%)	3 (0.9%)
	Diploma or certificate program	6 (1.1%)	3 (0.7%)	2 (0.6%)
	Missing	240 (43.7%)	185 (42.1%)	141 (43.0%)

As described in the text, these data were not normally distributed. The measure of central tendency for this variable is therefore expressed as median (interquartile range).

To ensure that data from different nations could be compared to each other, we conducted a test equivalence analysis (Abubakar et al., 2013). Cronbach's alpha was acceptable in all countries involved in the study, with the highest alpha levels among Australia (0.915), Canada (0.932), and the United States (0.917), and only slightly lower levels among New Zealand (0.809), South Africa (0.872), and the United Kingdom (0.893). These

findings demonstrate that there are no important differences between the responses of participants from different nations.

Procedure

Research procedures were reviewed and approved by the Office of Research Ethics and Integrity at the University of Alberta, which was the institutional affiliation of the first author when the study began, as well as the local research ethics board at each of the universities from which participants were recruited. Recruitment emails and social media materials included a link to the complete survey, including the MHL-Q19 and additional four questionnaires, hosted online using the Qualtrics platform.[2] When they had completed the survey, participants could provide their email address for follow-up to assess test–retest reliability. Those who provided their email addresses were sent a new link to a survey consisting only of the MHL-Q19, which took ~5 min to complete. Participants who completed the second survey were offered a gift card for $5 Canadian or a similar value in a local currency. In the majority of cases, the gift cards were digital and two options were offered (e.g., Starbucks and Amazon). Local contacts were consulted as to the appropriateness of the incentives at each site, and if electronic gift cards were not available, arrangements were made with a suitable vendor to distribute gift cards to participants in accordance with the policies of the local research ethics board.

The second survey (MHL-Q19 only) was sent ~2 weeks after participants had responded to the first survey. This is consistent with the relevant literature (Nunnally and Bernstein, 1994; Marx et al., 2003; Bardhoshi and Erford, 2017).

Data analysis plan

Data were cleaned and collated. Frequencies, distribution of data and ranges of scores were calculated. Frequencies of missing items per question were evaluated. Non-parametric statistical tests were used where normality of data distribution was not evident. Normality of data was assessed by inspecting histograms, skewness, and kurtosis statistics. Responses of *don't know* on the MHL-Q19 were considered missing data and, where there were more than 20% missing responses for any participant, that participant's responses were deemed invalid. We did not identify any outliers. We conducted an inter-item correlation analysis of responses to the MHL-Q19 to assess potential relationships between items. Internal consistency was evaluated by calculating Cronbach's alpha. Values of Cronbach's α between 0.70 and 0.95 are considered good (Terwee et al., 2007).

In regard to construct validity, correlation testing was applied to calculate correlations between the scores on the different questionnaires. A correlation lower than 0.30 was considered weak, 0.30–0.60 moderate, and higher than 0.60 as strong (Terwee et al., 2007). As responses in the MHL-Q19 are scored using a Likert-style scale, the data were considered ordinal and nonparametric correlation statistics (Spearman *rho*) were used for hypothesis testing.

Data analyses were conducted using Statistical Package for Social Sciences (IBM SPSS) 28.0.0.0.

Results

Preliminary analysis

Data were cleaned and checked for missing values. As with previous HLS-EU tools assessing health literacy, any response of *don't know* was considered a missing value. The responses *very easy*, *easy*, *difficult* and *very difficult* were considered valid responses. Participants who gave fewer than 80% valid responses across the whole survey were excluded from analysis, in line with previous tool development research in health literacy (Pelikan et al., 2019). A total of 73 participants who responded to the first survey were excluded from the factor analysis for this reason, leaving 439. A total of 37 participants who responded to the second survey were excluded for the same reason, and 126 participants did not complete the follow-up survey. Valid responses to both the first and second surveys were provided by 350 participants, of whom 22 were eliminated because they reported voice as their primary instrument. As shown in Table 1, this left 328 valid responses for the test–retest reliability analysis.

Table 2 shows descriptive statistics for responses to the MHL-Q19 included in the factor analysis and hypothesis testing (column 2). A slight floor effect was evident for responses to Questions 13–17, with 17%–25% of responses in the lowest scale option. At the second administration, only questions 15 and 16 demonstrated this floor effect. Frequencies of responses to each of the questions in the MHL-Q19 are provided as Supplementary material.

We also conducted an inter-item correlation analysis of MHL-Q19 responses to assess potential relationships between items. Inter-item correlation was moderate, other than for Question 19, which was weakly correlated with 14 of the 18 other items ($r < 0.3$, $p < 0.001$).

Exploratory factor analysis

As described above, the items comprising the MHL-Q19 were developed using an adapted version of the HLS-EU Health Literacy Matrix (Figures 1, 2). This matrix provided a number of theoretically sound options for a factor solution for the present data. For this reason, Exploratory Factor Analysis was selected as the best choice of analysis for dimension reduction.

2 www.qualtrics.com

TABLE 2 Descriptive statistics of responses by scale item.

	Time 1						Time 2					
	N	Missing values	Mean (SD)	Median (IQR)	Skewness	Kurtosis	N	Missing values	Mean (SD)	Median (IQR)	Skewness	Kurtosis
Question 1	426	13	2.62 (0.679)	3 (1)	0.229	−0.398	353	9	2.6 (0.712)	3 (1)	0.272	−0.425
Question 2	428	11	2.41 (0.714)	2 (1)	0.49	−0.019	356	6	2.4 (0.679)	2 (1)	0.594	0.117
Question 3	428	11	2.45 (0.774)	2 (1)	0.332	−0.305	360	2	2.58 (0.735)	3 (1)	0.268	−0.41
Question 4	427	12	2.48 (0.845)	2 (1)	0.042	−0.59	357	5	2.57 (0.807)	3 (1)	−0.031	−0.478
Question 5	429	10	2.47 (0.789)	2 (1)	0.14	−0.405	357	5	2.51 (0.752)	2 (1)	0.196	−0.337
Question 6	418	21	2.24 (0.772)	2 (1)	0.308	−0.177	353	9	2.31 (0.756)	2 (1)	0.182	−0.255
Question 7	430	9	2.54 (0.806)	3 (1)	0.032	−0.485	360	2	2.54 (0.726)	3 (1)	−0.024	−0.266
Question 8	433	6	2.41 (0.731)	2 (1)	0.178	−0.213	360	2	2.47 (0.687)	2 (1)	0.524	−0.121
Question 9	432	7	2.42 (0.752)	2 (1)	0.081	−0.308	356	6	2.43 (0.711)	2 (1)	0.202	−0.17
Question 10	430	9	2.65 (0.733)	3 (1)	−0.088	−0.267	356	6	2.74 (0.702)	3 (1)	−0.129	−0.17
Question 11	428	11	2.52 (0.738)	3 (1)	0.007	−0.297	359	3	2.56 (0.714)	3 (1)	0.126	−0.298
Question 12	435	4	2.29 (0.769)	2 (1)	0.379	−0.087	357	5	2.37 (0.728)	2 (1)	0.185	0.065
Question 13	422	17	2.31 (0.835)	2 (1)	0.04	−0.659	357	5	2.49 (0.785)	3 (1)	−0.125	−0.416
Question 14	431	8	2.18 (0.885)	2 (1)	0.376	−0.558	357	5	2.28 (0.769)	2 (1)	0.363	−0.101
Question 15	433	6	2.12 (0.858)	2 (2)	0.298	−0.654	351	11	2.2 (0.803)	2 (1)	0.33	−0.283
Question 16	430	9	2.08 (0.854)	2 (2)	0.448	−0.415	345	17	2.17 (0.741)	2 (1)	0.276	−0.13
Question 17	420	19	2.06 (0.758)	2 (0)	0.467	0.076	345	17	2.19 (0.699)	2 (1)	0.293	0.088
Question 18	415	24	2.66 (0.73)	3 (1)	−0.353	−0.027	346	16	2.83 (0.684)	3 (1)	−0.42	0.396
Question 19	413	26	2.61 (0.776)	3 (1)	0.02	−0.437	344	18	2.78 (0.762)	3 (1)	−0.161	−0.358

Principal axis factoring was conducted on the 19 items, using oblique rotation (direct oblimin). Oblique factor rotation was used because it would be theoretically coherent to assume that factors of health literacy are related to one another (Sørensen et al., 2012). The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis (KMO = 0.91) and all KMO values for individual items were >0.857, indicating that the sample size was sufficiently large for the factor analysis. Initial analysis found four factors with eigenvalues >1. However, the mean communality was 0.456, suggesting that Kaiser's criterion of extracting factors with eigenvalues >1 may be inappropriate. The scree plot was ambiguous, with grounds for extracting one, two, or three factors. Ultimately, we chose to retain three factors because of the convergence of support from the inflection of the scree plot and the theoretical congruence of the factors extracted.

This initial solution gave us three factors that were congruent with the theoretical foundation of the tool, in that they correspond roughly to the horizontal axis of the HLS-EU Health Literacy matrix displayed in Figure 1. The pattern matrix for this solution is displayed in Table 3 and the correlation between the factors is shown in Table 4.

Naming the factors

The factors extracted were largely in line with the theoretical constructs of Health Promotion, Disease Prevention, and Healthcare from the HLS-EU Health Literacy matrix. Closer examination of the factor loadings for each question revealed a slightly different pattern in our findings than in the design of the questionnaire. Question 18 ("Understand treatment advice if you have performance health issues") and Questions 19 ("Follow treatment advice if you have performance health issues") were notable in that they both loaded onto a factor with the Disease Prevention items, rather than with Healthcare as we had anticipated when developing these items.

Hypothesis testing

We tested our hypotheses using summary scores for each of the subscales of the MHL-Q19 determined by the factor analysis. Table 5 shows the correlations between scores for each of the subscales of the MHL-Q19 and for the other four comparator tools. The data were ordinal, so Spearman's *rho* was used as the correlation statistic. We also conducted the hypothesis testing using an overall summary score for the MHL-Q19, and this scoring structure was likewise supported by our factor analysis.

> *Hypothesis 1*: was supported in that scores on the MHL-Q19 and HLS-EU-16 were significantly moderately (rather than weakly) correlated.
>
> *Hypothesis 2*: was not supported in that scores on the MHL-Q19 were weakly but significantly negatively correlated with scores for both MPIIQM pain interference

TABLE 3 Pattern matrix.

	Factor		
	Risk to performance health (Disease prevention)	Healthcare	Health promotion
10. Understand information about risks to your performance health	0.823		
11. Judge which risks relate to your performance health	0.758		
8. Make informed decisions to optimize your performance health	0.598		
9. Find out about risks to your performance health	0.55		
18. Understand treatment advice if you have performance health issues	0.534	0.358	
7. Judge how performance health information applies to you	0.506		
13. Understand information about healthcare for musicians	0.387		
12. Decide how to prevent performance health issues	0.371		
19. Follow treatment advice if you have performance health issues	0.334		
16. Find treatment if you have performance health issues		0.863	
15. Judge where to seek help if you have performance health issues		0.806	
17. Judge the advantages and disadvantages of different treatment options for performance health issues		0.569	
14. Judge when to seek help if you have performance health issues		0.568	
3. Understand how your physical environment contributes to performance health			0.797
4. Understand how your social environment contributes to performance health			0.654
5. Judge how performing affects your health			0.505
2. Find reliable advice for your performance health			0.473
6. Judge if information about performance health is reliable	0.309		0.397
1. Find information about healthy performance habits			0.381

Extraction Method: Principal Axis Factoring. Rotation Method: Oblimin with Kaiser Normalization. b. Rotation converged in 15 iterations.

and intensity; we had predicted a moderate positive correlation with the former, and a weak positive correlation with the latter.

Hypothesis 3: was partially supported in that scores on the MHL-Q19 were weakly positively correlated with both the physical and mental component scores of the RAND-12; we had predicted a stronger correlation with the former than the latter.

Hypothesis 4: was partially supported in that scores on the MHL-Q19 were weakly but significantly correlated with scores on the GSE; we had predicted a moderate correlation between them, on the basis of the previous literature reporting a relationship between health literacy and self-efficacy.

Reliability

Each subscale demonstrated high reliability using Cronbach's alpha (Health Promotion, $\alpha = 0.802$; Risks to Performance Health, $\alpha = 0.854$, Healthcare, $\alpha = 0.826$). When the same analyses were run using the whole scale, Question 19 demonstrated a corrected item-total correlation ($r = 0.408$, $p < 0.01$) that was considerably lower than the other items (r values between 0.503 and 0.67). Cronbach's alpha for the entire scale was also high ($\alpha = 0.919$).

TABLE 4 Correlations among factors.

	Risk to performance health	Healthcare	Health promotion
Risk to performance health	–		
Healthcare	0.536	–	
Health promotion	0.585	0.372	–

Each of the subscale scores were moderately and significantly correlated between the first and second administrations of the new tool. Health Promotion ($rho = 0.651$, $p > 0.001$), Risks to Performance Health ($rho = 0.692$, $p < 0.001$), and Healthcare ($rho = 0.629$, $p > 0.001$) all demonstrated acceptable levels of test–retest reliability. Test–retest reliability of an overall summary score was higher ($rho = 0.779$, $p > 0.001$).

Discussion

This is the first study evaluating the validity and reliability of a new instrument for measuring musicians' health literacy. The findings support the need for the development of such a tool and show promising psychometric features with great potential for measuring this construct. Some variation in Cronbach's alpha levels was present across the countries where participants lived; however,

TABLE 5 Hypothesis testing.

	Performance health			Risks			Issues			All		
	rho	*p*	CI (95%)	*rho*	*p*	CI (95%)	*rho*	*p*	CI (95%)	*rho*	*p*	CI (95%)
HLS-EU-Q16	0.37	<0.001	[0.28, 0.46]	0.50	<0.001	[0.42, 0.57]	0.45	<0.001	[0.37, 0.53]	0.54	<0.001	[0.46, 0.61]
MPIIQM												
Interference	−0.16	0.038	[−0.32, −0.00]	−0.16	0.042	[−0.31, 0.00]	−0.15	0.067	[−0.30, 0.02]	−0.20	0.013	[−0.35, −0.04]
Intensity	−0.10	0.215	[−0.26, 0.06]	−0.16	0.051	[−0.31, 0.01]	−0.14	0.082	[−0.29, 0.02]	−0.16	0.045	[−0.31, 0.00]
RAND												
Physical	0.08	0.114	[−0.02, 0.17]	0.23	<0.001	[0.14, 0.32]	0.17	<0.001	[0.08, 0.26]	0.21	<0.001	[0.12, 0.30]
Mental	0.18	<0.001	[0.09, 0.27]	0.26	<0.001	[0.16, 0.34]	0.24	<0.001	[0.15, 0.33]	0.29	<0.001	[0.19, 0.37]
GSE	0.17	<0.001	[0.07, 0.26]	0.19	<0.001	[0.10, 0.29]	0.20	<0.001	[0.10, 0.29]	0.22	<0.001	[0.12, 0.31]

in some countries multiple schools participated in the study, and participation varied between schools. However, these small differences in Cronbach's alpha do suggest a need for future research to assess the validity of the tool in different geographical and/or cultural settings.

With respect to construct validity, some of our findings were consistent with our hypotheses, while others were not. Responses to the HLS-EU-Q16 were moderately correlated with their responses to the MHL-Q19, while we had predicted a weak correlation. This indicates that musicians' health literacy and general health literacy are related constructs; however, the overlap between the two is not strong. This finding further justifies the need for this musician-specific health literacy assessment tool as argued by Wijsman et al. (forthcoming; see footnote 1).

Responses to the GSE were less strongly correlated with responses to the MHL-Q19 than we had predicted. As described in the Introduction, the research literature suggests that health literacy and self-efficacy are related constructs. However, these conclusions have been drawn from research using tools that are designed to measure general health literacy in large populations. Our results, by contrast, indicate that self-efficacy is less important in determining post-secondary music students' ability to access, understand, appraise, and apply health information related to music performance. This might suggest that other factors may have more influence on music students' health literacy, and setting the expectation that they will take responsibility for their own health and well-being may be unfounded.

While we had predicted a stronger correlation between the RAND 12 physical component scores and MHL-Q19 scores than between the mental component scores and MHL-Q19 scores, correlations between both physical and mental health component scores and the MHL-Q19 scores were weak. This suggests that music students' health literacy is weakly related to, but not entirely predicted by, their individual health status alone.

Our results did not support the hypothesis that participants scoring higher on the MPIIQM for pain and its interference with performance would also score higher for musicians' health literacy. While the correlation was relatively weak, these participants in fact scored lower on the MHL-Q19. In other words, lower health literacy in these student musicians was associated with more pain and interference symptoms. It is possible that students who have – and possibly struggled with – performance-related health issues, may have worse health outcomes, and therefore, less confidence in being able to cope with these issues, leading to lower health literacy scores. However, research has also shown that music students do not always consider PRHIs to be health issues (Guptill et al., 2000; Waters, 2019, 2020). Therefore, when they are faced with PHRIs, they may not try to access health information at all, nor consult healthcare professionals or identify health resources to assist them in addressing these concerns. The relationship between lower scores on the MHL-Q19 and higher scores on the MPIIQM therefore may reflect a lower level of health literacy in these music students, specifically in relation to their occupational health. It is also possible that lower health literacy may lead to more PRHIs, a primary rationale for the development of the MHL-Q19 (Wijsman et al., forthcoming; see footnote 1). The relationship between pain intensity/interference and musicians' health literacy appears to be complex and could prove to be an important focus of future research on musicians' health.

Figure 2 shows the questions from the MHL-Q19 and their corresponding domains from the adapted matrix created during the development of this new measurement tool. Comparing this figure with Table 3, it can be seen that the results of the factor analysis are a good but not perfect fit with the theoretical design of our questionnaire. As indicated above, Q18 and Q19 mapped onto domains that were not those we had intended when we created the tool. As a result, the construct represented by this domain, which was called Disease Prevention in the HLS-EU tools, might not represent the way participants in our survey understood these particular items. Based on the grouping provided by their responses, we have proposed a new name for this domain: Risk to Performance Health. Further evaluation of the tool could include using methods such as cognitive interviews (Willis and Artino, 2013; Willis, 2018), which ask participants to complete questionnaires while describing their thought processes as they complete the tool. Such evaluation may shed more light on how musicians relate questions in these three domains to one another.

While the internal consistency of the MHL-Q19 is high, its test–retest reliability was somewhat lower than we would have expected. Streiner et al. (2008) suggest three possible explanations

for low test–retest reliability: 1. The scale itself is unreliable; 2. The construct changes over time; or 3. The participants' perception of the construct is changed by filling out the questionnaire. The latter explanation is the most likely. In retrospect, the majority of the institutions from which we recruited participants were those with which we had previous relationships, or where we had contacts; and these institutions were more likely to be sympathetic to the need for health promotion and injury prevention education, or indeed, already offered some health education to their students. It is possible, therefore, that participants were, in fact, learning about health promotion and injury prevention over the course of the 2 weeks between the first and second administration of the MHL-Q19. It is also possible that their health literacy was quite low to begin with, and that completing the questionnaire caused them to consider these issues for the first time or to take them more seriously, and thus, this changed the construct for them. For example, some of the Health Promotion items asked participants to consider what they would do if they had a PRHI. After having been prompted to consider this possibility, their awareness and confidence in accessing, understanding, appraising and applying information related to PRHI may have increased. If this is indeed the case, it would suggest that initial interventions that were focused on raising awareness of PRHI and health literacy might have an impact. However, we cannot rule out the possibility that the wording of the questions led to lower test–retest reliability. Given that the wording of MHL-Q19 items was chosen to be simple and relatable for musicians, and to resemble the items in the well-established HLS-EU-Q tools that have been used in many countries around the world (Wijsman et al., forthcoming; see footnote 1), we think that this is unlikely.

During the factor analysis, Questions 6 and 18 were found to load onto more than one factor. In addition, as mentioned above, Questions 18 and 19 loaded onto factors that were not the ones we initially assigned to them during the design of the questionnaire, namely Disease Prevention (Risks to Performance Health) rather than Healthcare. This caused us to reflect on the questions themselves. Questions 18 and 19 would be difficult for participants to answer if they had never experienced a PRHI, and both questions also introduce an "if," thereby requiring the respondent first to decide if they had had a PRHI, and second to decide how difficult it would be to understand or follow treatment advice they might not have received. The loading of Questions 18 and 19 onto Risks to Performance Health factor rather than Healthcare suggest that our thinking as developers when we designed these items might be somewhat different than that of participants when answering these questions. Future research employing cognitive interviews with participants about their thought processes as they complete the questionnaire, as described previously, could also help us to change the wording of the questions so that participants' responses are better aligned with our intended outcomes.

Overall, the psychometric properties of this new tool are promising. We anticipate that this tool could be used by healthcare professionals, educators, and educational programs to measure students' health literacy at baseline (e.g., upon entry to the program or at the beginning of treatment), to determine the effectiveness of educational interventions or healthcare. It could also be used in conjunction with measures of health to further our understanding of the relationship between musicians' health literacy and their health and well-being.

Limitations

Limitations of this validation study include the fact that the questionnaire was administered in English only in English-speaking, primarily higher-income countries. We intend to translate this tool into other languages and test non-English versions in a variety of countries in future.

As with the development of any tool to measure a newly identified construct, it is possible that the process we followed to develop our tool from the pre-existing HLS-EU family of questionnaires resulted in a tool that did not fully address health literacy for musicians. There are other ways that the development of such a tool could progress, such as beginning the process from qualitative interviews with musicians. Other health literacy tools have been developed using such a process (Osborne et al., 2013). However, when considering the selection of a model for the development of our tool, we rejected Osborne et al.'s health literacy questionnaire because it only addressed one of four health literacy competencies (decision-making/critical thinking, evaluation, responsibility, and confidence/self-efficacy) that were suggested in the literature to be enablers of positive health outcomes for musicians (Wijsman et al., forthcoming; see footnote 1). At this time, our tool is the only one to address health literacy in musicians, and its utility in practice and research remains to be demonstrated in future research.

During the development of the questionnaire, the MHLC chose to maintain the scoring structure of the HLS-EU including the four valid responses (*very difficult*, *difficult*, *easy*, and *very easy*), the optional response *don't know*, scored as missing data, and the determination that 20% or more *don't know* responses rendered the participant's responses invalid. This decision was made to maximize the comparability with the HLS-EU suite of tools. It should be noted that the HLS-EU tools were initially designed to be administered verbally, either in person or over the telephone. It seems reasonable to assume that *don't know* might not be selected as often when the questionnaire is administered verbally as when *don't know* appears as an available response option in print or online, and this may explain the lower invalidity rate found for HLS-EU questionnaires than for the MHL-Q19. The developers of the HLS-EU questionnaires did, however, intend their tools to be delivered online in future applications, although the literature on the HLS-EU-Q (Sørensen et al., 2013, 2015; Pelikan et al., 2019) does not include any visual representation of how it would appear. Thus, while we acknowledge that there might be differences between the rates of invalid responses if the MHL-Q19 were to be administered verbally as well as online, we think it unlikely that these differences would be significant.

Conclusion

In this paper, we have evaluated the validity and reliability of a new health literacy questionnaire for musicians, the MHL-Q19. The tool showed acceptable reliability. Questions that arose from the reliability evaluation point to the intriguing possibility that music students' health literacy may be changed by completing this questionnaire, which should be explored in future research. Factor analysis indicates that MHL-Q19 questions generally map onto the domains of the health literacy conceptual framework as intended, with a few exceptions. Our hypotheses about how the new tool would perform in comparison with other validated instruments were partially supported, with some unexpected results. These can be partly explained by reflection on additional literature, and some of which point to the need for more research to further investigate the utility of this new questionnaire. In addition, because musicians' health literacy is a developing construct, the partial support for the hypotheses described above may provide useful insight into the construct of musicians' health literacy itself.

In summary, given that this is a new instrument, the validity evidence presented is positive and promising. Further studies are needed to refine the tool. The results from this study support the view of the MHLC that musicians' health literacy is a distinct construct that cannot be fully evaluated with existing health literacy tools. The MHL-Q19 has demonstrated great potential for measuring this construct and we anticipate that future research will further strengthen both the tool itself and our understanding of musicians' health literacy.

Data availability statement

The data in this article are potentially sensitive health information. We do not have ethics approval to share them outside of the research team. Requests to access the datasets should be directed to cguptill@uottawa.ca.

Ethics statement

The studies involving human participants were reviewed and approved by University of Alberta Research Ethics Office. A letter of information was presented as the first page of the online surveys and consent was inferred when participants completed the questionnaires.

Author contributions

CG was the lead researcher and primary author for the manuscript, with significant contributions from TS and SW. CG, TS, VB, MRR, and SW were the primary researchers designing and implementing this study. TS, with assistance from MRR, analyzed the data. RL, BR-S, JG, and SW assisted in obtaining research ethics board approvals and recruiting participants. CG, VB, RL, BR-S, BA, JG, PV, and SW participated in the design of the MHL-Q19 questionnaire. SW is the Lead Academic for the Musicians' Health Literacy Consortium. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.886815/full#supplementary-material

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Preference of harmonic loudness degree on piano timbre

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This study exploratively conducted two investigations of timbre influenced by harmonic loudness. Investigation 1 examined piano timbre preference between non-processed melodies and two kinds of adjustments created *via* an equalizer–a basic tool used for sound engineering and for producing audio materials. Using the paired comparison method, 98 respondents were surveyed. The results show that in the bass range of the piano sound, the preferred audio material was that produced *via* an equalizer by reducing the loudness of the 7th and 9th harmonics by 15 dB, while enhancing the loudness of the 8th harmonic by 15 dB. Investigation 2 examined three degrees of the processed melodies—adjusting the harmonics by 15, 10, and 5 dB. The results show that the 15 dB change was the best, while the 10 dB change was the worst. These results provide a new approach to improving the sound timbre for sound engineering and artificial intelligence music production.

KEYWORDS

piano timbre, equalizer, harmonics loudness, audio preference, digital music

Introduction

Timbre is not a consciously processed dimension of the image, although some composers and orchestrators' knowledge is declarative "(for instance, knowing in the abstract that particular sounds blend well), the remainder is presumably based on inner hearing or 'musical imagery'." "A pilot experiment manipulated instrumentation, while the main experiment manipulated sound filters. The hypothesis that participants are able to internalize timbral aspects of music was supported by an ability to perform the timbre discrimination task, and by facilitated response when imaging the timbre context compared with non-imaging." The results suggest that timbre may be a sound characteristic that is optionally present in imagery for music (Bailes, 2007, p. 21). Up to now, the view of timbre as subjective music imagery is still supported by some musicians. After all, timbre perception is still a complex issue in both theory and practice. In the field of theory, timbre is thought of as "a misleadingly simple and exceedingly vague

word encompassing a very complex set of auditory attributes, as well as a plethora of intricate psychological and musical issues" (McAdams and Giordano, 2008, p. 72). Those intricate issues relate to many parameters of perception that are not accounted for by pitch, loudness, spatial position, or duration (McAdams, 1999, p. 85).

From a psychoacoustics view, the parameters—attack time, spectral centroid, and spectrum fine structure—appear as major determinants of timbre (Caclin et al., 2005, p. 471). Timbre is a multidimensional perceptual attribute with multiple underlying acoustic dimensions of both temporal and spectral types (Caclin et al., 2007, p. 159). In respect to spectral type, using event-related potentials (ERPs), Caclin et al. examined the processing of auditory dimensions in sensory memory and found that interactive behavior occurred in the pair with two spectral dimensions—spectral center of gravity (SCG) and even harmonic attenuation (EHA) (Caclin et al., 2006, p. 1968–1969). Early ERP effects (before 200 ms) of the condition factor were observed for the SCG/EHA, and the effect of the condition factor is more pronounced after 500 ms; before 200 ms, there was a significant Condition × Congruency interaction, "in the 250–350 ms latency range, a significant congruency effect is observed, and slightly later (280–400 ms), a significant Condition × Congruency interaction arises for this pair of dimensions" (Caclin et al., 2008, p. 55–58). In respect to materials, using a categorization task, wood, metal and glass were examined; the results revealed that the processing of metal sounds differed significantly from glass and wood sounds as early as 150 ms and up to 700 ms (Aramaki et al., 2009, p. 1). This research advanced the understanding of perceptions of timbre.

Besides understanding perceptions of timbre, when focusing on piano manufacturing technology, many researchers have tried to better understand experimental results of hammer-string interaction, and to obtain a better agreement between the experimental and theoretical results. The main points of interest in the hammer-string interaction are: (1) time pattern of the force acting between the hammer and the string; (2) contact time; (3) temporary loss of contact between the hammer and the string; (4) spectral pattern of partials; and (5) energy transfer efficiency (Suzuki and Nakamura, 1990, p. 158).

The spectral pattern of partials can be taken as a spectrum fine structure "related to the local shape of the spectrum, modeled by even-harmonic attenuation" (Caclin et al., 2005, p. 481). Turning to the piano manufacturing theory corresponding to spectral pattern of partials, one approach—using hammer positions at a cord length of 1/8—controls the 7th and 9th discord harmonics while decreasing the loudness of the 8th concord harmonic (Li, 1992, p. 14–17). The relationship between the root and the 7th, 8th, and 9th harmonics can be explained by the following two examples. C root's 7th, 8th, and 9th harmonics correspond to B-flat, C, and D, while D root's 7th, 8th, and 9th harmonics correspond to C, D, and E. Many piano manufacturers have used Young's Law to select hammer positions at string lengths of 1/7, 1/8, 1/9, and so on, in the mid-to-low-range pitch of the piano to improve piano timbre by controlling the inconsistent harmonic loudness (Jin et al., 2002, p. 5–6). However, contemporary recording techniques (equalizers) used for timbre adjustment can be employed without sacrificing harmonic loudness (Ramo and Valimaki, 2014, p. 302–303). Thus, the following question arises: can ordinary listeners, once used to hearing natural piano timbre, perceive changes in timbre processed *via* an equalizer?

A study conducted by Huang and Xie (2005, p. 4–5) used a real piano (the Zhujiang brand made in China) and equalizers processing the 7th and 9th harmonics of each sound. When the 7th and 9th harmonic loudness was attenuated by 6 dB, its sound quality was highly praised by the tuner respondents. If the 7th and 9th harmonic loudness was attenuated by 10 dB–20 dB, the tuner respondents thought that the sound became thin. However, the survey used in this study suffered from several limitations: (1) the sample size was small, with only six and seven subjects recruited in the first and follow-up surveys, respectively; (2) the survey only used isolated sounds rather than music clips as audio materials, which is different from the real experience of subjects listening to music; and (3) the investigation did not limit the sound range; that is, in the process of the piano making the chord, the point design of each range was not the same, so failing to limit the range and treating all sounds the same will bias the results. The present study addresses these limitations through four measures: (1) including 146 respondents; (2) employing a phrase written specifically for this survey instead of using isolated sounds; (3) selecting audio materials from the sound area where the striking point is 1/8 of the string length (piano production loses the 8th harmonic intensity in this sound area, which can be improved using equalizer technology); and (4) the sound was not directly obtained by piano but created using Spectrasonics's KeyScape 1.1 piano sound source software (Steinberg Cubase Art 10 Digital Audio Workstation), wherein we employed a customized piano Yamaha C7 to provide the character control function. The KeyScape piano sound source software is very popular among composers and recording engineers; it is widely used in music production fields, such as film and game music.

In this case, combining the theory of parameters of perception and spectrum structure, in our study of timbre, we defined loudness as the intensity shown by the equalizer.

This study explored the influence of harmonic loudness—manipulated by equalizer technology—on piano timbre preference. The research consisted of two investigations: (1) harmonics with the non-processed and processed sounds; and (2) three degrees of the processed harmonics.

Investigation 1 (harmonics with the non-processed and processed sounds)

Investigation 1: Materials and methods

We conducted a survey of 98 people (females = 75; mean age = 20.7 years; musicians = 30). Convenience sampling was employed, and subjects were recruited from the student population at Southwest University. Due to the difference in the number of male vs. female respondents, the survey results were also analyzed by gender. The musician respondents were majoring in bassoon, cello, clarinet, double bass, electric guitar, erhu violin, piano, pipa, vocal music, or zither. The average number of years they had spent learning music was 8.8.

The audio melody (Figure 1) used in the study was composed in the bass range (from 123.47 to 220 Hz)—equivalent to the hammer position at 1/8 of the string length—of the piano sound source software. An equalizer was used to adjust the harmonic intensity of a specific number of individual pitches in the audio material. The 20-s length melody comprised two phrases which were in the same key of C major. The first phrase ended on the dominant and the second phrase ended on the tonic. The melodic intervals included steps and jumps, while the rhythmic patterns included sixteenth notes (short tones) and half notes (long tones). Since piano timbre is based on two processes—percussion and continuation—this investigation manipulated continuation with short and long tones, which made it possible to adjust it to different schemes.

The method applied when using the equalizer to adjust the 7th–9th harmonic loudness of each tone in the audio materials was as follows. Using Steinberg Cubase Art 10, after each tone had been independently divided into a sound track, the equalizer software (iZotope Ozone 9.1) was opened, the adjustment mode was set to Proportional Q, and the *Q* value was set to the maximum value of 12. The larger the *Q* value, the smaller the adjusted frequency range and the more accurate the adjustment. The loudness frequency was then repeatedly adjusted on the F parameter. After determining the frequency with the best effect, the harmonic loudness could be accurately adjusted (Figure 2).



FIGURE 1
20-Second piano melody written for this study. © 2022 IEEE. Reprinted with permission from Cai and Zhou (2021).



FIGURE 2
Effect drawing of harmonic loudness adjustment. Image reproduced with permission from Ozone software. © 2022 IEEE. Reprinted with permission from Cai and Zhou (2021).

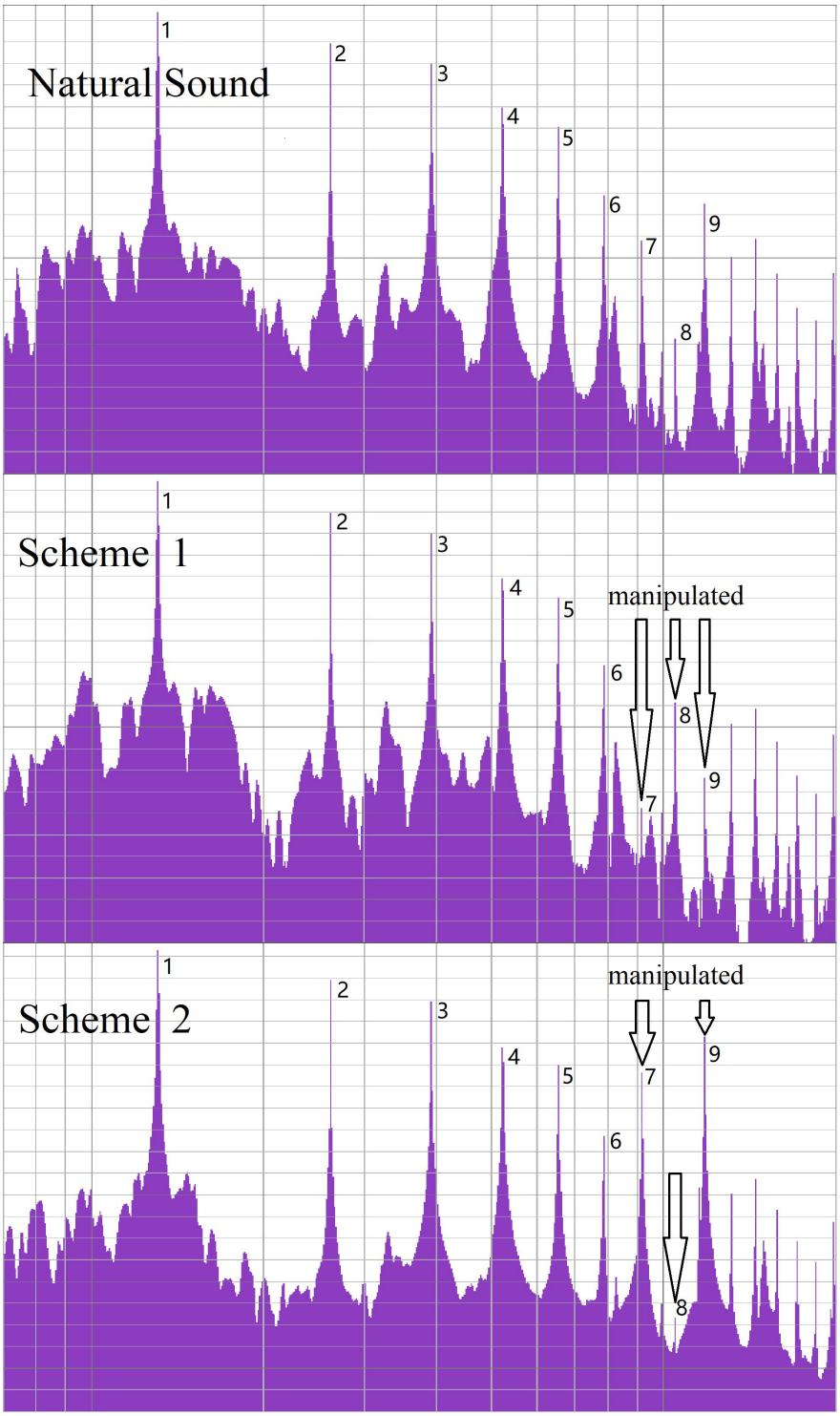


FIGURE 3
Harmonic loudness in investigation 1.

According to the paired comparison method (Tarrow, 2010, p. 232–233), each of the five factors—audio materials A, B, C, D, and E—was paired with each of the other audio materials side-by-side. Factor A enhanced the 8th harmonic by 15 dB—the decibel value was used to describe the sound level—while the 7th and 9th harmonics were reduced by 15 dB

(Huang and Xie, 2005, p. 5). Factor B comprised the non-processed sound—the original sound output under the piano sound source software default settings. Factor C enhanced the 8th harmonic by 15 dB, while the 7th and 9th harmonics were reduced by 15 dB on short tones; in addition, the 7th and 9th harmonics were enhanced by 15 dB while reducing the 8th harmonic by 15 dB on long tones (Figure 3). Factor D enhanced the 7th and 9th harmonics by 15 dB while reducing the 8th harmonic by 15 dB on short tones; simultaneously, the 8th harmonic was enhanced by 15 dB, while the 7th and 9th harmonics were reduced by 15 dB on long tones. Finally, Factor E enhanced the 7th and 9th harmonics by 15 dB while reducing the 8th harmonic by 15 dB on both short and long tones (Table 1). All ten pairs (AB, AC, AD, AE, BC, BD, BE, CD, CE, and DE) were obtained.

During the survey, random pairs of the whole melody with different schemes (Table 1) were played by a Hewlett-Packard 17-w119TX laptop. The respondents wore professional-grade Sony MDR-7,506 monitor headphones to listen to the audio and listened to each pair twice to test whether the participants chose a stable option. Respondents were then required to write down their preference.

Prior to the experiment, participants were told to listen to three sets of test audio, which ensured that they fully understood the investigation procedure. The formal survey took 30 min to complete. To minimize respondent fatigue, 5 min' rest time was provided in the middle of the listening procedure.

TABLE 1 Factors used for each of the five audio materials in investigation 1.

Factors	Schemes
A	Enhancing the 8th harmonic by 15 dB while the 7th and 9th harmonics were reduced by 15 dB
B	No processing
C	Enhancing the 8th harmonic by 15 dB while the 7th and 9th harmonics were reduced by 15 dB in short tones; enhancing the 7th and 9th harmonics by 15 dB while the 8th harmonic was reduced by 15 dB in long tones
D	Enhancing the 7th and 9th harmonics by 15 dB while the 8th harmonic was reduced by 15 dB in short tones, enhancing the 8th harmonic by 15 dB while the 7th and 9th harmonics were reduced by 15 dB in long tones
E	Enhancing the 7th and 9th harmonics by 15 dB while the 8th harmonic was reduced by 15 dB

Investigation 1: Results

In line with previous studies, the difference analysis based on paired comparisons was performed using a Chi-square test (Saito, 1996, p. 36–37; Ge et al., 2005, p. 850). After the survey, we calculated the average number of times that respondents in each group (musician vs. non-musician) chose each audio used in the survey (Table 2). The Chi-square test revealed that the preferences of professional and non-professional subjects for audio materials did not differ significantly ($p = 1.000$).

Further Chi-square tests were conducted to determine differences in the preferences of musician and non-musician subjects for each audio material. The results indicated that only material A was close to statistical significance ($X^2 = 6.317$, $p = 0.097$); there were no significant differences among the other materials (Table 3). At the same time, the Chi-square test was used to calculate the differences between male and female participants in the average selection frequency of five audio materials. The results ($p = 1.000$) suggested that the participants' gender had no significant effect on their preference for audio materials.

To investigate the differences in subjects' preferences for the five kinds of audio, we conducted Chi-square tests on the selection frequency of musician vs. non-musician subjects and found that there were significant differences in musicians' preferences for the five kinds of materials ($X^2 = 88.792$, $p < 0.001$). There were also significant differences in the preferences of non-musicians for the five materials ($X^2 = 103.214$, $p < 0.001$). This indicates that both musicians and non-musicians can distinguish the differences between the five audio materials. Specifically, musicians and non-musicians chose the A audio most frequently ($M = 3.398$, $SD = 0.104$), followed by the B audio ($M = 2.920$, $SD = 0.104$), C audio ($M = 1.725$, $SD = 0.104$), D audio ($M = 1.211$, $SD = 0.104$), and E audio ($M = 0.747$, $SD = 0.104$). The results also showed that the average selected frequencies of A, B, C, D, and E decreased in turn. Audio A received the highest number of votes, followed by audio B; likewise, audios C, D, and E received significantly fewer votes than the first two categories (Figure 4).

Regarding the short tones in the audio materials, we take audio materials A and C as a reference and compare them against the votes for audio materials D and E. The findings indicate that, compared with long tones, the short tones in audio A and C were preferred. This may suggest that listeners are more sensitive to sound quality when listening to continuous

TABLE 2 Frequency statistics of audio material preference analysis of musician and non-musician subjects.

Average selected frequency	A	B	C	D	E
Musician	3.63	3.13	1.70	0.97	0.57
Non-musician	3.16	2.71	1.75	1.46	0.93

TABLE 3 Chi-square test of preference of musician and non-musician subjects for audio material selection.

	A	B	C	D	E
X^2	6.317	6.667	5.240	5.485	5.390
p	0.097	0.155	0.264	0.241	0.250

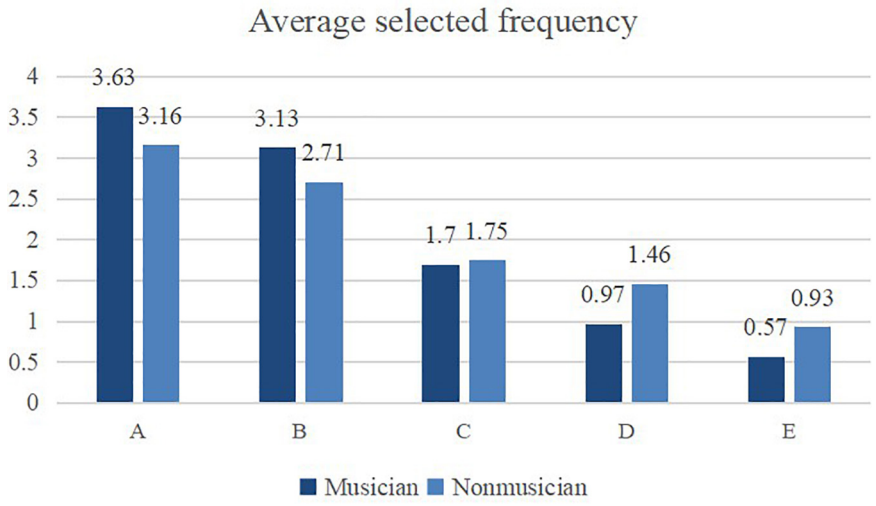


FIGURE 4
Frequency statistics of audio material preference analysis of musician and nonmusician subjects.

dense sound. Finally, Audio E was the least preferred by respondents, as expected.

Investigation 2 examines the specific value of overtone loudness and the critical point of tolerance.

Investigation 2 (three degrees of the processed harmonics)

Investigation 2: Materials and methods

In Investigation 2, the 20-s piano melody written specifically for this study (Figure 1) was again used as the manipulated base. We examined three degrees—adjusting harmonics by 15, 10, and 5 dB—of the processed harmonic and conducted another survey. Participants were again recruited from the student population at Southwest University; they included 48 musicians (females = 32; mean age = 20.5 years), of whom 28 were majoring in piano and 20 were majoring in marimba, saxophone, clarinet, guzheng, violin, or vocal music. The average number of years spent learning music was 9.5.

Each of the three audio materials (A, F, and G) was paired with other audio materials side-by-side. Factor A was the same as in Investigation 1. Factor F enhanced the 8th harmonic by 10 dB, while the 7th and 9th harmonics were reduced by 10 dB. Factor G enhanced the 8th harmonic by 5 dB, while the 7th and 9th harmonics were reduced by 5 dB (Figure 5). A total of six pairs (AF, FA, AG, GA, FG, and GF) were obtained.

During the survey, random pairs of the whole melody with different schemes (Table 4) were played by a Hewlett-Packard 17-w119TX laptop. The respondents wore professional-grade Sony MDR-7,506 monitor headphones to listen to the audio (again listening to each pair twice to test whether participants chose a stable option). Then they were required to write down their preference.

Prior to the experiment, participants listened to three sets of test audio, which ensured that they fully understood the investigation procedure. The formal survey took 15 min to complete. After the listening survey, the respondents were required to answer the following questions: (1) When listening, do you feel any differences between the two audio materials in each group? and (2) If there is any difference, can you describe the specific audio?

Investigation 2: Results

As in the first survey, we calculated the average number of times each audio material was selected by the musician respondents (Table 5). Chi-square tests were performed for the selected frequencies of each audio, and the effect was significant ($X^2 = 40.042$, $p < 0.001$). A Chi-square test also showed that there were again no significant gender differences ($p = 1.000$), which means that gender has no effect on subjects' preferences for the audio materials.

The average selected frequency of each audio material shows that, among the three audio materials, audio A was still the most popular, followed by G and F, the latter of which received far fewer votes (Figure 6). Therefore, the procedure that enhanced the 8th harmonic by 15 dB and weakened the 7th and 9th harmonics by 15 dB was preferred by respondents. This finding supports the results of Investigation 1.

Here, Audio A (enhancing the 8th harmonic by 15 dB and weakening the 7th and 9th harmonics by 15 dB) was preferred by

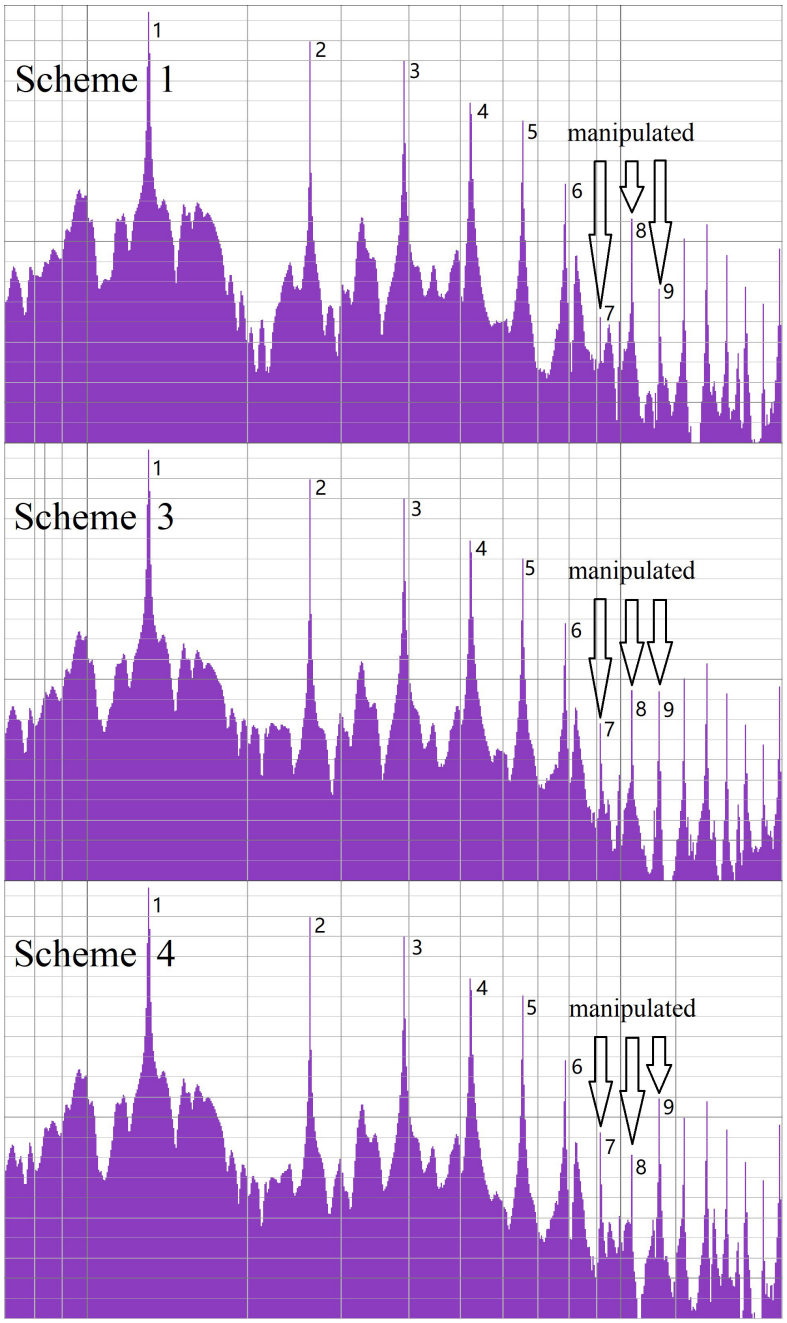


FIGURE 5
Harmonic loudness in investigation 2.

the respondents. This conclusion may benefit from further study using the isolated sounds view (Huang and Xie, 2005, p. 4–7) and phrase view.

Audio F (enhancing the 8th harmonic by 10 dB, while the 7th and 9th harmonics were reduced by 10 dB) received the lowest average selected frequency—only 0.96. Is this the critical point? The results of the interviews conducted after the listening survey might be close to this question.

Audio F's corresponding descriptors were mostly "thin," "rough," and so on. Compared with audio A's highly descriptive words—"delicate," "clear," and "ethereal"—and audio G's descriptive words (e.g., "plump"), audio F was described as negative words and received a much lower number of votes. Compared with the results of the study by Huang and Xie (2005, p. 4–7)—which found that timbre was highly praised when the 7th and 9th harmonic loudness was attenuated by 6 dB and

TABLE 4 Factors used for each of the three audio materials in investigation 2.

Factors	Schemes
A	Enhancing the 8th harmonic by 15 dB while the 7th and 9th harmonics were reduced by 15 dB
F	Enhancing the 8th harmonic by 10 dB while the 7th and 9th harmonics were reduced by 10 dB
G	Enhancing the 8th harmonic by 5 dB while the 7th and 9th harmonics were reduced by 5 dB

TABLE 5 Average frequency of three audio materials selected in paired comparison.

	A	G	F
Average selected frequency	2.96	2.08	0.96

described as "thin" when the 7th and 9th harmonic loudness was attenuated by 10–20 dB—the aesthetic perceptions noted here are similar.

General discussion

The two investigations conducted in this study did not directly reference other research in the fields of timbre theory, psychoacoustics, and timbre perception understanding. However, the designs of the investigations were based on the idea that timbre is not a simple issue accounted for by ordinary parameters; rather, its auditory effect might be improved. In this case, shaping harmonic loudness of the spectrum fine structure, examining example of patterns in "real" music (Vuust et al., 2012, p. 141), and exploring the sound characteristics, became three discussions as follows:

Firstly, shaping harmonic loudness. Comparing with the EHA model, the current investigations were designed to change the value of the 7th, 8th, and 9th harmonic loudness, the difference of which might be discussed. The current study

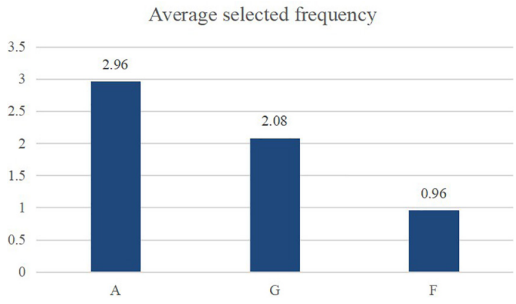


FIGURE 6
Average frequency of three audio materials selected in paired comparison.

attenuated and/or enhanced the value by 15, 10 or 5 dB, which resulted in a large-scale change for ascending and descending. Such a change was based on the study of Huang and Xie (2005, p. 4–5) who attenuated the 7th and 9th harmonics of a single sound by 6 dB or 10–20 dB. This way aims for practical application. While Caclin et al. (2006) did the EHA from 0 to 8 dB (2005, p. 480), 0 or–6.4 dB (2006, 1963), 0 or 10 dB (2008, p. 51), Tużnik et al. (2018) attenuated the EHA 5 or 10 dB (2018, p. 11). The EHA model contributed to the principle of timbre. Either in principle or application, does 10 dB serve as a threshold of negative timbre perception? This deserves further investigation.

Secondly, examining preference of phrase. Previous research—using audio samples produced by four piano performers on a real piano in a concert hall, which did not change the spectrum's shape—found that (1) timbre preferences for single sounds might relate to different spectrum shapes of the 1st, 2nd, 3rd, 4th, and 5th harmonic intensities, as shown by the software Audacity; (2) no relation between the single sound and phrase was found (Zhou et al., 2018, p. 33–34). (1) Suggested that the perceived timbre might be a measurable item but not an abstract rule. (2) Suggested, as Clarke explained, "perception must be understood as a relationship between environmentally available information and the capacities, sensitivities, and interests of a perceiver" (Clarke, 2005, p. 91). The current study employs two phrases composed as real music, shaping the harmonic loudness by Spectrasonics's KeyScape 1.1 piano sound source software and the equalizer. The investigations focused on the whole phrase and ignored the single sound, being inclined to a top-down processing method. Just as the study of musical syntactic perception pursues some abstract rule, this study, which took a phrase as the research object, also explored from an overall perspective. Although our exploration has not found abstract rules from the different design schemes of long and short tone conditions (please see Factors C and D in **Table 1**), it would be interesting to combine top-down attention and selective attention to enable effective encoding and maintenance of relevant information in memory (Lim et al., 2015, p. 16102).

Thirdly, exploring the sound characteristics. The results of interviews after investigation 2 can be seen as a description of phrase timbre characteristics. Although they cannot be quantified, some descriptors can reflect and be abstracted visual graphics. In some experiments, graphics presenting three different geometrical shapes (triangle, square and circle) each constituted a cue for the subject to induce auditory imagery of a specific sound (Tużnik et al., 2018, p. 11). However, the current study is not as good as the previous ERP study—highlighted in the introduction—in terms of detecting the time course of accurately perceiving sound characteristics. Besides, using the stimulus of Alberti Bass and rising and falling sequences of thirds, research

found that jazz musicians overall have larger MMNs to the six sound deviants—pitch, timbre, location, intensity, slide and rhythm—than all other groups (the other three are band musicians, classical musicians and non-musicians). Jazz musicians learn and perform music to a great extent by ear, "furthermore, jazz music is characterized by complex chord changes, rich harmonies, and challenging rhythmic material, which may boost these performers' theoretical and ear training skill"(Vuust et al., 2012, p. 145). That is to say, more sound characteristics need be studied; training benefits reflect distinct sensorimotor processing stages (Garner et al., 2015, p. 2091).

Conclusion

This study conducted two investigations comprised of a melody phrase listening examination that manipulated timbre variables in the bass range of the piano sound. The following conclusions can be drawn. First, listeners' preferences regarding piano timbre were more positive when equalizers were used to enhance the 8th harmonic by 15 dB while reducing the 7th and 9th harmonics by 15 dB. Second, participants least preferred the processed harmonics when we enhanced the 8th harmonic by 10 dB while the 7th and 9th harmonics were reduced by 10 dB.

This result can be extended to recording engineering and artificial intelligence music production, such as by helping manufacturers of musical instrument sound source software and electronic effector software to improve the timbre of their products, and by providing manufacturers of audio processing software containing artificial intelligence algorithms with a new timbre optimization algorithm.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the College of Music Ethics Committee, Southwest University, China. The patients/participants provided their written informed consent to participate in this study.

Author contributions

YC: study design and execution, data interpretation and analysis, and manuscript. YL: data statistics. GC: data analysis and statistics. XZ: study design, manuscript drafting, and reviewing. All authors contributed to the article and approved the submitted version.

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Judgment of togetherness in performances by musical duos

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Musicians experience varying degrees of togetherness with their co-performers when playing in ensembles. However, little is known about how togetherness is experienced by audiences and how interpersonal dynamics in body motion and sound support the judgment of togetherness. This research investigates audience sensitivity to audio and visual markers of interperformer coordination and expressivity in ensembles, in relation to modality of stimulus presentation and audience music background. A set of duo ensemble performances, comprising motion capture recordings of the musicians' upper bodies and instruments, were presented to participants with varying music background, including novices and semi-professional musicians. Participants were required to: (i) watch and listen, (ii) only watch, and (iii) only listen to the selected recordings, whilst providing dynamic ratings of how much togetherness between musicians they perceived. Results demonstrate that sound intensity and similarity in right arm motion (quantified using cross-wavelet transform analysis) were significant predictors of rated togetherness in novices, whilst sound synchronization and chest motion coordination predicted togetherness responses in semi-professional musicians. These results suggest the relevance of the quality of body motion coordination and of certain features of the audio outputs in the audience perception of togetherness. This research contributes to a better understanding of the perceptual mechanisms supporting socio-cognitive judgments of joint action activities.

KEYWORDS

togetherness, ensemble performance, motion capture, joint action, music perception, flow, interpersonal synchronization

1. Introduction

During music ensemble performances, musicians experience varying degrees of musical, cognitive and emotional alignment with their co-performers, that is, varying intensities of musical togetherness (Sawyer, 2006; Seddon and Biasutti, 2009; Hart et al., 2014; Hart and Di Blasi, 2015; Gaggioli et al., 2017). Togetherness experiences are socially and aesthetically rewarding (Berliner, 1994), and can change in intensity over time as the quality of interactions between group members evolve. Aspects of togetherness have been investigated through studies of synchronization in body motion (Hart et al., 2014) and note timing (Wing et al., 2014). Strong experiences of togetherness may be

associated with shared absorption or group flow, colloquially described as being "in the zone" (Sawyer, 2006; Gaggioli et al., 2017), and characterized by seemingly-effortless collaboration between group members as well as behavioral and physiological synchrony (Hart et al., 2014). Playing music with others, or simply synchronizing rhythmic body movements, can strengthen the relationships between musical partners more broadly, with effects that persist beyond the end of the performance. Prosocial benefits of rhythmic synchronization have been observed for infants (Cirelli et al., 2014a,b), pre-schoolers (Rabinowitch and Meltzoff, 2017a,b), and adults (Valdesolo et al., 2010; Mogan et al., 2017).

A growing corpus of research has focused on experiences of togetherness that are self-reported by performers in amateur musical bands (Gaggioli et al., 2017), experienced musical and improvising groups (Hart et al., 2014; Hart and Di Blasi, 2015), professional ensembles (Seddon and Biasutti, 2009), and therapeutic settings (Smetana et al., 2022). However, very little is known about how audiences judge togetherness and how togetherness manifests in musicians' body motion and musical outputs. This study investigates how an audience evaluates the strength of togetherness between musicians during piano duo and clarinet duo performances, and how this judgment relates to specific visual and audio features of the performance. This research contributes to a better understanding of how people communicate the quality of their social interactions through non-verbal behavior (see also Aucouturier and Canonne, 2017; Lee et al., 2020).

The following sections provide an overview of how auditory and visual information shape audiences' experiences of performed music and how music expertise changes audience perceptions of ensemble coordination.

1.1. Evaluation of music performance based on visual cues

Musicians' body motion is a core element that can influence listeners' experiences of music (Leman et al., 2017). In addition to some aspects of motion supporting sound production and modifying the sound, certain aspects of body motion (referred to as "ancillary motion") facilitate coordination and interaction between co-performers (Jensenius et al., 2010) and can also influence listeners' experience of the music that they see performed (Jensenius et al., 2010; Leman et al., 2017). Head movements can relate to the emotionally expressive intentions that musicians aim to communicate. The amount of information flow (measured in the head motion) between members of a professional trio was found to be higher when playing with emotional expression rather than performing mechanically without expression (Chang et al., 2019).

Ancillary motion can also be shaped by the ensemble context and become more predictable in certain situations. Distinctive patterns in the head movements of first violinists differentiate solo and ensemble performances, with head movements being more predictable when the first violinists performed with a string quartet than solo. Visual signals can also reflect the leader-follower relationships between co-performers. Assigned leaders in string quartets tend to influence others more than they are influenced by others, as can be seen in their head motion (Chang et al., 2017). Assigned leaders in piano duos tend to raise their fingers more than assigned followers (Goebl and Palmer, 2009).

Head movements also contribute to the synchronization of certain parts of the music. Certain acceleration patterns in head gestures (i.e., instances of deceleration following acceleration peaks) facilitate piece entrances in piano duos by communicating beat position (Bishop and Goebl, 2017). Increased quantity of head movements in irregularly-timed passages compared to other parts of a piece ease interpersonal coordination during these periods of temporal instability (Bishop et al., 2019b). In summary, musicians' body motion is tied to individual and group expressivity, becomes more predictable in ensemble settings, and can facilitate coordination between ensemble members.

A line of research on audience perception has investigated how audiences perceive musicians' body motion, and have shown that audience members can distinguish the expressive content of a music performance based on musicians' body motion. Members of an audience rating silent video clips were able to detect happiness, sadness and anger in clips where musicians intended to communicate these emotions to others (Dahl and Friberg, 2007). Anger was mostly communicated through jerky movements, happiness through large movements, and sadness through slow and smooth movements. Audio and visual cues interact when the music is both heard and seen, such that happiness and sadness are perceived more accurately when accompanied by compatible music (e.g., happy music accompanying happy interactions) than incompatible music (e.g., happy music accompanying sad interactions) (Kaiser and Keller, 2011). Audiences can also distinguish between reduced and exaggerated levels of expressive intensity in performances by pianists (Vuoskoski et al., 2014) and clarinetists (Vines et al., 2011). The kinematic features of conductors' gestures also inform the perception of expression, and higher ratings of expressivity in conductors' gestures were found to be correlated to higher amplitude, variance, and speed of movement of the conductors (Luck et al., 2010).

In addition to the expressive content, listeners can also gain information about the social interactions between musicians based on their body motion. Regardless of their music background, listeners can distinguish different social intentions (i.e., dominance, insolence, caring, conciliatory, and disdainful) conveyed between musicians in video and sound recordings of jazz duo performances (Aucouturier and Canonne, 2017).

Trained musicians can detect leadership dynamics between members of a conductor-led violin ensemble (D'Ausilio et al., 2012), as it was found that an increased influence of the conductor on the musicians related to improved ratings of performance quality. Furthermore, listeners can detect social bonds in group dance (Lee et al., 2020); specifically, ratings of formidability and social closeness were found to be higher in unison rather than coordinated dancing, implying that, in order for perception of social bonds to be maximized, movements should be fully synchronized. In summary, audience members gain information about the expressive content of music and the relationships between musicians by watching musicians' body motion. However, it remains unclear what body motion communicates about musicians' experiences of cohesion. This study aims to address this question with an investigation of how different body motion features contribute to listeners' evaluation of the degree of togetherness between musicians during ensemble performances.

The coupling in periodic body motion that arises between ensemble co-performers may have a particular effect on how audiences judge ensemble coordination. Eerola et al. (2018) observed that over 80% of interaction bouts in non-pulsed, free duo improvisations, manually annotated by experts, were predicted by strength of body movements coordination in common periodicities. In a follow-up study, Jakubowski et al. (2020) analyzed the perception of interpersonal synchrony in improvised duo performances, and found that ratings of synchrony were positively related to measures of common periodic movements of the two performers. Researchers in these studies used computer vision techniques to measure the coordination between musicians related to the overall body motion. However, it remains unclear whether judgments of interactions between musicians might depend on the coordination strength of specific body parts. Head motion, closely tied to visual expressivity (Goebl and Palmer, 2009; Keller and Appel, 2010; Glowinski et al., 2013; Leman et al., 2017; Bishop et al., 2019b) might be more relevant to perception of coordination than other body parts such as hand motion, which is highly dependent on the technical demands of sound production. The current study analyzes audience perception of coupling in periodic motion of musicians' heads, chests, shoulders and arms. This study achieved this through motion capture data analysis, aiming to identify the individual contribution of multiple body parts of interest.

1.2. Evaluation of music performance based on auditory cues

Audiences are sensitive to changes in many audio features in music. Differences in loudness, a parameter informative of musical expression, to some extent, can be distinguished regardless of the listeners' training and familiarity with the music being listened to. Manipulations in acoustic intensity induce changes in listeners' perception of the levels of arousal expressed in music (Dean et al., 2011). Audiences relate loudness to musical expression and emotional arousal (Dean et al., 2011) with soft music rated as more pleasant and less energetic and tense than loud music (Ilie and Thompson, 2006). Acoustic intensity also relates to perceived effort or force (Olsen and Dean, 2016).

Furthermore, audiences are, to some degree, sensitive to synchronization between musicians in ensemble playing. It has been reported that listeners without specialized music training were sensitive to the variability of note onset asynchrony and degree of correction gain (i.e., the size of the adjustments relative to the asynchrony), when judging the level of togetherness in computer-simulated string quartet performances of a short excerpt from Haydn's String Quartet Op. 74 No. 1 (Wing et al., 2014). More recently, it has been clarified that listeners, regardless of their music training, can perceive differences in asynchronies in singing ensembles only above a certain threshold placed somewhere between 10 and 38 ms. In a study involving singing duo tokens and singing quintet performances, it has been shown that listeners were able to distinguish asynchronies in duo performances that differed on average by 38 ms, but were not able to perceive differences between singing quintet performances that differed in synchrony by only 10 ms on average (D'Amario et al., 2019). The preference of the degree of synchronization was also investigated in a set of jazz trio performances comprising the original performances (with asynchronies up to 26 ms) as well as recordings manipulated with increased and reduced asynchronies. Results suggest that listeners, regardless of their music training, preferred ensemble performances containing asynchronies as accurate as in the original recordings or even smaller than 19 ms but with natural temporal variabilities rather than performances with increased asynchronies (Hofmann et al., 2017).

In summary, audiences can perceive changes in the acoustic intensity of the music performances and in the interpersonal synchronization between musicians. These two parameters, contributing to the expressive content of the performance and boosting performance excellence, may represent auditory cues to the perception of feelings of togetherness. This research tests this hypothesis, by analyzing whether audio features of the music performances such as sound intensity and synchronization predict togetherness ratings.

1.3. Multimodal evaluation of music performance

Human judgements of music performances are formed based on both visual and auditory information, if both

modalities are available. However, listeners are unreliable in their ability to pair audio and visual cues, as shown by studies observing that participants gave different expressivity ratings to the same audio performance when it was paired with different videos (Behne and Wollner, 2011). A growing body of empirical research has demonstrated that a number of different structural and cognitive factors (e.g., the spatial and temporal co-occurrence and the semantic congruence of the stimuli) contribute to the multisensory integration of auditory and visual stimuli (Vatakis and Spence, 2006, 2007; Spence, 2007).

Another corpus of research has focused on the dominance of the audio or visual modality related to music performance recordings. A study evaluating performance quality judgments of music recordings presented with only video, only audio and with both audio and video of the performances reported the dominance of visual information over sound (Tsay, 2013). The music performances used in the study were short 6 s clips of the top three finalists of several prestigious music competitions. A later study expanded on this, demonstrating that when differences in performance quality were evident, participants' judgements were most accurate when evaluating the performances with only the audio, suggesting that the sight-over-sound effects in the judgments of music performance do not always hold and auditory information can inform audience response in case of clear differences in performance quality (Mehr et al., 2018).

These aspects were further analyzed in a recent study conducted by Jakubowski et al. (2020) investigating the multimodal perception of interpersonal synchronization in musical duo improvisations. Researchers in the study observed that stimuli with only video were judged less synchronized than stimuli with only audio or audio plus video of the performance, based on continuous perceptual ratings. These effects were found mostly for pulsed jazz duo improvisations. They also found relative dominance of the visual modality in predicting perceived synchrony for the stimuli displaying both audio and video. However, this depended on the stimulus duration and the ratings' type. Visual information tended to provide more cues than audio features, in line with Tsay (2013), when participants rated continuously pulsed music clips lasting on average 54.5 s and non-pulsed clips that were on average 41.9 s long. However, the analysis of synchronization judgments based on global ratings of short video clips (of about 10 s long) implies that auditory features might be better predictors of synchronization judgements than visual aspects of the performance. Overall, these results suggest that the modality of stimulus presentation impacts judgments of music performances, depending on the quality and duration of the music performance. The evaluation of short performances might rely more on auditory information. In contrast, visual cues might contribute more to the judgment of longer recordings. Sound synchronization, in fact, manifests at lower time-scales than body motion coordination (Bishop et al., 2019b). Further research is needed to show how different modalities shape audiences' understanding of how together an ensemble is. The current study addresses this by analyzing differences in perception of togetherness between musicians in relation to the modality of stimulus presentation, comprising audio only, video only, and video and audio of the music performance.

Since visual information is clearly important, it is also valuable to understand more specifically where visual attention is directed when people are watching performances. Studies on audience gazing behavior suggest that audience visual attention is influenced by the dominance of the musical part (Kawase and Obata, 2016). In a study based on singing duo performances, it was found that the musicians singing the melody part attracted more visual attention than those performing the accompaniment (Kawase and Obata, 2016). They also found that audience gaze behavior is related to the gaze shift between co-performers, as audience attention followed when performers shifted their gazes toward the co-performer (Kawase and Obata, 2016). It remains unclear where participants would most look at when judging ensemble performances with a more balanced distribution of leadership than in the previous studies and when the eye gaze of the musicians is not visible. What attracts the audiences' gaze whilst evaluating the level of togetherness between musicians? This study investigates which parts of musicians' body audiences look most at, whilst rating togetherness between musicians in a piece featuring a balanced leadership distribution. A better understanding of the factors that attract visual attention when appreciating the level of togetherness in music performance contributes to a holistic understanding of human communication.

1.4. The role of music expertise on perception of interpersonal coordination in ensembles

Furthermore, another line of research analyzing human perception of music performance has studied the impact of the participants' music background. As described above, it has been shown that musically untrained listeners are sensitive to the degree of interpersonal synchronization in string quartet performances (Wing et al., 2014). The sensitivity to asynchrony can increase with training in asynchrony and order discrimination tasks (Mossbridge et al., 2006), but members of an audience are not able to discriminate differences in asynchronies between musicians in the order of 10 ms in singing quintet performances, regardless of the music training of the participants (D'Amario et al., 2019). These results suggest that synchrony perception might depend on the participants' music background. Differences between musical expertise groups in continuous perceptions of the arousal of an electroacoustic piece were also found (Dean et al., 2014). Overall, these

findings suggest the relevance of music expertise when judging music performance.

This aspect might also play an important role in the togetherness evaluation. Music training changes how we hear/see music by making us more sensitive to small-scale differences in musical parameters, for instance in the asynchronies' magnitude (Mossbridge et al., 2006) and pitch contours (Schon et al., 2004). Music training also changes how we understand music as a construct and what we find meaningful (Hansen et al., 2016). However, perception of togetherness in participants with varying degrees and types of music background remains unclear. Musicians might have a more complex understanding of what it means "to be together in music" than novices, for example, thinking of togetherness as partial alignment and complimentarity in how collaborating partners experience the music that they are creating rather than simply sound synchronization.

1.5. The current study

This research investigates the perception of togetherness in audio and video recordings of duo performances, from the perspective of an audience with varying musical expertise and instrumental background and in relation to different modalities of stimulus presentation.

Based on studies on the perception of music ensemble performance and expressiveness, we hypothesized that ratings of togetherness are related to the modality of stimulus presentation, and that the audiences' music background as well as sound intensity, a factor contributing to expressive intensity that could relate closely to togetherness, impact judgment of togetherness to some extent. Novices were especially expected to respond to certain expressive parameters such as sound intensity related to emotional arousal. In contrast, professional musicians were expected to respond to interpersonal synchronization, based on previous studies observing that the sensitivity to synchrony can increase with training (Mossbridge et al., 2006). Furthermore, we predicted that higher ratings of togetherness are related to higher strength in body coordination, based on findings showing listeners' sensitivity to leadership dynamics in large ensembles measured in terms of magnitude of multidirectional information flow, i.e., how much performers influence each other (D'Ausilio et al., 2012), and to the quantity of body motion, which is a measure of energy of the performances.

In addition to the above aims of this study, we were also interested in the eye-gaze behavior of the audience whilst rating togetherness, as this would allow us to contextualize any findings of the impact of audio and visual features of the music performances on togetherness perception. The current study was exploratory in terms of participants' visual attention whilst ratings togetherness. We could predict that visual attention of professional musicians whilst ratings togetherness is drawn to head motion rather than upper body motion, as head motion would be expected to convey expressivity and inter-performer dynamics most strongly (Goebl and Palmer, 2009; Keller and Appel, 2010; Glowinski et al., 2013; Bishop et al., 2019b), and is not involved in sound production. But, novices might look more at the upper body motion as they might find it more difficult to discern sound-producing movements of arms and hands than expressive movements of the head.

TABLE 1 Classification of participants based on their music training and instrumental expertise.

Classification	Group (sample size)		
Music background	Novices (10)	Semi-professional musicians (20)	
Instrumental expertise	N/A	Pianists (10)	Clarinetists (10)

2. Methods

2.1. Participants

Thirty participants (age $M = 24.7$ years old, $SD = 4$ years; 19 females, 11 males) took part in the study. As shown in Table 1, they were classified based on their music training as: (i) *novices* ($n = 10$), comprising university students from the University of Vienna with little or no music background, or (ii) *semi-professional musicians* ($n = 20$), comprising advanced music students from mdw—University of Music and Performing Arts Vienna.

The semi-professional musicians reported having on average 14.5 years of formal training ($SD = 3.2$ years) and practicing on average 3.5 h per day ($SD = 0.6$ h). The semi-professional group was split in 2 subgroups: pianists ($n = 10$) and clarinetists ($n = 10$) based on their instrumental experience. All participants self-reported normal hearing and three self-reported perfect pitch. They received a nominal award of 20 Euros.

The Ethics Committee at mdw—University of Music and Performing Arts Vienna approved the procedures of this study (reference EK Nr: 05/2020).

2.2. Stimuli

2.2.1. Stimulus selection

Two sets of recordings were presented to the participants for the togetherness rating task. These comprised a set with 8 piano duo recordings and a set with 8 clarinet duo recordings. These recordings were previously collected for Bishop et al. (2019b,a), which evaluated the effects of rehearsal on body coordination in musical duos. The duos in the studies recorded the same piece, composed by the second author of Bishop et al. (2019b),

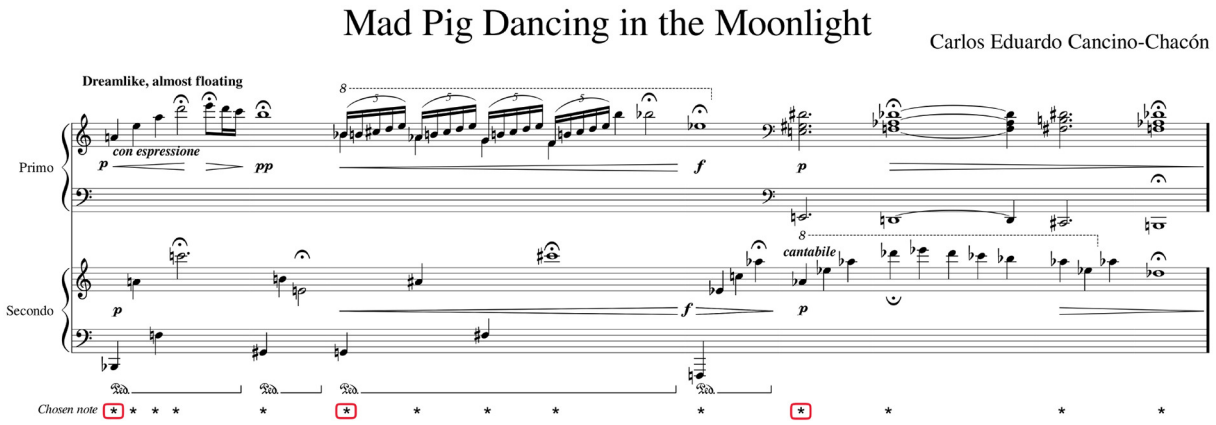


FIGURE 1
Piano duo excerpt from Bishop et al. (2019a) that was used in the current investigation. The figure displays the notes and chords, highlighted with *, upon which the analysis of interpersonal synchronization was based, as well as the initial note, highlighted with red rectangle, of the three musical phrases comprising this section. The figure is ©Bishop et al. (2019a), licensed CC-BY.

several times over. The current study focused on a section of the piece, shown in Figure 1, that presented a particular challenge to performers: this section has no notated meter and could be performed with free timing. This section was selected for the current study as it was expected to encourage variable experiences of togetherness. As shown in Figure 1, it comprises three main phrases: in the first two phrases, the Primo plays the melody and therefore is likely to assume the role of leader; in the third phrase, the Secondo plays the melody and is therefore likely to assume the role of leader. The first two phrases were on average 13 and 15 s long, respectively, whilst the last one was longer and lasted on average 18 s. The recordings of the full excerpt (i.e., all the three phrases together) were on average 47 s long. Recordings of the full excerpt were presented to the participants in this study.

The recordings in the current study were selected from the full data-set collected for Bishop et al. (2019b,a) on the basis of the overall quantity of body motion (QoM), in order to represent its full distribution. QoM was computed for all markers mounted on the musicians' bodies and for markers mounted on the clarinets. In order to compute QoM, first, raw position data recorded at 240 Hz were smoothed using the Savitzky-Golay filter[1] with a window size of 25 frames, and the first derivative of smoothed marker positions was calculated for each marker. Second, summed velocities were computed from the Euclidean norm of 3D positions for each marker and musician per second, and then summed for each duo per second, pooling together the velocities of each marker and musician. Finally, an overall grand mean of summed velocities for each duo was computed per recording. As shown in Figure 2, this process provided a list of 16 QoM values (i.e., one per stimulus), representing the full distribution of QoM features of the original data set.

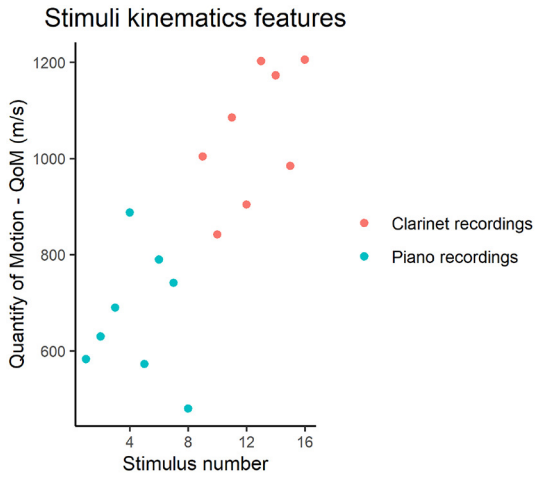


FIGURE 2
Kinematics features of the piano and clarinet recordings selected for the current study, showing the overall quantity of motion (QoM) in the y-axis for each stimulus. The QoM for the piano recordings was computed across all the markers applied on the musicians bodies; in addition to these markers, QoM for the clarinet recordings also included motion of the four markers applied on the clarinets.

2.2.2. Stimulus processing

Performance data included: (i) MIDI recordings from two Yamaha Clavinovas for piano duos; (ii) stereo audio recordings from a room microphone (Neumann KM A P48) and close-proximity microphones (DPA d: vote 4099) placed on the

1 This is a low-pass filter used for smoothing data based on local least-squares polynomial approximation (Savitzky and Golay, 1964).

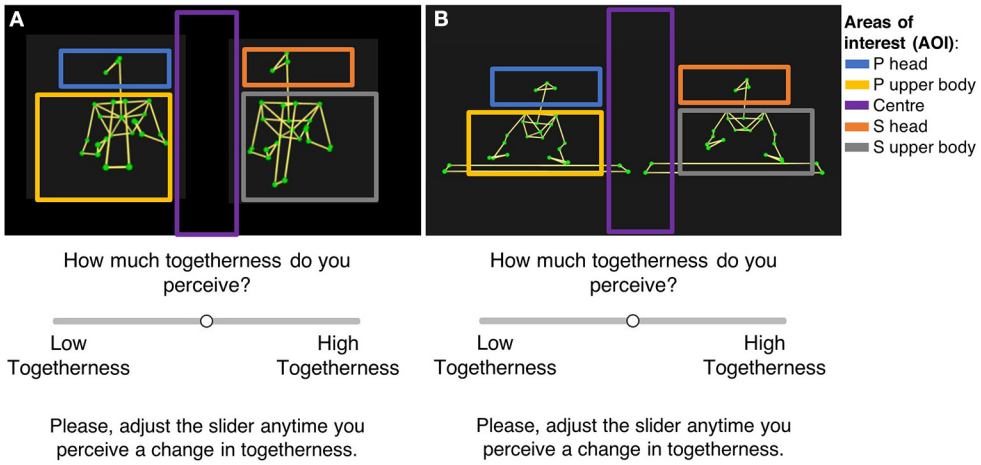


FIGURE 3
Example of the perceptual task during which participants rated how much togetherness they perceived in the clarinet performances **(A)** and piano duo performances **(B)** in a sliding scale from low to high togetherness. In both displays, the Primo (P) was on the left and the Secondo (S) on the right side of the screen. The figure also displays the five areas of interest (AOI) defined for each stimulus to analyze participants' eye-gaze during the rating task; these comprises Primo and Second head, upper body (including musicians' arms, hands, and the instrument), and the center of the screen. The AOI markers have been added to this figure for demonstration purposes and did not appear in the videos that participants saw.

clarinets; and (iii) infra-red motion capture (MoCap) recordings of body and instrument markers. Audio and MIDI data were collected using a Focusrite Scarlett 18i8 sound card, and recorded as separate tracks in Ableton Live.[2] Motion data were recorded at 240 Hz using a 10-camera (Prime 13) OptiTrack motion capture system. A film clapboard with reflective markers was used to synchronize audio and motion data. Body motion data consisted of trajectories of 21 reflective markers per musician placed on the head and upper body, as follows: three markers on the head and back, three per hand, two per shoulder and arm, and one on the chest. Instrument motion was tracked using four markers per instrument. The four markers were placed at the corners of each keyboard for piano duos. For clarinet duos, two markers were mounted on a small stick across the bottom and the top of the clarinet.

The stereo recordings of the selected performances were imported into Audacity[3], and the section of interest for this study was exported as mono wave file with 32 bit PCM at a 44.800 sampling rate. Since the level of the piano audio recordings was very low, audio rendered from the MIDI recordings was added to improve the audio experience. Audible breaths at the beginning of the performances were removed. The overall level of the audio was manually equalized across recordings so that all recordings were heard approximately at the same level, but the relative expressive dynamics of each performance remained unaltered.

MoCap data of the clarinet and piano recordings were imported into Qualysis Track Manager[4], where visual segments (bones) were added between markers. The section of interest was exported as an .avi file at 30 frames per second (fps). The exported MoCap recordings and the audio were then imported into the video software OpenShot[5] to create audio-only (AO), video-only (VO), and audio plus video (AV) versions of each stimulus. A visual 5-s countdown was added to all stimuli to signal the beginning to the participants. Stimuli were exported as video files (.mp4) at 720 p and 30 fps. These files showed the musicians from the front standing next to each other, with the Primo to the left side of the screen, and the Secondo to the right side, as shown in Figure 3.

2.3. Apparatus

The stimuli were presented to participants using a Desktop PC computer with an Intel Core i7-6700 3.40 GHz central processing unit with 16 GB of RAM, running Windows 7. Participants wore headphones, and volume was set to a level of 75 db. The headphone level was measured using an audio sine wave and a professional sound level meter placed 3 cm from the left loudspeaker driver of the headphones and pointing at its center.

2 http://www.ableton.com
3 https://www.audacityteam.org/
4 https://www.qualisys.com/
5 https://www.openshot.org/

The stimuli were presented to the participants through the Gorilla online platform[6] running in Google Chrome 87.0.4280.88). Gorilla was found to achieve precision of about 10 ms in reaction times (Bridges et al., 2020) on a number of browser configurations, including Google Chrome. Gorilla was set to collect slider values every 100 ms (the smallest setting available), and the handle of the slider at the beginning of the recording was placed at the center of the slider.

Eye-gaze data from participants whilst completing the rating tasks were collected using SMI ETG 2 wireless glasses sampling at 120 Hz. Magnetic snap-on corrective lenses were applied over SMI glasses for the required distance correction for those participants wearing prescription glasses within the range of –4.0 and +4.0. Participants were seated approximately 80 cm from the screen, and lights level were maintained unaltered during the task.

TABLE 2 List of the explanatory and response variables of the study, including the related cues to togetherness, the metrics computed, and the data-set from which they have been extracted.

Variable	Cue	Metric	Data-set
Explanatory	Visual	QoM	Motion capture recordings
Explanatory	Visual	CWT power	Motion capture recordings
Explanatory	Auditory	Sound intensity	MIDI recordings
Explanatory	Auditory	Note onset synchronization	Audio and MIDI recordings
Response	Perception	Togetherness ratings	Slider response
Response	Eye-gaze	Fixation	Eye-tracking data

Onset synchronization of the piano performances was estimated using the MIDI recordings, whilst that of the clarinet performances was computed using the audio recordings.

2.4. Design

This study used a 2 (stimulus group: piano duo vs. clarinet duo recordings) × 8 (stimuli, i.e., performances within stimulus group) × 3 (modality of stimulus presentation: audio only, AO; video only, VO; and, audio plus video, AV) × 2 (music background: novices vs. semi-professionals) design. Stimulus group, duo performance and modality were the within-subject variables, whilst music background was the between-subjects variable. In addition, the instrumental expertise of the semi-professional musicians, being either pianists or clarinets, was a between-subject variable. The order of stimulus group was counterbalanced within music background, and the order of stimuli randomized within each stimulus group. Each recording of the selected excerpt was presented one time in each condition to each participant, except for two randomly selected clarinet and two piano recordings that were presented twice to participants for future analyses of individual consistency. Thus, each participant was presented with a total of 52 recordings (48 stimuli presented once + four repetitions of selected stimuli); the responses related to the four recordings presented the second time were not included here in the analysis of togetherness evaluation.

2.5. Procedure

Participants were invited to take part in a single session that took place at the Department of Music Acoustics of mdw—University of Music and Performing Arts Vienna. First, participants received spoken and written explanations of the research project and the tasks, then they gave written consent to take part in the study and filled in a background questionnaire regarding their music experience. Next, participants were presented with a description of togetherness as follows: "Togetherness is a mental state characterized by the feeling of being in full cognitive synchrony with the co-performer(s). It is often described as being in the zone, or entering a zone of magic, where things naturally flow and click, and everything becomes concerted and blended. During these optimal performance periods, a sense of individual control disappears, and musicians strike a groove together and tend to do everything together."

Then, participants were fitted with wireless glasses tracking their eye-gaze, which were calibrated using a white board with calibration markers. Ultimately, whilst wearing their glasses, participants were asked to watch and/or listen to ensemble recordings presented on a computer screen and simultaneously rate their perception of togetherness between musicians, by moving a horizontal slider from low to high togetherness with a computer mouse, as shown in Figure 3.

Participants completed three practice trials before beginning the first stimulus group, consisting of three piano and clarinet recordings randomly selected from the pool of stimuli prepared for the study. Participants were invited to take a 2-min break between stimulus groups in order to reduce fatigue.

2.6. Analysis

To investigate how visual and audio musical features contribute to audiences' judgments of togetherness between musicians, an analysis procedure was carried out comprising the following three consecutive steps:

1. Extraction of visual and audio features of the duo performances (explanatory variables) as well as participants' togetherness responses (response variable), as listed in Table 2.

6 https://gorilla.sc/

TABLE 3 Generalized linear mixed models fitted in the study to analyse the impact of sound intensity and body motion on togetherness perception by modality of stimulus presentation (i.e., AO, audio only; VO, video only; AV, audio and video) and participants classification (i.e., a, semi-professional musicians; b, novices; c, pianists; d, clarinetists).

Model *n*	Fixed effect(s)	Random effects	Data-set
1	Sound intensity		
a		Participants	AO, semi-professional musicians
b		Participants	AO, novices
c		Participants	AO, pianists
d		Participants	AO, clarinetists
2	QoM, CWT measures		
a		Participants	VO, semi-professional musicians
b		Participants	VO, novices
c		Participants	VO, pianists
d		Participants	VO, clarinetists
3	QoM, CWT measures, sound intensity		
a		Participants	AV, semi-professional musicians
b		Participants	AV, novices
c		Participants	AV, pianists
d		Participants	AV, clarinetists

2. Analysis of the perception lag, since participants' slider movements were expected to lag to some extent behind the musical events.
3. Implementation of step-wise mixed modeling to investigate the impacts of visual and auditory features on the judgment of togetherness, and testing also the effects of modality of stimulus presentation and participants' background, as shown in Table 3).

Details of the three steps are reported in Sections 2.6.1–2.6.5, respectively. In addition, details of the analysis of the eye-gaze behavior of participants whilst completing the rating task are also provided at the end (see Section 2.6.6).

2.6.1. Visual cues: Quantity of motion and between-players coordination

The analysis tested the impact of: (i) coordination in body acceleration and (ii) quantity of body motion (QoM) on togetherness ratings. Strength of coordination was operationalized in terms of the power of common periodic oscillations in musicians' motion, calculated using cross wavelet transform analysis. Coordination of body motion was analyzed for a total of six paired markers placed on the chest, front head, left and right shoulder and arm of each musician (e.g., chest of the Primo with that of the Secondo, etc...). Hand markers were excluded from the coordination analysis as hand motion is more tightly linked to sound production and largely dictated by the score.

In order to measure the strength of coordination, first, acceleration for each marker was computed as the second derivative of smoothed marker positions. They were then subject to cross-wavelet transformation (CWT), using the R package "WaveletComp" (Roesch and Schmidbauer, 2018) with the complex-valued Morlet wavelet as mother wavelet. The range of periods to be considered was decided based on the structure of the music, which comprised three phrases, each lasting about 15 s. The selected periods ranged from 0.3 to 7 s, corresponding to the mean duration of the semi-phrase. Time-series data for the period within this range that had the highest power was extracted for each stimulus and down-sampled to 10 Hz, in order to match the sampling rate of the togetherness response data.

For QoM, two related measures were calculated: (i) total QoM calculated for each duo across all markers and (ii) local QoM computed for the subsets of markers that were selected for the CWT power analysis, i.e., head, right and left arm and shoulder, and chest. Total QoM was computed by summing QoM values across markers at each timestamp, for each musician, then averaging per timestamp across duo partners, to obtain one average series of summed QoM values per duo. Total QoM for the clarinet recordings also included motion of the markers on the clarinets. Local QoM was calculated by averaging QoM per timestamp, across duo partners, for each of the selected markers (i.e., head, chest, and right and left arm and shoulder). Both total and local QoM were sampled at 10 Hz, in line with the togetherness ratings.

It was of interest to test how QoM and strength of coordination differed between body parts (i.e., head, chest, left/right arm/shoulder). This was achieved using step-wise linear mixed models. Body part was entered in the model as the explanatory variable, and time-series CWT power data and local

QoM data were input as response variables. Stimulus number was fitted in the model as a random effect; times nested in stimuli were also entered in the model as auto-regressive errors to address temporal autocorrelation and potential endogeneity within each stimulus across time.

2.6.2. Auditory cues: Sound intensity and onset asynchronies

The effects of auditory cues on togetherness ratings were investigated for two auditory parameters: (i) sound intensity and (ii) interpersonal synchronization. Sound intensity was calculated as the root-mean-square (RMS) of the audio recordings. Values were extracted at 10 Hz with a rectangular window and 50% overlap, since the signals were periodic and all points were equally weighted. Sound intensity data were extracted in Python using Madmom (Böck et al., 2016).

Interpersonal synchronization was calculated for onsets of notes and chords that, according to the music score, were supposed to be performed simultaneously. Notes of interest for the synchronization analysis (including the chords) are indicated in Figure 1. For the piano recordings, note onset timestamps of the chosen notes/chords were extracted from the MIDI recordings, and note asynchronies were computed by subtracting the onset time of the Primo from that of the Secondo. Therefore, positive asynchronies indicate that the Primo was leading, and negative asynchronies indicate that the Primo was lagging. In case of the piano chords (i.e., notes 11, 12, 13, 14 highlighted in Figure 1), average asynchronies were computed by referring to the latest onset (within each chord) of each musician (i.e., Primo and Secondo) and then by subtracting the timestamp of the last onset of the Primo from the timestamp of the last onset of the Secondo.

For clarinet recordings, onset times were first manually labeled by one of the authors (LB, with extensive experience on onset estimation) using Praat based on the waveform and spectrogram of the audio recordings, with a 2 s window display. Then, perceptual onset timestamps were estimated at 70% of the max RMS with 10 ms windows. Asynchronies were eventually computed as for the piano recordings, by subtracting the onset timestamp of the Primo from that of the Secondo.

2.6.3. Ratings of togetherness

The togetherness ratings (the response variable) and corresponding timestamps were recorded *via* the Gorilla platform as dense data: values were reported each time participants moved the sliders, and no values were recorded when the slider remained stationary. For this reason, the exported response data were de-sparsed. A constant interpolation was used to obtain slider values evenly sampled at 10 Hz, since Gorilla was set to collect slider values every 100 ms, which was the smallest setting available. This step produced a list of togetherness ratings per stimulus/duo sampled at 10 Hz.

Two participants reported no change in togetherness (i.e., did not move the slider) in 10 performances. Participants reported on average 46.6 changes per stimulus ($SD = 40.4$), and on average 1 change every 1.11 s. An analysis of the logs from the Gorilla online platform showed that eight of the 1568 trials collected in total during the experiment [i.e., 30 (participants) × 52 (valid trials) + 8 (partial trials)] were loaded twice, because of loading issues during the first attempt. These eight partial trials were excluded from the analysis. An investigation of the total duration of the responses for each stimulus was also computed as the difference between the true duration of each stimulus and the duration of the responses to each stimulus that Gorilla recorded. This difference was on average 144.9 ms ($SD = 30.6$ *ms*), and might have been induced by initial delays in the visual display due to the Internet connection or the computer processor. This discrepancy is considered negligible in light of the total duration of the entire stimulus.

2.6.4. Rating lag response

Togetherness ratings were expected to lag about 1 to 3 s behind changes in auditory and visual signals, in line with literature investigating continuous response to musical events (Schubert and Dunsmuir, 1999; Schubert, 2004; Dean and Bailes, 2010). To estimate a more exact lag time, three mixed linear models per modality condition (i.e., AO, VO, and AV) were implemented. Togetherness ratings lagged by 1 s, 2 s and 3 s comprised the response variables. The explanatory variables were: sound intensity for the AO condition; QoM and CWT power data for the VO condition; and sound intensity, QoM, and CWT power data for the AV condition. Since sound intensity, QoM and CWT power data were highly positively skewed, they were log transformed for the models.

Multicollinearity of model terms related to QoM and CWT per paired markers for the VO and AV condition was tested using the performance (Ludecke et al., 2021) package in R. The variance inflation factor (VIF), which measures the correlation and strength of correlation between the predictor variables in a regression model, was computed for each model. The results demonstrate that VIF was very low for the CWT power measures, but moderate and high for QoM computed per paired markers. For this reason, in each model, total QoM (i.e., summed across all chosen body markers) rather than local QoM (i.e., computed per paired marker) was entered as a fixed effect along with the CWT power measures.

In each model, times were entered within stimuli as first-order auto-regressive errors, and participants were included as random effects. Stimuli number was not entered in the models because the variance was negligible.

Then, to evaluate the three different models related to the three different lags, the K-fold cross-validation (CV) method,

widely adopted as a model selection method (Jung, 2017), was implemented with K = 10, (K - 1) folds of the data used for model construction and the hold-out fold allocated for model validation. In light of the nested nature of the data (i.e., participants fully crossed within all variables), folding was done by participants. Model accuracy was then estimated by computing the average Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) across folds. The model with the lowest MAE and RMSE was selected as the best model.

2.6.5. Impact of expertise, stimuli, and auditory and visual cues on togetherness ratings

After the analysis of the visual, auditory, and perceptual features of the ensemble performances, and the estimation of the most accurate perception lag, the analysis moved to the investigation of changes in togetherness ratings. First, the simple effects of music background, modality, and stimulus group as well as their interactions on togetherness ratings were investigated through a two-way ANOVA on the whole data set. Then, an additional two-way ANOVA was conducted to analyse the simple effects of instrumental expertise, stimulus group, and modality on togetherness ratings. In both ANOVAs, togetherness ratings were entered as mean values for each recording rated.

Three model groups were implemented to test the fixed effects of (i) sound intensity in the AO recordings (see Table 3, Models 1a-1d); (ii) body motion (Models 2a-2d) in the VO recordings; and, (iii) sound intensity and body motion in the AV recordings (Models 3a-3d). Within each model group, model (a) included data from semi-professional musicians, model (b) included data from novices, and models (c) and (d) included data from pianists and clarinetists, respectively.

Explanatory variables (i.e., sound intensity, QoM, and CWT measures) were entered in the models as log transformed data. All of the explanatory variables (i.e., togetherness ratings, QoM, CWT power, and sound intensity) were entered as continuous variables. Togetherness ratings were entered in the models as lagged data, with lag time corresponding to the most accurate model resulting from the k-fold validation (see analysis description above). Participant number was entered as random intercept; stimulus number was not entered as a random effect in any model as the variance was negligible. In addition, the random effects of time nested within stimuli with first-order auto-regressive errors were fitted in the models to address temporal autocorrelation and potential endogeneity within each stimulus across time. Following Bonferroni correction, the alpha level for each model was set at $\alpha = 0.0125$ (four mixed models per modality).

In addition to the models above, the impact of interpersonal synchronization (explanatory variable) on togetherness perception (response variable) was investigated. This was done for individual modality conditions (i.e., AO and AV) using data for semi-professionals and novices in separate models, and for pianists and clarinetists in separate models. Participant number was entered in each model as random intercept, whilst the effects of the chosen note number was negligible and for this reason was not entered in the model. Importantly, whilst sound intensity, QoM and CWT measures were entered in the previous models as continuous variables, onset asynchronies are discrete values. In order to analyse the impact of synchronization on togetherness response, these two measures had to be temporally aligned; for this purpose, the last note onset time of each chord was used as a reference point, and togetherness ratings were taken that lagged behind each reference point by the duration dictated by the most accurate perceptual model resulting from the k-fold validation analysis presented in the previous section.

Generalized linear mixed modeling was implemented using the glmmTMB package (Brooks et al., 2017) in R. Assumptions of linearity and homoscedasticity were checked for the residuals using the DHARMa package in R; results show that assumptions were met.

2.6.6. Fixation times

Having analyzed changes on togetherness perception for some visual and auditory features of the recordings, it was of interest to analyse the eye-gaze behavior of the participants who completed the rating tasks. We carried out post-processing in SMI BeGaze. Five areas of interest (AOI) were manually defined for each stimulus video: (1) Head of the Primo, (2) Upper body and hands of the Primo, (3) Head of the Secondo, (4) Upper body and hands of the Secondo, and (5) Center (see Figure 3). Beginnings and endings of each stimulus were manually annotated in the eye-tracking takes. Percentage of total fixation time for each AOI was computed and extracted with 1 s bins. Average fixation times were then computed for each stimulus/participant/AOI. Finally, mean fixation values (response variable) were fit in a linear mixed model to estimate the fixed effects of music training and AOI, with random effects of stimuli and participants.

3. Results

This section reports first the results of the music performance features (see Section 3.1), analyzed to contextualize the findings regarding changes of perception of togetherness based on performance cues, then presents the results of the impact of the external music performances' features (i.e., participants' background and expertise, modality of stimulus presentation and stimulus group, see Section 3.2) and the performance cues (i.e., visual and auditory cues, see Section 3.3) on togetherness ratings. This section concludes with the findings related to the eye-gaze analysis (see Section 3.4).

3.1. Music performances features

As shown in Figure 4, both QoM (Figure 4A) and CWT power (Figure 4B) differed significantly across body parts. Interestingly, they were both highest in head motion, followed by the right arm motion. Chest motion was lowest in QoM and CWT power.

For interpersonal synchronization, mean absolute asynchronies were 127 ms ($SD = 221$ *ms*) in the piano recordings and 137 ms ($SD = 207$ *ms*) in the clarinet recordings. These asynchronies are larger than those that arise in music with less temporal flexibility and a steadier beat (Keller, 2014).

3.2. Impact of external music performances' features on togetherness ratings

Simple main effects analysis from the two-way ANOVA showed that music background had a significant effect on

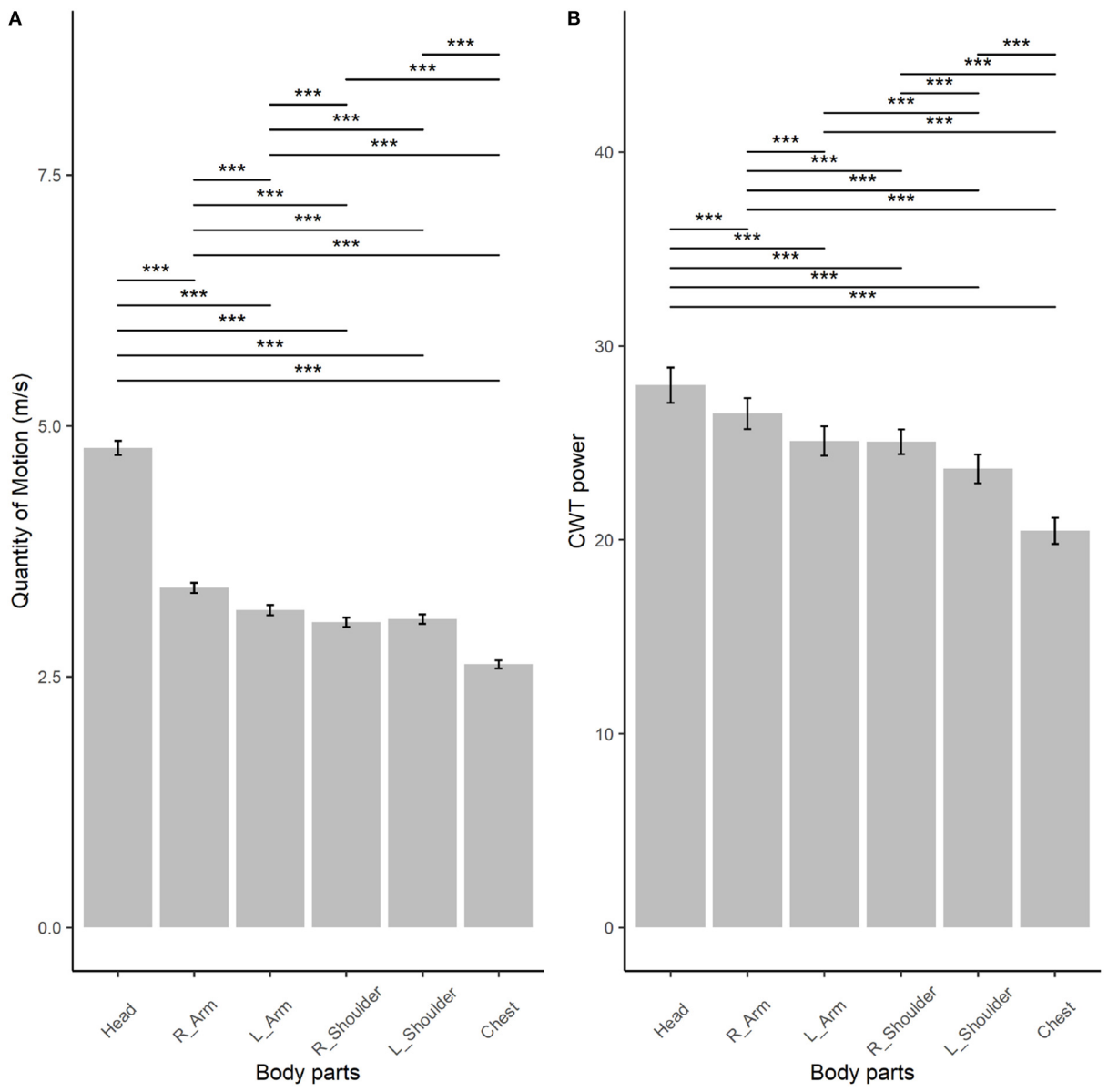


FIGURE 4
Quantity of motion (QoM, **A**) and cross-wavelet transforms (CWT, **B**) power by body parts (i.e., head, right and left arm [R_Arm and L_Arm] and shoulder [R_Shoulder and L_Shoulder], and chest), based on linear mixed modeling. Error bars represent 95% CI of the mean. *P*-values were adjusted using the Tukey *post-hoc* tests. ***$p < 0.001$.

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togetherness ratings [$F_{(1,1428)} = 95.3$, $p < 0.001$], whilst modality of stimulus presentation and stimulus group were non-significant. As shown in Figure 5A, novices rated the stimuli as more together than did the semi-professional musicians. The ANOVA also revealed a significant interaction between music background and modality of stimulus presentation [$F_{(2,1428)} = 7.5$, $p < 0.001$], but there were no significant interactions between any remaining pairs of effects (i.e., stimulus group and modality, music background and stimulus group, or stimulus group, music background and modality).

Tukey's HSD test for multiple comparisons found that novices' ratings of AV and AO recordings were significantly higher that those of the semi-professionals related to the same modality [$p < 0.001$, 95% $CI = [-15.6, -6.7]$ and $p < 0.001$, 95% $CI = [-15.8, -6.9]$, respectively]. Interestingly, novices' ratings of VO stimuli was not different than semi-professionals' ratings of AV and VO stimuli (see Figure 5B), suggesting that the differences in ratings between novices and semi-professional musicians relied on presence/absence of the audio modality.

An additional two-way ANOVA on the subset of data comprising only the semi-professional musicians showed that the instrumental expertise of the musicians and the modality of stimulus presentation had a significant effect on togetherness ratings [$F_{(1,948)} = 9.4$, $p < 0.01$ and $F_{(2,948)} = 4.2$, $p < 0.05$, respectively]. As shown in Figure 5C, pianists rated the recordings as more together than did clarinetists. There was no overall effect of stimulus group, and no significant interactions between modality of stimulus presentation, instrumental expertise and stimulus group.

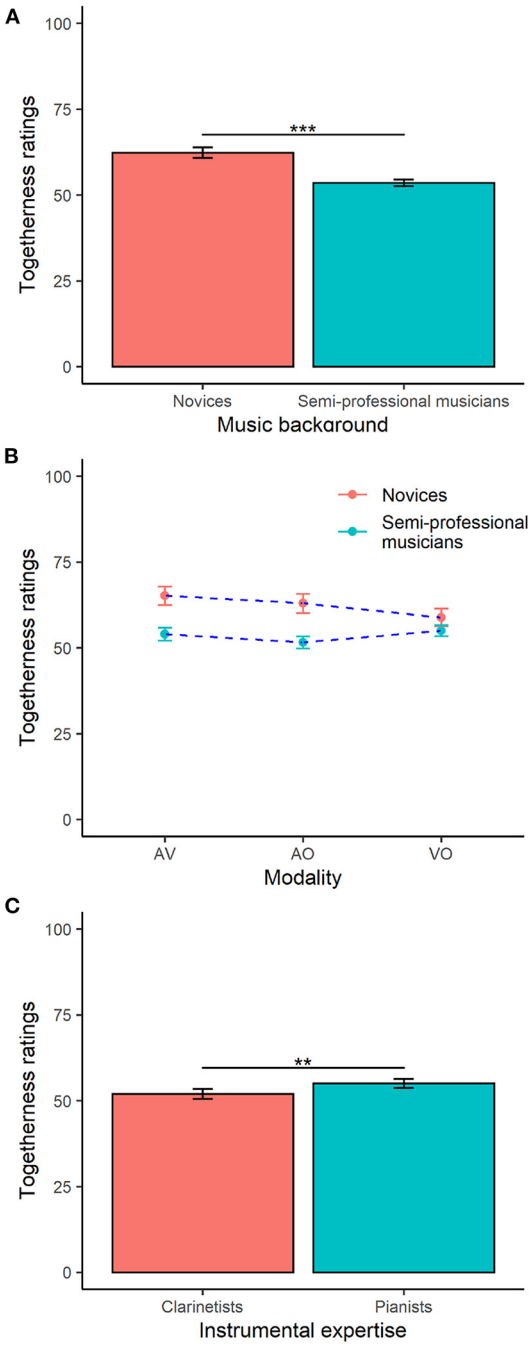


FIGURE 5
Ratings of togetherness by music background [**(A)**, novices vs. semi-professional musicians]; the interactions **(B)** between modality of stimulus presentation (audio plus video [AV], video only [VO] and audio only [AO]) and music background; and, instrumental expertise of the semi-professional musicians [**(C)**, clarinetists vs. pianists]. Maximum and minimum values on the y-axis have been fixed to allow comparison between the graphs against the full range of the scale. Error bars represent 95% CI of the mean. $^{**}p < 0.01$; $^{***}p < 0.001$.

3.3. Impact of performance cues on togetherness ratings

3.3.1. Lag response

The k-fold cross validation conducted for each condition in order to estimate model accuracy demonstrated that the three models, implemented to evaluate the response time of the togetherness ratings, performed better at lag 1, although with a decimal point of difference, as shown in the accuracy measures in Figure 6. Based on these results, the analysis of the impact of visual and auditory cues on togetherness ratings was conducted accounting for a 1 s lag of the togetherness ratings.

3.3.2. Sound intensity and body motion

Togetherness ratings of pianists, clarinetists and semi-professional musicians were not predicted by the sound intensity of the AO and AV stimuli (see models 1a,c,d and 3a,c,d in

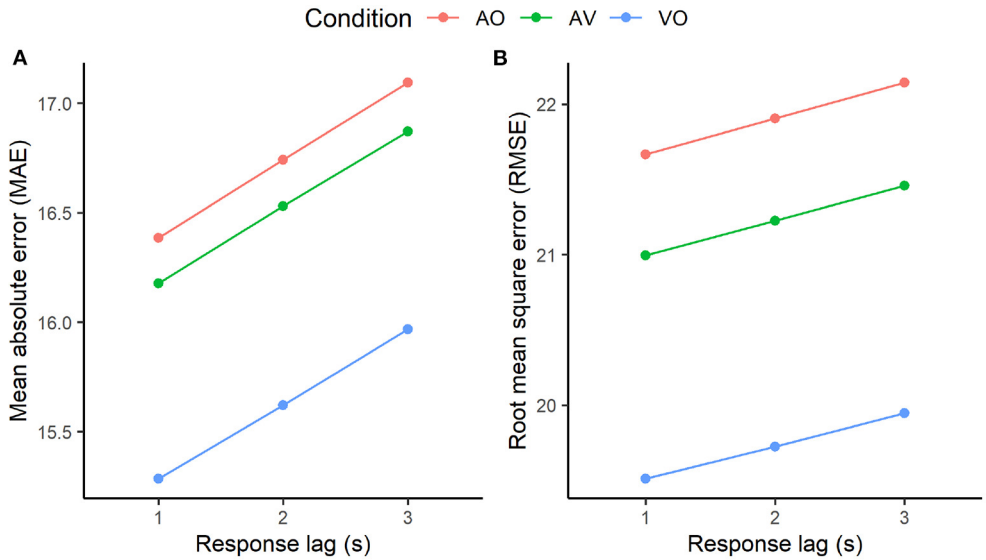


FIGURE 6
K-fold cross-validation accuracy of models computed at different response lag times (i.e., 1, 2, and 3 s lag) for the audio only (AO), video only (VO), and audio plus video (AV) conditions. Model accuracy was measured in terms of mean absolute error (MAE, **A**) and room mean square error (RMSE, **B**).

Tables 3, 4). Interestingly, novices' ratings of AO and AV stimuli related positively to sound intensity: the higher the sound intensity, the more together the recordings were judged [model 1b in Table 4: $\beta = 3.8$, 95% $CI[1.5, 6.1]$, $t_{(72420)} = 3.2$, $p < 0.01$; and, model 3b in Table 4: $\beta = 3.7$, 95% $CI[1.3, 6]$, $t_{(74020)} = 3.1$, $p < 0.01$, respectively].

In addition, novices' ratings of VO stimuli related positively to the CWT power of the right arm: the greater the synchronicity in right arm acceleration, the more together the recordings were rated [model 2b, Table 4: $\beta = 0.7$, 95% $CI[0.3, 1.1]$, $t_{(74020)} = 3.2$, $p < 0.01$); conversely, semi-professional musicians did not rate togetherness in VO stimuli based on body motion (model 2a in Tables 3, 4].

Furthermore, novices' ratings of AV stimuli also related positively to right arm synchronicity: the higher the coordination in common periodicities, the higher the togetherness ratings [model 3b, Table 4: $\beta = 0.6$, 95% $CI[0.2, 1]$, $t_{(74020)} = 2.8$, $p < 0.01$]. Interestingly, pianists' ratings of AV stimuli related positively to chest motion: the higher the coordination in common periodicities in chest acceleration trajectories, the higher the togetherness ratings [model 3c, Table 4: $\beta = 0.5$, 95% $CI[0.1, 0.9]$, $t_{(74020)} = 2.5$, $p < 0.01$].

3.3.3. Sound synchronization

Interpersonal synchronization was a significant predictor of togetherness ratings only for semi-professional musicians, not for novices. Specifically, the smaller the asynchronies of the AV stimuli, the more together the performances were perceived by the semi-professional musicians [$\beta = -0.005$, 95% $CI[-0.01, 0.00]$, $t_{(4320)} = -3.5$, $p < 0.001$]. Interestingly, these results did not rely on the pianists' judgement, but on that of the clarinetists' evaluation [$\beta = -0.006$, 95% $CI[-0.01, 0.00]$, $t_{(4320)} = -3.0$, $p < 0.01$].

3.4. Eye-gaze

Participants spent most time looking at the upper body of the Secondo and their instrument; then, in descending order, participants looked at the upper body of the Primo and their instrument [$\beta = (-4.7)$, $t_{(45879)} = -8.9$, $p < 0.001$], the center of the screen [$\beta = (-17.4)$, $t_{(45879)} = -32.9$, $p < 0.001$], the head of the Secondo [$\beta = (-18.8)$, $t_{(45879)} = -35.5$, $p < 0.001$], and the head of the Primo [$\beta = (-20.4)$, $t_{(45879)} = -38.7$, $p < 0.001$] (see Figure 7). The music training of the participants did not predict how visual attention was distributed across AOIs.

4. Discussion and conclusion

This study investigated the real-time, continuous judgement of togetherness in musical duos by an audience with varying music background. Ratings of togetherness were analyzed in relation to certain visual and auditory features of the music performances as well as the modality of stimulus presentation. Audio only (AO), video only (VO) and audio plus

TABLE 4 Overview of the generalized mixed models displaying β coefficients and significance measuring the relationship between performance cues (i.e., auditory and visual cues) and togetherness ratings for each modality (i.e., AO, audio only; VO, video only; and AV, audio+video) and each participant group (i.e., semi-professional musicians, novices, pianists, clarinetists, and all participants).

Condition	Predictors	Semi-pro	Novices	Pianists	Clarinetists	Model *n*
AO						
	Sound intensity	ns	3.8**	ns	ns	1a-d
	Synchronization	ns	ns	ns	ns	4a-d
VO						2a-d
	QoM	ns	ns	ns	ns	
	Head	ns	ns	ns	ns	
	Chest	ns	ns	ns	ns	
	L Shoulder	ns	ns	ns	ns	
	R Shoulder	ns	ns	ns	ns	
	L Arm	ns	ns	ns	ns	
	R Arm	ns	0.7**	ns	ns	
AV						
	Sound intensity	ns	3.7**	ns	ns	3a-d
	Synchronization	−0.005***	ns	ns	−0.006**	5a-d
	QoM	ns	ns	ns	ns	3a-d
	Head	ns	ns	ns	ns	3a-d
	Chest	0.5**	ns	0.5**	ns	3a-d
	L Shoulder	ns	ns	ns	ns	3a-d
	R Shoulder	ns	ns	ns	ns	3a-d
	L Arm	ns	ns	ns	ns	3a-d
	R Arm	ns	0.6**	ns	ns	3a-d

The table also displays the model number used for the analysis of the continuous variables (i.e., 1 and 4 for AO stimuli, 2 for VO stimuli, and 3 and 5 for AV stimuli; "a" for models regarding semi-professional musicians, "b" for the novices, "c" for the pianists, and "d" for the clarinetists). The auditory cues were sound intensity and synchronization whilst visual cues were: total quantity of motion (QoM) and CWT power measures related to head, chest, left (L) and right (R) shoulder and arm. Semi-pro, semi-professional musicians; ns, non-significant; $^{**}p < 0.01$; $^{***}p < 0.001$.

video (AV) modalities were tested. In addition, the eye-gaze behavior of the participants whilst rating togetherness was also analyzed, in order to contextualize any findings related to the togetherness response.

Audience perception of togetherness was found to be heavily informed by the music background of the participants and its interaction with the modality of stimulus presentation. Novices in our study generally rated the performances more together than the semi-professional musicians. This is somewhat in contrast to results reported by Jakubowski et al. (2020), who found that synchronization ratings for non-pulsed music were slightly positively correlated with the numbers of years of musical training. Overall, musical training may play a different role in the perception of synchronization than that of togetherness. Notably, in our study, novices' ratings of togetherness in AV and AO stimuli were higher than the semi-professional musicians' ratings of AV, AO, and VO stimuli, but novices' ratings of VO did not differ than those of the semi-professional musicians. This implies the relevance of the audio information in the togetherness evaluation of novices and semiprofessional musicians. These results are somewhat also in line with previous studies on synchronization judgements observing higher ratings of synchrony in the evaluation of AO and AV stimuli than VO recordings (Jakubowski et al., 2020).

The study also showed that novices' judgment of togetherness between musicians was positively related to sound intensity, in both AO and AV recordings: the higher the sound intensity, the more together novices judged the recordings. Previous studies on listeners' perception of sound intensity demonstrate that this feature is perceived in terms of physical effort and physical expression of the performance (Olsen and Dean, 2016). Novices in this study responded to perceived loudness as they might have understood togetherness in terms of increasing emotional intensity, or loudness might have been the most noticeably changing feature for them. Conversely, semi-professional musicians did not respond to sound intensity when rating the AV recordings, but to note-to-note synchronization, a factor that often contributes to performance excellence in ensemble playing. This effect arose mostly for the clarinetist listeners. This result is also somewhat in line with Jakubowski et al. (2020) observing that mean

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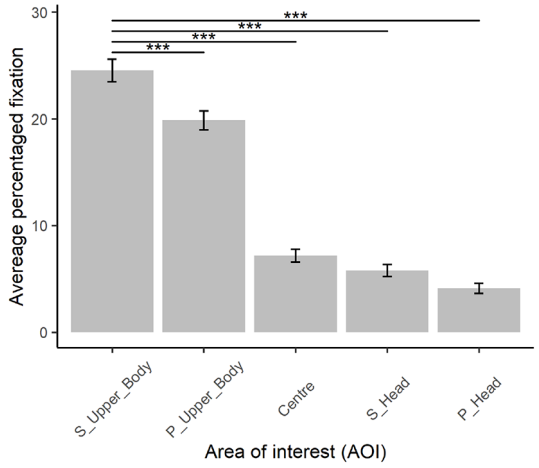


FIGURE 7
Distribution of visual attention across different areas of interest (AOI): S_Upper_Body (upper body of the Secondo), P_Upper_Body (upper body of the Primo), center of the screen, S_Head (head of the Secondo) and P_Head (head of the Primo). Error bars represent 95% CI of the mean. ***$p < 0.001$.

synchrony ratings were positively related to the years of musical training of the listeners, i.e., the higher the number of years of musical training, the higher the level of synchrony between musicians was judged.

Overall, these results imply that trained musicians are sensitive to asynchrony in music, and that precision in perception of asynchrony increases with training (Mossbridge et al., 2006) and affects judgments of togetherness. Novices associate togetherness with loudness, maybe because loudness changes are relatively easy to discern. Future studies might also investigate to what extent the relationship between synchronization and togetherness ratings depend on the style of the music and the artistic intentions of the musicians. Listeners might also rate as highly together music that explicitly avoids a tight synchronization between musicians for expressive reasons, for example, to increase grooviness (Skaansar et al., 2019).

Interestingly, novices also rated the VO and AV recordings based on the coordination of the right arm motion: the greater the synchronicity in common periodicities of acceleration trajectories of the right arm, the more together recordings were rated. Quantity of body motion (QoM) and similarity in acceleration trajectories were highest for head motion, followed by right arm motion. The latter was part of the upper body area where participants spent more time looking whilst rating togetherness. Overall, these results suggest that novices were informed by similarity in right arm coordination as they were looking at body parts with higher QoM and with more similar coordination. Conversely, semi-professional musicians rated AV recordings in relation to the chest, which represents the body center: the higher the coordination in common periodicities in chest acceleration trajectories, the higher the togetherness ratings. Taken together these results imply that semi-professional musicians sought information in the overall quality of coordination of the body motion, whilst novices were informed by individual body parts that had the highest QoM and coordination power, such as right arm motion.

Whilst perception of togetherness in AO and VO stimuli was related to sound intensity and right arm motion, perception in the AV stimuli was related to sound synchrony and chest motion (for semi-professional musicians) and sound intensity and right arm motion (for novices). This suggests that perceptions of togetherness are shaped in complex ways by the different information that is available about a performance. The fact that both auditory and visual features of the performances contributed significantly to perceived togetherness in the AV recordings further expands Jakubowski et al. (2020) in which the authors demonstrated, in line with studies on performance quality (Tsay, 2013), that some aspects of the visual information (i.e., total QoM and energy of the similarity in common periodicities of body motion) were better predictors of continuous synchrony ratings than certain auditory cues (i.e., event density, pulse clarity and spectral flux). Taken together, these results suggest the relevance of auditory and visual information in the perception of interpersonal synchronization and feelings of togetherness between musicians in ensembles.

Contrary to our prediction, quantity of body motion did not contribute to the perception of togetherness, but in other research this was found to be a predictor of perceived synchrony (Jakubowski et al., 2020). The different material used for the study might explain these results. Another explanation might be that the overall quantity of motion indeed does not contribute to togetherness judgments but to perceived synchrony, and that participants judged togetherness more in terms of quality (and therefore they responded to the similarity of certain body parts' coordination) than quantity of motion.

This study also analyzed the perception of togetherness in relation to the eye-gaze behavior of an audience whilst rating togetherness. Results showed that our participants looked most at the Secondo upper body and their instrument. Participants' attention to body rather than head motion suggests that they may have sought information where there was more motion. Their attention might have been drawn instead to the players' heads if the players' faces had been visible. Future studies might replicate this investigation by having musicians' full body visible, rather than just skeletons, and further investigate whether periods of togetherness are associated with players' faces. Participants' visual attention to the Secondo might be due to the fact that the Secondo was placed on the right side of the screen, which participants might assume indicates a more important role.

In this study, we investigated how audience members judged how much the musicians experienced togetherness, and we measured this by relating audience ratings to certain objective

measurements that might be informative of togetherness between musicians (i.e., sound synchronization and body motion similarity). Future investigation might replicate this study considering also musicians' perception of togetherness in parallel to the audience perspective of togetherness. A mixed design allowing the triangulation of musicians' and audiences' perceived togetherness as well as togetherness measured in body motion and sound recordings is currently underway in our lab and should shed more light on the relationships between subjective and objective measurements of togetherness from the perspective of the musicians as well as the audiences.

Some limitations of the study should be noted. First, in this study, participants were presented with reduced stimuli comprising only audio and body motion, without other potentially useful cues like facial expressions or gaze. This was done to investigate systematically whether body motion would inform audience evaluation of togetherness. Future studies might replicate this study with a more ecological recordings, showing musicians' face too.

Second, the study does not allow for conclusions to be drawn about how the different temporal resolutions of auditory and visual processing affect togetherness judgements. Timing is perceived more precisely in auditory signals than in visual signals (Hove et al., 2013). Correspondingly, the same absolute magnitude of asynchrony might be more readily noticed in musicians' sound output than in their periodic body motion. It remains an unresolved question how audiences integrate information about auditory and visual synchrony in music performances, especially if, for example, the performers look synchronized despite asynchronies in their sound being audible. The current study was not intended to investigate this sort of conflict; indeed, to do so, it would be necessary to construct very controlled stimuli where auditory and visual synchrony were independently manipulated. However, our finding that both sound and visual coordination contribute to judgments of togetherness lays the groundwork for future studies, which may investigate how these cues to togetherness interact.

To conclude, this study contributes to a better understanding of how togetherness is judged. By building on literature investigating togetherness from the perspective of the performer (Sawyer, 2006; Hart et al., 2014; Hart and Di Blasi, 2015; Gaggioli et al., 2017) and focused mainly on self-reported experiences of togetherness, this study shows that togetherness judgements are multimodal and shaped by several interacting factors, including both auditory and visual features of the performances. Sound intensity, sound synchronization, and similarity in body motion coordination play major roles in the evaluation of togetherness. This complex construct can be meaningfully understood by novices, even if in a different way than the experts. The results of this study advance our understanding of the visual and auditory cues that contribute to the perception of togetherness between musicians in ensemble playing. These findings also provide a valuable contribution to social psychology by clarifying the perceptual mechanisms involved in socio-cognitive judgments of human interactions and coordination.

Data availability statement

The datasets, including stimuli and the togetherness ratings, can be found at https://doi.org/10.5281/zenodo.7128672.

Ethics statement

The Ethics Committee at mdw—University of Music and Performing Arts Vienna approved the procedures of this study (reference EK Nr: 05/2020). The participants provided their written informed consent to participate in this study.

Author contributions

SD made a substantial contribution to data acquisition, analysis, and interpretation and drafted the article. LB and WG contributed to the analysis and interpretation of the data collected. All authors equally contributed to the conception and design of the study, critically revised the article, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Differences of respiratory kinematics in female and male singers – A comparative study using dynamic magnetic resonance imaging

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Breath control is an important factor for singing voice production, but pedagogic descriptions of how a beneficial movement pattern should be performed vary widely and the underlying physiological processes are not understood in detail. Differences in respiratory movements during singing might be related to the sex of the singer. To study sex-related differences in respiratory kinematics during phonation, 12 singers (six male and six female) trained in the Western classical singing tradition were imaged with dynamic magnetic resonance imaging. Singers were asked to sustain phonation at five different pitches and loudness conditions, and cross-sectional images of the lung were acquired. In each dynamic image frame the distances between anatomical landmarks were measured to quantify the movements of the respiratory apparatus. No major difference between male and female singers was found for the general respiratory kinematics of the thorax and the diaphragm during sustained phonation. However when compared to sole breathing, male singers significantly increased their thoracic movements for singing. This behavior could not be observed in female singers. The presented data support the hypothesis that professional singers follow sex-specific breathing strategies. This finding may be important in a pedagogical context where the biological sex of singer and student differ and should be further investigated in a larger cohort.

KEYWORDS

respiration, phonation, singer, diaphragm, voice, sex, gender, dynamic magnetic resonance imaging

Introduction

Effective respiratory control is an important factor of voice production and its dysbalance has been associated with several voice disorders (Hixon and Hoit, 2005). However, in voice pedagogy very different descriptions can be found for what is considered an efficient breathing strategy, and a wide variation of respiratory movement patterns can be observed in successful singers during Western style classical singing (McCoy, 2005; Sonninen et al., 2005). These differences could be related to the singers' sex, but studies analyzing sex-related influences on respiratory kinematics during voice production so far showed conflicting results (Watson and Hixon, 1985; Watson et al., 1990; McCoy, 2005): a questionnaire-based survey reports significant differences in the localization of breathing motions between female (lower abdomen) and male singers (upper abdomen). McCoy describes that these differences correlated well with the sex of authors of relevant singing pedagogic literature and their descriptions on where respiratory movements should take place during singing (McCoy, 2005a). However, a degree of mismatch between the believed and measured respiratory movements are described even for professional singers (Watson and Hixon, 1985; Griffin et al., 1995). In measurements by Watson and colleagues of the anterior–posterior diameter of the chest and the abdomen during singing, the authors were not able to experimentally confirm the sex-related difference postulated by McCoy (Watson and Hixon, 1985; Watson et al., 1990). Still, a recent study analyzed ventilation profiles of professionally trained singers and suggested sex-related difference in the movement pattern of thorax and diaphragm (Traser et al., 2017a). With dynamic MRI respiratory movements can be imaged dynamically during phonation. Dynamic MRI was first used in a pilot study on six professional singers to compare sustained phonation with exhalation (Traser et al., 2017b). General aspects of breath support during singing were here firstly described by specific respiratory kinematics of the thorax and diaphragm during sustained phonation.

The aim of this study is the analyzation of respiratory movements during phonation with regards to sex-related differences. A better understanding of possible sex-specific differences in respiratory movements during singing could help to avoid counterproductive or even vocal health threatening habits in singing voice training.

MRI was chosen as imaging technique as it provides a radiation-free, non-invasive way to record dynamic physiological processes inside the human body. It is therefore possible to analyze inter-individual differences in respiratory kinematics as well as respective changes of lung volume related anatomical distances in individuals including healthy ones. Still, beside the pulmonary aspects during singing it is also important to acquire information about the processes in the other parts of the voice instrument (e.g., vocal fold vibration, subglottic pressure, and resonance properties) as these systems are always interdependent (Sundberg, 1987). Nevertheless, due to the magnetic forces and the loud noise during MR scanning, it is necessary to record supplementary data outside the scanner in a separate session as described in detail in the method section. Only electroglottography (EGG) could be successfully implemented synchronously to MRI recording (Özen et al., 2015).

Materials and methods

Subjects

This study was approved by the institutional review board (Medical Ethics Committee) of the University of Freiburg, Germany (273/14). Twelve singers trained in the Western classical singing tradition were included, of which 10 were professional singers, defined as having their primary income from singing, and two subjects (Nr. 6 and 7) were experienced semi-professional singers with more than 15 years of singing training who regularly sing in semi-professional ensembles. All professional trained singers were graduates from different music universities. Here they were trained by different singing teachers in the Western classically singing technique. The semi-professional singers did not graduate from music university but had received regular singing lessons for more than 15 years from professionally trained singing pedagogues. Table 1 lists age, sex, voice classification, classification according to the Bunch and Chapman taxonomy[1] (Bunch and Chapman, 2000) and subject characteristics including vital capacity (VC), forced expiratory volume in 1 s (FEV1), body height and weight and body mass index (BMI) of all subjects. At the time of the study none of the participants reported vocal diseases, histories of voice disorders, or respiratory pathologies. Spirometry was performed in all subjects to analyze pulmonary function using a spirometer (ZAN, Messgeräte GmbH, Oberthulba, Germany) according to current clinical guidelines (Sorichter, 2009).

Magnetic resonance imaging

The imaging of the singers' breathing apparatus was performed using a clinical 1.5 T MRI system (Tim Symphony, Siemens, Erlangen, Germany) as reported in the pilot study (Traser et al., 2017b). The subject positioning was supine (see limitation section for detailed discussion of the potential effects of gravity on the results). Dynamic imaging was done using a 2D

1 The Bunch and Chapman taxometrie offers criteria for determining the classification of singers in research. It suggests a system in which scientific research related to singing is based on a quantifiable singing standard. It includes nine singer categories based on proven performance achievement. These categories range from superstar (household name) to local community and amateur singers with com-prehensive subcategories under each topic for each type of singer, that is, opera, pop, jazz, etc.

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TABLE 1 Subject number, age, sex, voice classification, classification according to the Bunch and Chapman taxonomy (Bunch and Chapman, 2000), vital capacity (=VC), forced expiratory volume in 1 s (= FEV1), body height and body-mass-index (=BMI).

Subject	Age	Sex	Voice classification	Bunch and Chapman taxonomy	VC in l	FEV1 in l/s	Height in cm	BMI in kg/m²
1	25	Female	Soprano	3.15b1	3.87	3.46	167	19.72
2	28	Female	Soprano	4.5	4.72	3.88	165	23.87
3	25	Female	Soprano	3.15b1	3.71	3.28	158	18.82
4	34	Male	Tenor	3.4	5.10	3.35	175	21.55
5	32	Female	Soprano	3.1b	3.28	2.90	157	21.50
6	33	Male	Tenor	5.4	4.92	3.21	171	21.20
7	32	Female	Soprano	5.4	4.56	3.77	170	22.49
8	25	Male	Tenor	7.2	5.11	4.15	186	22.25
9	27	Male	Tenor	3.1b	5.13	4.11	172	27.04
10	42	Male	Tenor	4.5	6.32	5.31	192	25.22
11	30	Male	Baritone	3.1a	6.26	5.29	190	27.70
12	33	Female	Soprano	3.4	3.19	2.29	162	26.67

Subjects 1–3, 10, 11 were also part of the pilot study (Traser et al., 2017b).

trueFISP imaging sequence (repetition time/echo time = 3/1.5 ms, $\alpha = 6°$, bandwidth (BW) = 977 Hz/px, slice thickness = 10 mm, acquisition matrix = 256, field of view (FOV) = 420 mm) with a temporal resolution of approximately three frames per second. First, localizer images at three different planes were acquired to define the imaging planes in sagittal and coronal orientations. For the sagittal trueFISP images, a slice through the right lung was chosen to avoid artefacts caused by heart motion, which would complicate the image analysis. The sagittal plane was selected so that the vertex of the DPH cupola and the apex of the lung could be identified (see Figure 1 for details). The coronal plane was chosen similarly, encompassing both vertices of the left and right DPH cupola and the apices of the left and right lung. During imaging the subjects wore headphones for hearing protection and communication.

Tasks

During the MRI, singers were first ask to breathe in and out as deeply as possible in order to assess the movements of their respiratory system during VC breathing. As in the pilot study (Traser et al., 2017b), singers were asked to sustain phonation on vowel [a:] at three different pitches for as long as possible (maximum phonation time, MPT) at medium loudness (mezzo forte, mf). The subjects were then asked to repeat phonation at the medium pitch in two additional loudness conditions (pianissimo, pp.; fortissimo, ff). The phonation tasks were chosen according to the voice classification of the singer and they represented a low (P_1), medium (P_2), and high pitch (P_3) in the tessitura of the respective repertoire of the singer (see Table 2 for details). The tasks were chosen to allow evaluation not only of a single frequency range but to provide a basic representation at different points of the voice range profile. First, all dynamic MRI acquisitions were performed in a sagittal image orientation, and then the entire protocol was repeated in a coronal orientation. The tasks were explained to the singers prior to the experiment and they had the possibility to repeat a task if the singer was not satisfied with the performance.

Data of the two semi-professional singers were collected as part of a different study protocol, which did not include VC breathing. Thus, their data could only be analyzed during phonation and was excluded for evaluation in relation to VC breathing. A total of 12 image series (six sagittal and six coronal) was acquired per subject (five image series for the two singers with the missing VC data).

Image analysis

In each dynamic MRI frame, distances between anatomical landmarks were measured using an in-house software developed in Matlab 9.1 (MathWorks, Natick, Massachusetts, United States). The dynamic changes of these distances during phonation allow comparing respiratory motion patterns in the different areas of the respiratory system. Six distances were derived from the sagittal images: anterior diaphragm height (DPH_{ant}), medial diaphragm height (DPH_{med}), posterior diaphragm height (DPH_{post}), anterior–posterior diameter at the height of the 3rd rib (pD3R), and anterior–posterior diameter at the height of the 5th rib (apD5R). From the coronal image series two parameters were extracted: medium diaphragm height of the right lung (DPH_{right}) and medium diaphragm height of the left lung (DPH_{left}). A detailed graphical description of distances and anatomical aspects in the images are shown in Figure 1. Measurement points are defined in Table 3. For best comparability these measures were selected based on existing literature on the subject (Traser et al., 2017b, 2020a, 2021).

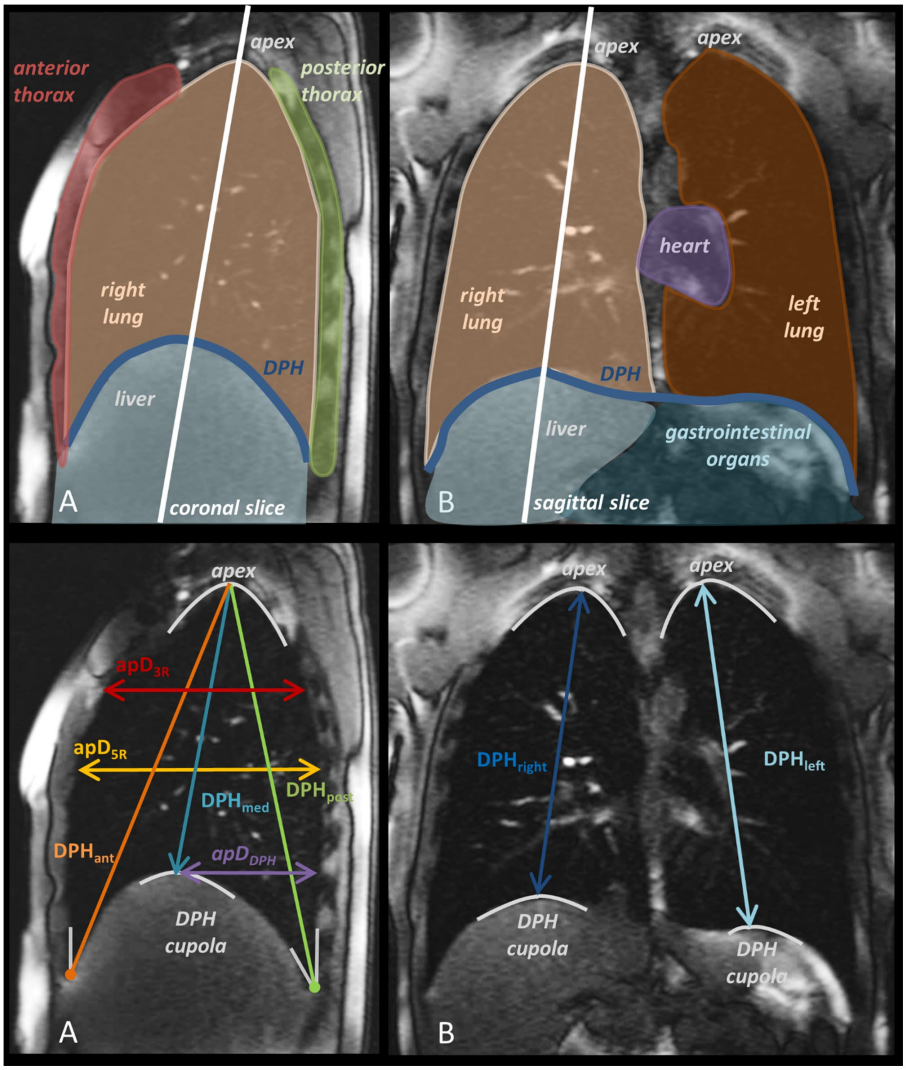


FIGURE 1
Sagittal **(A)**, and coronal **(B)**, MR image with anatomical designations and slice orientation (upper row) and measured distances with their definition according to anatomical landmarks (lower rows).

TABLE 2 List of the tasks performed by the subjects according to different voice classifications including pitch and loudness.

	Female		Male			
Voice classification/task	**Soprano**		**Tenor**		**Baritone**	
Vital capacity breathing	**Maximal inspiration and expiration**					
	Pitch	**Loudness**	**Pitch**	**Loudness**	**Pitch**	**Loudness**
P1mf:	A3 (220Hz)	mf	A2 (110Hz)	mf	F2 (87 Hz)	mf
P2mf:	A4 (440Hz)	mf	A3 (220Hz)	mf	F3 (175Hz)	mf
P3mf:	A5 (880Hz)	mf	A4 (440Hz)	mf	F4 (349Hz)	mf
P2pp:	A4 (440Hz)	pp	A3 (220Hz)	pp	F3 (175Hz)	pp
P2ff:	A4 (440Hz)	ff	A3 (220Hz)	ff	F3 (175Hz)	ff

Data workflow and normalisation

To compare sustained phonation of different durations, the time axis was re-scaled: the beginning of phonation was defined as t_{start} and the end as t_{end}. The measured distances (A) at different timepoints $A(t)$ and different locations were normalized (A_{norm}) according to

TABLE 3 Anatomical definition of distances in sagittal and coronal plane.

Sagittal plane	
DPH_{ant}	Craniocaudal lung height from the angle of the anterior DPH and the RC to the apex of the lung
DPH_{med}	Craniocaudal lung height from the medial part DPH at its highest point of the cupola to the apex of the lung
DPH_{post}	Craniocaudal lung height from the angle of the posterior DPH and the RC to the apex of the lung
apD_{3R}	The anterior–posterior lung diameter at the height of the 3th rip
$apD5_{R}$	The anterior–posterior lung diameter at the height of the 5th rip
apD_{DPH}	The anterior–posterior diameter from the highest point of the cupola of DPH to the posterior boundary of the lung
Coronal plane	
DPH_{right} and DPH_{left}	Craniocaudal lung height from highest point of DPH to the apex of the right and left lung

DPH = diaphragm.

$$A_{norm}(t) = \frac{A(t) - A(t_{end})}{A(t_{start}) - A(t_{end})} \cdot 100\%$$

Additionally, the slope (*m)* of all graphs was calculated in steps of 20% as the ratio of changes in measured distances over time (m_1 to m_5).

$$m_n = \frac{A_{norm}(t_n) - A_{norm}(t_{n-1})}{t_n - t_{n-1}}$$

In the next step, data were normalized according to vital capacity at maximum and minimum respiration. Here, the amplitude at maximal inspiration was set to 100% (A_{VCmax}), and the amplitude at maximal expiration was set to 0% (A_{VCmin}). Again, phonation time was scaled as described above. Based on the individual normalization to VC breathing, a quotient was established that represents the movement range during maximum sustained phonation in relation to the individual's VC respiration (range of movement, $ROM_{p/r}$). This was calculated from the raw data according to:

$$ROM_{p/r} = \frac{A(t_{start}) - A(t_{end})}{A(t_{VCmax}) - A(t_{VCmin})} \cdot 100\%.$$

Electroglottography and audio recording

To characterize the singing performance, additionally vocal fold contact and fundamental frequency was measured during dynamic lung MRI using an MRI-compatible electroglottography (EGG) system (Özen et al., 2015; Laryngograph Ltd. London, United Kingdom). EGG recordings were used to monitor the vibratory cycles of vocal folds and calculate the open quotient (OQ), i.e., the proportion of time within a cycle that the vocal folds are not in contact. OQ was calculated according to Howard et al. (Howard et al., 1990; Howard, 1995) combining an EGG-based threshold method for detection of glottal opening (at 3/7) with detection of glottal closing instants in the dEGG (derivative of EGG) signal. Additionally, the EGG signal was used to determine the fundamental singing frequency (f_o). The mean value of f_o was calculated for a stable phonation segment of 1 s. Deviations from the expected f_o were calculated in cents due to its logarithmic scale. The audio signal was also simultaneously recorded using a microphone system recorded at 30 cm from the mouth (Pre-polarized Free-field 1/2″ Microphone, Type 4,189, Brüel&Kjær, Nærum, Denmark).

Pressure and sound pressure level measurements

To determine the subglottic pressure p_{sub}, each subject repeated the performance of the tasks in section "Tasks" outside of the MRI in a supine position. P_{sub} was measured in a separate sound treated room directly before the MRI measurement and was determined from the oral pressure during the/p/−occlusions according to Baken and Orlikoff (2000). Oral pressure was measured *via* a short plastic tube (inner diameter: 1.5 mm) mounted in a Rothenberg mask that was placed in the right-hand corner of the subject's mouth, and which was connected to a pressure transducer (PT-70, Glottal Enterprises, Syracuse, United States). The audio and EGG recordings were also performed during p_{sub} measurements. The audio signal was recorded at a distance of 1 m from the mouth by a omnidirectional microphone (Laryngograph Ltd. London, United Kingdom) to calculate the sound pressure level (SPL). A calibration of the SPL was performed prior to each measurement using a sound level meter (Sound level meter 331, Tecpel, Taipe, Taiwan). P_{sub} and SPL were analyzed using the Aeroview software (Version. 1.4.5, Glottal Enterprises, 2010, Syracuse, United States). Due to technical problems p_{sub} and SPL data from subject 6 had to be excluded from the analysis.

Statistics

Sex-related differences of the gradients of normalized movement curves were analyzed using a repeated-measures ANOVA (rmANOVA) by including five timesteps of a curve progression (m_{1-5}, = levels in rmANOVA = 5). As an overview, first all data were initially included in one calculation with covariates

(subject, task and location) and factor: sex. The Greenhouse–Geisser correction was used in order to correct the degrees of freedom. In a second step separate rmANOVA calculations were performed for each location and each task separately again with factor sex and Greenhouse–Geisser correction.

Sex-related differences of $ROM_{p/r}$ were assessed using a univarite ANOVA test. Correlation analysis between OQ, p_{sub} and SPL was performed using a two-tailed Spearman-rho correlation ($r_s = 0.2–0.5$: low to medium correlation, $r_s = 0.5–0.8$: substantial correlation, $r_s = 0.8–1.0$: high to perfect correlation). For all statistical analyses, SPSS 23.0 software (SPSS, Inc., Chicago, IL) was used. The level of significance was set to $p < 0.05$.

Results

Study cohort characteristics

Female singers were significantly smaller and had a lower VC compared to male singers, but there was no statistical difference between the BMI of men and women (see Table 4). Boxplots in Figure 2 give an overview of mean OQ, SPL and p_{sub} for male and female singers' different tasks: OQ correlated significantly with f_o ($r = 0.38$, $p = 0.04$) in female singers with a higher mean OQ with increasing f_o. In contrast, no significant correlation was found between OQ and f_o for male singers ($r = 0.05$, $p = 0.80$). Additionally no significant correlation was found for either male or female singers between SPL and OQ (female: $r = -0.32$, $p = 0.19$; male: $r = -0.14$, $p = 0.62$). On average across all tasks, female singers phonated with a larger OQ compared to male singers [mean OQ female/male = 0.68 ± 0.02/0.56 ± 0.1; $F(1/59) = 25.68$, $p = <0.001$, $\eta^2 = 0.32$]. Each task was also evaluated individually (see Supplementary Table S1): OQ was significantly higher for female compared to male singers for P2mf, P3mf, and P2ff but not for P1mf and P2pp.

P_{sub}, both as an overall average and for each task separately (see Supplementary Table S1), did not differ significantly between female and male singers [mean p_{sub} female/male = 12.96 ± 1.24/15.26 ± 1.55 mmH_20; $F(1/59) = 1.24$, $p = 0.27$, $\eta^2 = 0.02$]. Significantly higher p_{sub} occurred with higher f_o (female: $r = 0.60$, $p < 0.001$; male: $r = 0.69$, $p < 0.001$) and higher SPL (female: $r = 0.76$, $p < 0.001$; male: $r = 0.70$, $p = 0.004$) for both female and male singers.

Similarly, mean SPL as well as SPL of each task (See Supplementary Table S1) did not differ significantly between

TABLE 4 Mean female and male body-mass-index (BMI), vital capacity (VC) and body height including standard error and the results of analysis of statistical differences (significant differences are marked in darker grey).

Parameter	Mean female (Standard error)	Mean male (Standard error)	Statistical difference
BMI	22.18 (0.82)	24.16 (0.83)	$F(1;11) = 1.44$, $p = 0.26$, $\eta^2 = 0.13$
VC	3.89 (0.18)	5.47 (0.18)	$F(1;11) = 18.55$, $p = 0.002$*, $\eta^2 = 0.65$
Body height	163.17 (1.47)	181.00 (2.72)	$F(1;11) = 16.60$, $p = 0.002$*, $\eta^2 = 0.62$

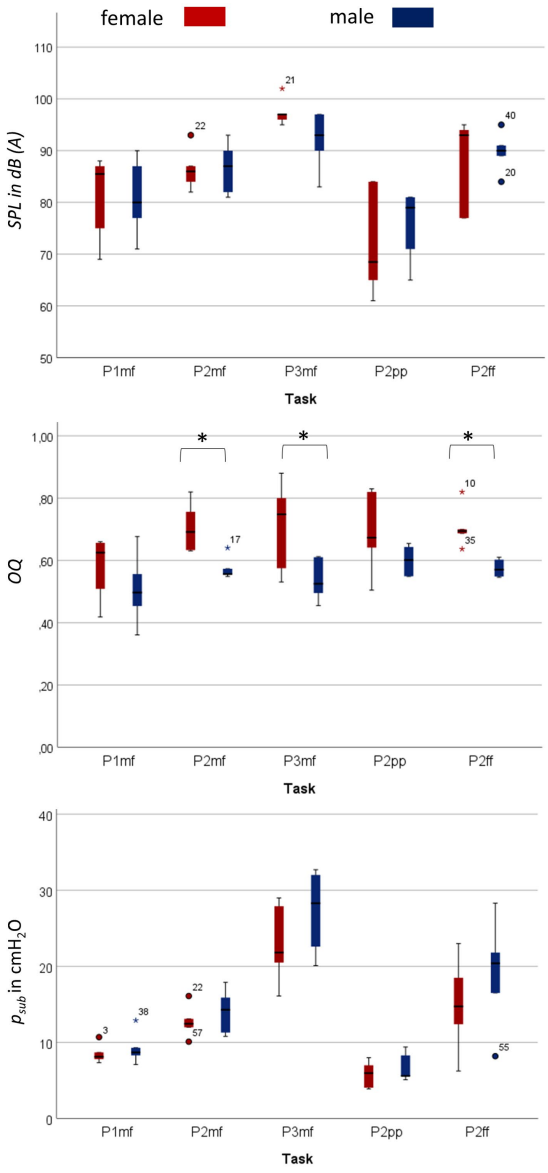


FIGURE 2
Significantly larger open quotient (OQ) for female compared to male singers in the respective task, no significant difference for subglottic pressure (p_{sub}) and sound pressure level (SPL). The figure shows boxplots of OQ, p_{sub} and SPL for each task separately for male and female singers. An increase in p_{sub} can be seen from the lowest to highest pitch (P1 mf to P2 mf to P3 mf) as well as from the lowest to the highest loudness condition (P2 pp to P2 mf to P2 ff). The same trajectory can also be seen for the measured SPL. No significant difference is found between male and female singers. In contrast, while OQ increases with pitch in female singers, no pitch-dependent relationship was found for male singers. Significant differences are marked with *. Details on statistic evaluation can be found in Supplementary Table S1.

female and male singers [mean *SPL* female/male = 85.10 ± 1.96/84.96 ± 1.51 dB; $F(1/59) = 0.002$, $p = 0.97$, $\eta^2 < 0.001$], although significantly higher SPL correlated with higher f_o, for both female and male singers (female: $r_s = 0.55$, $p = 0.002$; male: $r_s = 0.50$, $p = 0.01$).

The maximum phonation time (MPT) was significantly longer for male compared to female singers [$F(1,119) = 39.9$, $p = <0.001$, $\eta^2 = 0.28$].

Respiratory kinematics during sustained phonation

Respiratory kinematics of diaphragm and thorax show no major difference between the normalized movement curves of male and female singers for all measured locations (Figure 3): The motion of the posterior and mid part of the DPH is quicker during the first half of maximum phonation time and slower at the end, while that of the anterior DPH and the thorax distances is slower in the beginning and quicker toward the end. rmANOVA of the curve gradient showed no statistically significant sex-related difference in curve progression [$F(4,472) = 1.94$, $p = 0.10$, $\eta^2 = 0.02$]. Still, subgroup analysis of each location separately revealed a difference in progression of apD3R: While this distance decreased rapidly in the first 20% of phonation time in female singers (mean gradient in $m_1 = -1.50$), male singers held it more consistently (mean gradient in $m_1 = -0.73$). In contrast, the posterior movement of the DPH cupola (apDDPH) was faster in the first 20% of the phonation time in male singers (mean gradient in $m_1 = -1.50$) and held more consistently in female singers (mean gradient in $m_1 = -0.66$).

Comparison with VC breathing

In the next step the kinematic data was analyzed in relation to the individual respiratory behavior during VC breathing. Figure 4 displays the respiratory kinematics in relation to each singers' maximum inspiration and expiration. While on average, male singers started to phonate at 87% of their maximal thorax expansion, female singers began phonation between 65% (apD3R) to 75% (apd5R) of theirs. Figure 5 displays an example of the lung configuration in a sagittal image of a female (#5) and a male subject (#10). Here, a difference between the inspiratory behavior during singing and breathing can be inspected visually: The male subject increased his thorax movement during singing, while the female subject decreased it. Another dynamic example is given in a Supplementary Video (Supplementary Video S3). Here synchronized respiratory kinematics during inspiration and phonation of one female and one male singer are shown in a dynamic MRI video of the right lung in a sagittal slice. The video is played three times, in the last version at half speed, inspiration and phonation are marked.

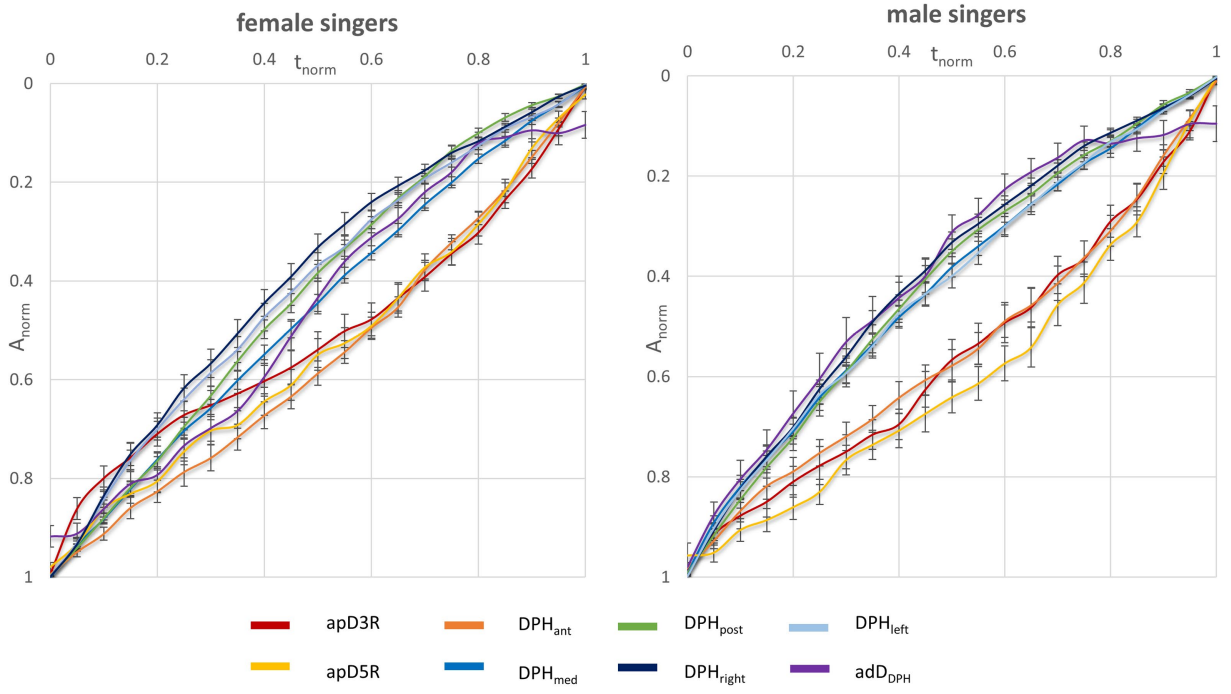


FIGURE 3
No major difference in movement velocities during sustained phonation between female and male singers. The figure displays the normalized amplitude (A_{norm}) of the mean movement curves for different locations for male (right) and female singers (left) as a function of normalized phonation time.

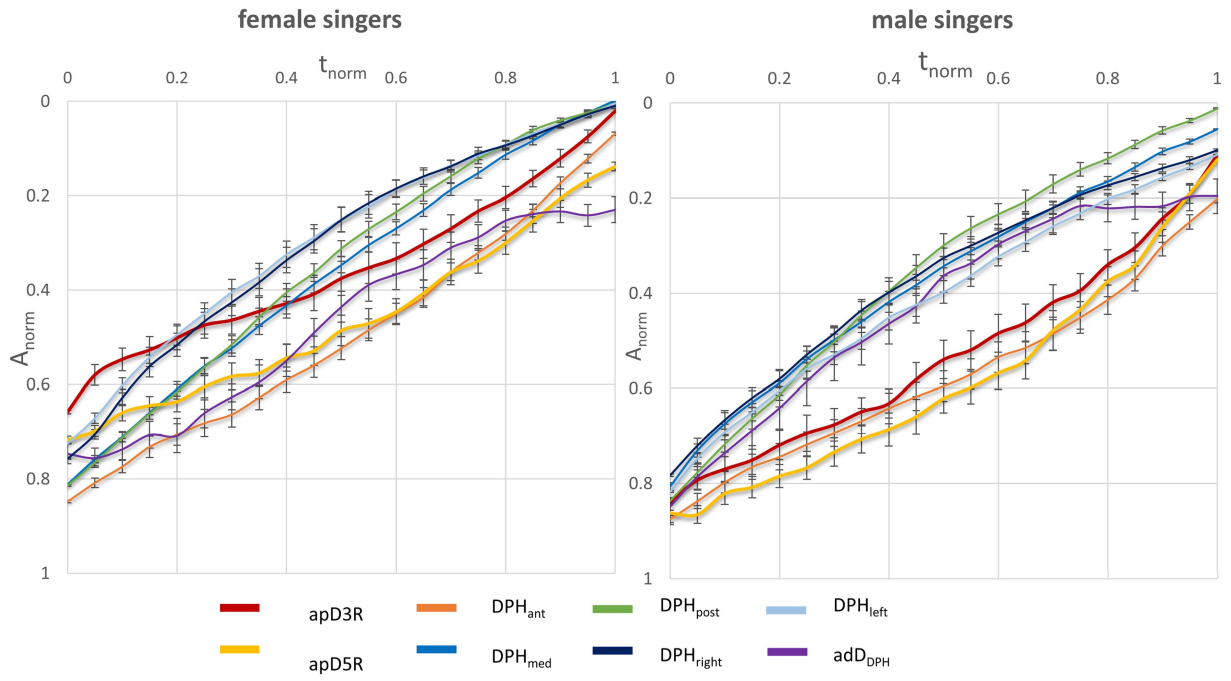


FIGURE 4
Female singers started at lower thoracic vital capacity levels compared to male singers. Mean movement curves of female (left) and male (right) normalized to vital capacity inspiration and expiration are displayed including standard error bars. The x-axis displays normalized maximum phonation time (t_{norm}) and the y-axis displays the normalized curve amplitude (A_{norm}) as a percentage of individual maximum inspiration and expiration. Each location of the respiratory system is displayed in a separate curve.

To further analyze the visual differences in Figures 4 and 5 and Supplementary Video S3, an individual quotient was calculated that represents the movement range (ROM) during maximum sustained phonation in relation to the individual VC respiration ($ROM_{r/p}$). Larger ROM values indicate a larger utilization of the possible range of motion for the individual localization (see Table 5 and Figure 6). Respiratory movement of the thorax during phonation was stronger in male singers compared to females. In contrast, in female singers no statistically significant difference was found for $ROM_{r/p}$.The $ROM_{r/p}$ for the diaphragmatic movement in the anterior section (DPH_{ant}) failed to reach statistical significance only marginally.

Discussion

In this study, sex-related differences of respiratory kinematics were analyzed during phonation using sagittal and coronal cross-sectional MRI data of the thorax of professional singers. While respiratory kinematics during phonation (see "Respiratory kinematics during sustained phonation") were essentially consistent between male and female singers, male singers increased thoracic excursion during singing, which was not found in female singers. Additionally, distinct differences in movement velocities of individual anatomical regions became apparent that support the theory that there are certain differences between the phonatory strategy of female and male singers.

Breath support during singing is generally characterized by a simultaneous inspiratory activation of the DPH and thorax at the beginning of phonation to reduce p_{sub} when recoil forces exceed the intended phonation threshold pressure (Sundberg, 1987). The DPH contraction during inspiration is then continuously relaxed during singing, at first in the posterior part of the DPH, while thorax and anterior DPH are held in an inspiratory position and thus move slower (Traser et al., 2017b). These kinematic movements are inverted at lower lung volumes when thorax movement accelerates driven by the increasing need for pressure generation to maintain the aspired p_{sub} when negative recoil forces develop. These kinematics lead to the elliptic shape of the curves (Figure 2) observed in all subjects regardless of sex and comparable to observations of a previous pilot study (Traser et al., 2017b). Differences between female and male singers were found by inspection of separate anatomical locations (see section "Respiratory kinematics during sustained phonation"): in the upper thorax, inspiratory activation at the beginning of phonation was stronger in men, resulting in a lower motion velocity. In female singers the same happened for the anterior positioning of the DPH cupola (see Figures 3, 5). This is congruent with the observed predominance of thorax movement in relation to VC breathing: female singers elevated their thorax 20% less for maximum sustained phonation compared to male singers. Male singers initially show increased thoracic inspiratory activity to reduce the subglottic pressure, whereas female singers achieve this more

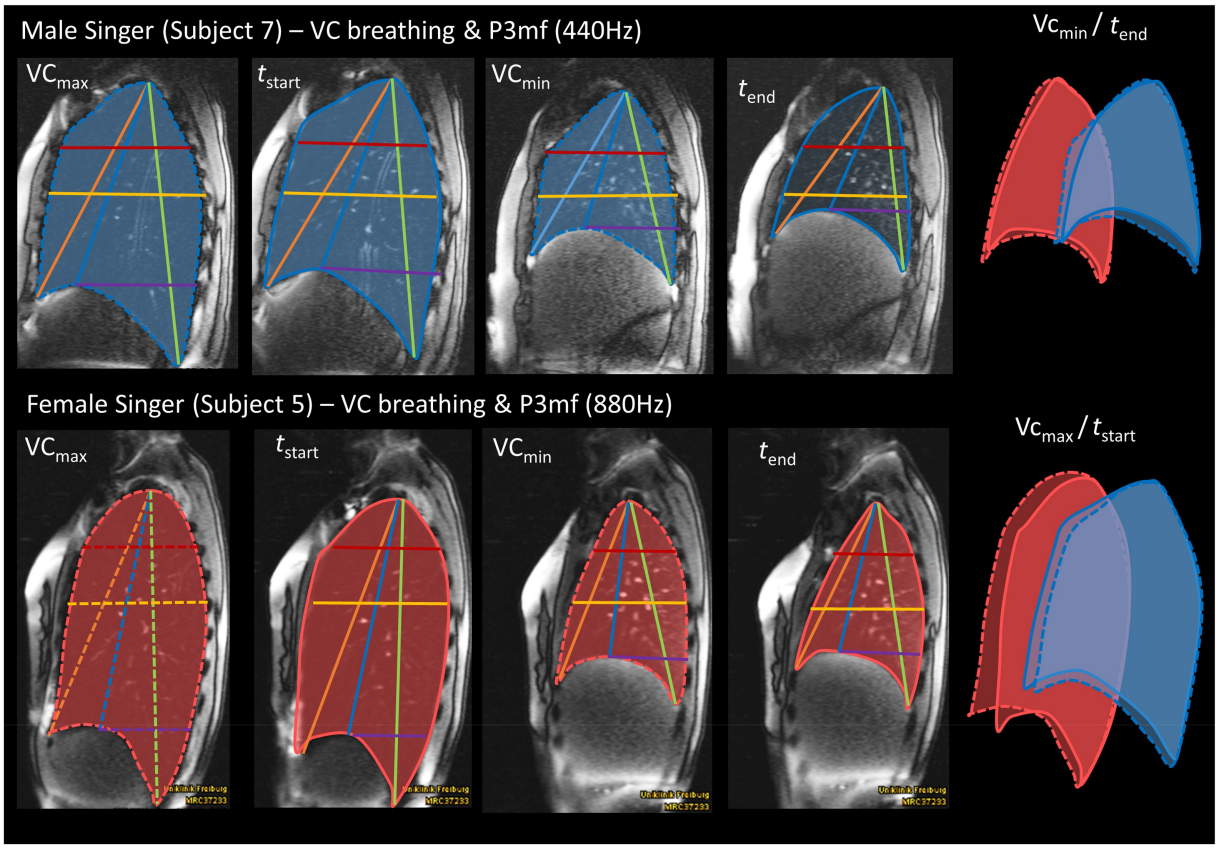


FIGURE 5
Exemplary illustration of a female singers' reduction and male singers accentuation of thorax elevation for phonation compared to vital capacity breathing. The figure displays MR images of an example male (10) and female (5) subject during maximum inhalation (VC_{max}), maximum exhalation (VC_{min}), start of sustained phonation (t_{start}) and end of sustained phonation (t_{end}). A corresponding pitch (P3 mf, 880 Hz in female/440 Hz in male) was chosen. The superimposed lung cross-sections of a sagittal MR image illustrate that the female singer reduced her thoracic inhalation movement for phonation, while it was increased by the male singer.

TABLE 5 Differences between male and female subjects' phonatory movement range in relation to the respiratory movement range ($ROM_{p/r}$), separately analyzed for each location.

Location	Statistical difference of $DeltaROM_{p/r}$ in female vs. male singers
DPH_{right}	$F(1,49) = 0.01$, $p = 0.92$, $\eta^2 < 0.001$
DPH_{left}	$F(1,49) < 0.001$, $p = 0.99$, $\eta^2 < 0.001$
DPH_{ant}	$F(1,49) = 3.08$, $p = 0.09$(*), $\eta^2 = 0.06$
DPH_{med}	$F(1,49) = 2.05$, $p = 0.16$, $\eta^2 = 0.01$
DPH_{post}	$F(1,49) = 0.20$, $p = 0.65$, $\eta^2 = 0.004$
apD_{3R}	$F(1,49) = 2.67$, $p = 0.11$, $\eta^2 = 0.05$
apD_{5R}	$F(1,49) = 9.5$, $p = 0.003$*, $\eta^2 = 0.17$
apD_{DPH}	$F(1,49) = 3.22$, $p = 0.08$(*), $\eta^2 = 0.06$

Significant differences are marked with *($p = < 0.05$) and tendencies with (*$p = < 0.10$).

through DPH activity [the anterior–posterior movement of the diaphragm cupola is a good measure of DPH contraction (Traser et al., 2020a)]. In addition to the predominance of thorax movement during the inspiration, male singers' range of thorax motion was about 20% larger during phonation compared to that of female singers. Females, in contrast, tended to use a larger diaphragmatic movement range (especially in the anterior section) but results were not statistically significant. Watson et al. described that male singers initiated the majority of their vocal passages within the 80–100% VC range of rib-cage volume (Watson and Hixon, 1985) while female singers started at only 57–82% VC of their rib-cage volume (Watson et al., 1990). Their data is based on magnetometry, a technique that monitors anterior–posterior diameters of the thorax and abdomen but cannot image DPH motion directly. Instead, the anterior–posterior diameter of the abdomen was measured: Male singers initiated their vocal passages at abdominal volumes between 15 and 60% of VC compared to 53–86% in female singers. Even if this value is not directly transferable to DPH movement (as it is also affected by abdominal wall contraction), it could be an indication that a preference for DPH movement in females and thorax movements in males also occurred in Watsons' data. Still, the authors stated no significant difference between the respiration of male and female singers and only a weak correlation between the male subjects' self-perception of their breathing to the breathing measurements

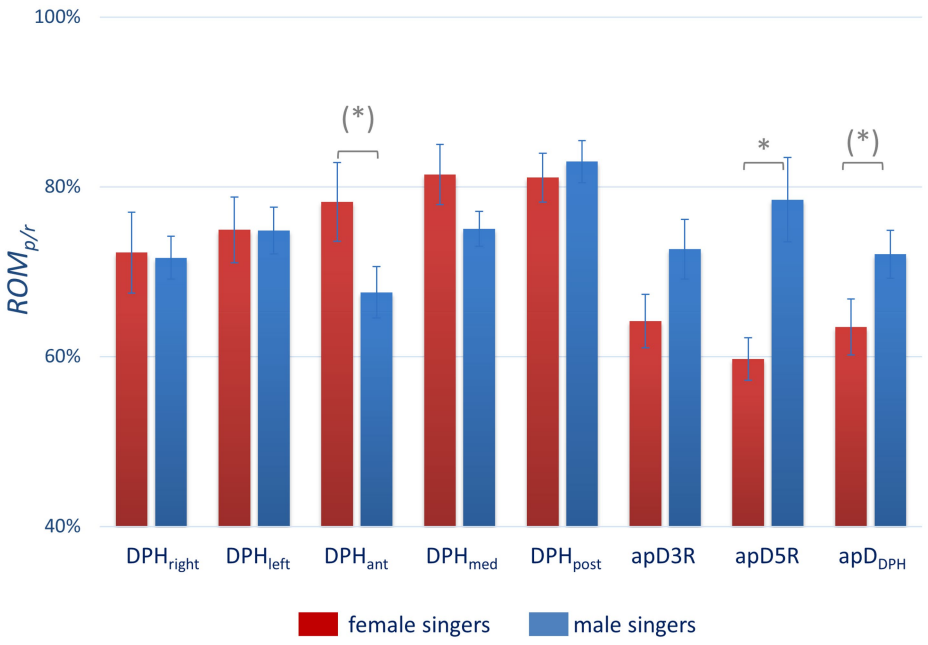


FIGURE 6
Significantly more thoracic movement in male and a tendency to more diaphragmatic movement in female subjects during maximal sustained phonation in relation to vital capacity respiration. The figure compares the phonatory movement range in relation to the respiratory movement range ($ROM_{p/r}$) for male (blue) and female singers (red) for different locations. Significant differences are marked with *(p=<0.05) and tendencies with (*p=<0.10). All p-values are displayed in Table 5.

(Watson and Hixon, 1985). However, their data and this work are in good agreement with a questionnaire-based survey of Scott McCoy, who found that females concentrated their breathing efforts in lower parts of the body than men (hypo-vs. epi-gastric regions; McCoy, 2005). A stronger breathing effort in the epigastric region could be caused by pronounced thoracic movements, while a focus in the hypogastric region could be more related to the DPH-induced movement to the abdominal organs and corresponding abdominal wall regulation. In the voice pedagogic literature McCoy finds two pedagogic concepts about breathing for singing: the first uses a method that is mainly described by men, which sees breathing as an activity centered on and controlled by actions of the thorax, epigastrium and/or middle-back. In contrast, the second concept (mainly described by women) sees breathing as an activity of the lower thorax, hypogastric region, lower back and pelvis (McCoy, 2005). These results are in line with our previous work on pulmonary ventilation during singing (Traser et al., 2017a). Here, the location of the maximum change in ventilation showed a greater anterior – posterior variation in men, while it remained largely constant in females which might be originated from a larger range of rib-cage movement in men. In summary, these descriptions seem to fit the theory of sex-related differences in respiratory control for singing. Figure 7 illustrates a typical sagittal lung cross section of a female and male singer at the beginning and end of phonation. The arrows emphasize the discussed sex-specific range of motion.

Discussion of potential origins of the described preferences in respiratory behavior between male and female singers

Sex related anatomical/physiological differences of respiratory system

Observed differences could be related to differences in the respiratory anatomy/physiology between males and females: On average, men are taller, have bigger lungs and larger RC dimensions than women and thus higher vital capacity (Thurlbeck, 1982; Bellemare et al., 2003; Torres-Tamayo et al., 2018). However, during respiration a greater contribution of inspiratory rib-cage motion to tidal volume displacement can be found in females than males. It has been discussed that the greater incline angle of the ribs in females may put the inspiratory rib-cage muscles at a better mechanical advantage (Bellemare et al., 2003; Romei et al., 2010; it is speculated that the greater contribution of the rib-cage in women may be propaedeutic for the functional adaptation to the hormonal and anatomical changes induced by pregnancy). Still, sex-related differences of operational lung volumes during exercise were attributable to differences related to lung size as well as differences in the compartmental analysis of the kinematics of the entire chest wall (Vogiatzis et al., 2005).

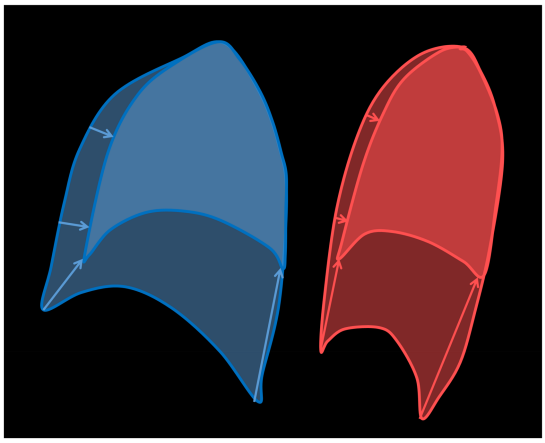


FIGURE 7
Illustration of a sagittal lung cross-section at the beginning (large area) and at the end (small area) of a phonation with drawing of the sex-specific movement ranges (arrows) for a male (blue) and a female (red) singer.

Thus, even if women might have a constitutionally more effective RC system, the presented data and reviewed literature could be taken as indications that female singers developed a pronounced DPH movement during singing phonation while men emphasized their RC movement. It could therefore be speculated that both sexes expand their capacities during singing training in the section that is less advantaged by nature. Nevertheless, since men and women in the described cohort differed significantly with respect to body size, it was not possible to further determine whether the cause of the described differences was their body configuration or control of phonation. Additionally, interactions between breathing kinematics and voice source also have been taken into account when the potential benefits of predominant control of voice production from the DPH or thorax is assessed.

Sex related anatomical/physiological differences of laryngeal functions

The male vocal folds are longer and thicker with larger vibrational amplitudes (Titze, 1989). This leads to a stronger and quicker glottal closure in men combined with higher airflow rates compared to females (Sulter and Wit, 1996). Classically trained female singers phonate proportionally more in a register function which is characterized by a reduction of the vibrating mass (also called head or falsetto register or M2). It stands in contrast to full vibration of the vocal folds also called (chest or modal register, M1), which is predominantly used in males (Henrich et al., 2005; Sundberg, 2018). OQ during singing is reported to be higher in female compared to male singers (Sulter and Wit, 1996), which is corroborated in the presented data. The OQ was found to remain essentially constant with f_0 in male singers while it increased with pitch in females (Howard, 1995), which is congruent to our data. As M2, in contrast to M1, was described to correlate well with OQ, the use of these different mechanisms seems to be responsible for the difference between male and female singers in our data as well.

Via the so-called tracheal pull, glottal closure is related to the lung volume (Thomasson, 2003). It was previously shown that high DPH activity corresponds to a lower laryngeal position that increases laryngeal abductory forces [as the cricothyroid muscle is more activated with increasing tracheal pull which generates glottal abduction (Leanderson et al., 1984; Sundberg et al., 1989; Iwarsson and Sundberg, 1998)]. This relation was less expressed in a study on professional female singers by Ternström et al., probably as they learn to control these parameters independently (Ternström et al., 2018). In male professional singers, DPH activation was found to relate to so-called "flow phonation," which is characterized by an increase in glottal airflow and thus OQ compared to normal phonation (Leanderson et al., 1987).

Consideration of the presented data in the context of type of phonation, leads to the question of whether a particular kind of breath support (more thorax or more DPH based) might be more or less beneficial for the intended vocal fold vibration. Thus, it might not be a coincidence that DPH predominance was typical for female singers of our cohort, as their vocal fold vibration (in the Western style classical context) is characterized by lower airflow rates and smaller amplitude of vibration. Interestingly, a reduction of respiratory thorax movement has also been observed when singers used the so-called DPH-co-contraction technique (Sundberg et al., 1989). Here a conscious overpressure from the abdominal wall muscles is actively reduced by DPH contraction during phonation. In contrast, a more thorax related respiratory pattern was utilized by male singers whose vocal fold vibratory patterns are generally characterized by higher glottal airflow, larger amplitude and thus maximum flow declination rate (MFDR; Sulter and Wit, 1996). In this context it is very interesting to see that in a single subject study, a professional female singer increased her thorax inspiration by about 20% when she switched from Western classically style to belting (Traser et al., 2020b), a contemporary music singing style which is characterized by a higher degree of glottal adduction (Sundberg et al., 1993) and higher vertical laryngeal position (Echternach et al., 2014). In the next step also the interaction between the vertical laryngeal position and the acoustics of the vocal tract shall be discussed.

Sex related anatomical/physiological differences of the vocal tract

The vocal tract is longer in males compared to females (Sundberg, 1987). Elevation of the larynx has an acoustical effect on the voice by shortening the resonance cavity, and this affects all

formant frequencies (Sundberg, 1987). A low larynx position is desired in some fields of Western classical singing, e.g., when male singers want to boost energy in the frequency region of the singers' formant (Sundberg, 1987). In contrast larynx elevation might be actively induced when female singers are adjusting the first two formants to their fundamental frequency to increase loudness [formant tuning; (Weiss et al., 2001)] as well as for some singing styles in contemporary music, e.g., belting (Echternach et al., 2014). Generally, the larynx has been found to elevate with pitch in untrained subjects (Shipp, 1975; Traser et al., 2014), but less so in trained singers (Shipp and Izdebski, 1975; Traser et al., 2013). It could therefore be speculated that, for men (who's timbre is more easily influenced due to lower f_o and thus closer partials), it would be more relevant to keep the larynx position steady, although some elevation is noted to occur in upwards scale singing even in highly trained tenors (Echternach et al., 2010). This technique could be supported through predominant thorax respiration, which would reduce tracheal pull compared to DPH activation. In contrast, in highly trained female singers even significant elevation of the larynx with pitch (Shipp et al., 1987; Weiss et al., 2001) and increased loudness (Mainka et al., 2021) has been observed. A more pronounced DPH activation could lead to a higher variability in larynx position, which is acceptable when singing in a high pitch range, where the formant frequencies are difficult to detect (because thousands of hertz lie between partials; Shipp et al., 1987).

Limitations

In this study only 12 classically trained singers were included – even though this is currently the largest cohort with an MRI-based analysis, the group is too small to exclude a group size effect. All data were first included in a rmANOVA test using covariates to test for the effect of confounding variables. In a second step individual calculations were performed for separated locations. Still, the problems of non-independence and heteroscedasticity of data remain and could confound the statistical analysis. Therefore, the statistical power of the data is limited. Still, it was not possible to include more professional singers to enrich the statistical power. In our opinion, including statistics in this manuscript is still an advantage in order to enable an initial classification of the results. However, the presented results need to be confirmed in a larger study.

In this study, beside one baritone, only sopranos and tenors were included. The recruitment of the singers was done through personal contacts, so the composition of the singers' voice classification was random. Thus it cannot be excluded, that the difference is only a typical behavior of sopranos vs. tenors and not female vs. male singers. Again, an expansion of the data with more subjects is necessary to further illuminate the question of whether there are also differences related to voice classification.

In this study measurements were taken in a supine body position due to the use of a clinical horizontal-bore MRI system. Lying on the back, gravity exerts a force on the lungs and thus influences p_{sub} so that the demand for raising p_{sub} by muscular means is smaller. Studies on posture-related differences during respiration showed that the DPH-motion in the supine position was significantly greater than that in the upright position (Takazakura et al., 2004) and the anteroposterior diameters of the chest wall motion were significantly lower in the supine position (Takashima et al., 2017). For untrained subjects Hixon et al. described a substantial change in respiratory kinematics during sustained utterances between upright and supine position (in supine position the inspiratory braking was solely performed by DPH without support by the inspiratory thorax muscles, which are normally primarily involved in the upright position (Hixon et al., 1976). Such a fundamental change in respiratory kinematics could not be confirmed in professional singers (Traser et al., 2021): The diaphragm was cranially displaced in supine position for both singing and breathing and its motion range increased. Still, regardless of body position, singers maintained their general principles of respiratory kinematics with combined diaphragm and thorax muscle activation for breath support. This was achieved by expanding their chest an additional 20% during inspiration when singing in the supine position but not for sole breathing (this stands in contrast to the reduction in thoracic motion for untrained subjects in supine position in the study of Takashima et al., 2017).

However, as both male and female singers were in supine position, it is unlikely that differences between the respiratory kinematics of men and women are posture-related. As all subjects were trained singers, they are used to singing in different body positions and have very consistent breathing strategies (Thomasson and Sundberg, 1999).

Another influencing factor might be the body configuration and weight of the singers. A previous study analyzed the correlation of body type and breathing tendencies by video analysis in young female singing students (Cowgill, 2009). The author found that overweight singers tended to breathe lower (movement in the umbilicus area), while muscular singers predominantly moved the rib-cage area and lean (and long) singers the lateral chest area. Another plethysmography study in untrained subjects did not find any between-group differences in respiratory motions for body type (Manifold and Murdoch, 1993). As obese people have a higher abdominal inertance, their body weight might affect breathing in a non-linear way. Nevertheless, as male and female singers did not differ concerning their BMI in the analyzed cohort, a large effect of body weight seems unlikely in the presented data. The male singers in this cohort were significantly taller than the females. Thus, to avoid scaling effects, relative distances were calculated and compared. Unfortunately, due to the small sample size no further subgroup analysis could be performed to differentiate between sex-or body height related differences. Still different body geometries, size/weight of abdomen or breasts could have varying degrees of impact on the singers especially in supine position, which cannot be excluded due to the limited sample size.

Conclusion

The presented data showed no sex-related difference concerning basic respiratory kinematics during phonation. However, male singers increased their thoracic contribution while singing, a difference which was not found in female singers, who tended to increase their DPH breathing during phonation. As DPH activation is associated with an increase in tracheal pull and thus activation of cricothyroid muscle with lower laryngeal position and glottal abduction, there might be a relation of respiratory kinematics with the intended vocal fold vibration as well as vocal tract configuration and thus resonance strategies (Leanderson et al., 1984; Sundberg et al., 1989; Iwarsson and Sundberg, 1998). However, other contributing factors like body configuration, the subject's Fach (e.g., lyric vs. dramatic voices, different repertoire) and genre (classical vs. contemporary music style) might also be relevant and due to limited sample size no final conclusion can be drawn from the presented data. Nevertheless, data indicate that the sex of the singer influences the predominance for different respiratory strategies during singing. When considering vocal pedagogical constellations with mixed-sex teacher-student combinations, it might be advisable to consider these aforementioned differences in the singing training.

Author's note

Effective breath control is considered to be an important factor in singing voice production, but descriptions of how this is accomplished vary widely. In addition to pedagogical concepts, gender differences could also play a role here. In order to enhance understanding of differences in respiratory kinematics between male and female singers, sagittal and coronal cross-sectional images of the lung were analyzed using dynamic MRI in 12 professional singers. While basic movement patterns of breath support were essentially consistent between male and female singer, male singers showed increased thoracic breathing compared to female singers. In contrast, female singers tended to increase their diaphragm movement during phonation. The presented data shows the need for an individual approach for teaching of breath support strategies during singing voice training.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Medical Ethics Committee of the University of Freiburg, Germany. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LT initiated the study, made measurements, analyzed data and wrote the paper. CS made measurements, analyzed data. ACÖ made measurements. FB made measurements. MB and BR conducted and supervised research. ME analyzed data, wrote the paper and supervised research. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.844032/full#supplementary-material

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An etude for post-pandemic practice: The impact of the COVID-19 pandemic on practice methods and instrumental technique

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This paper considers how the pandemic-related concert-free time affected musicians' practice, specifically in relation to technique. A semi-structured interview was carried out on 22 musicians based in Switzerland (11 males, 11 females; 7 students, 15 non-students; 11 with school-aged children, 11 without school-aged children; 16 with teaching duties and 6 non-teachers). The amount of practice during the pandemic-related concert-free time was reported as different to usual by 91% and usual for only 9% of participants (p=0.002). Forty-one percent of participants reported reduced, and 41% "fluctuating" amounts of practice. The proportion of practice time spent on technique was reported by 55% of participants to have increased and by only 9% to have decreased (p=0.019). Of those who reported an increase in technique practice, 75% agreed this had a positive impact on technique, and only 8% disagreed (p=0.037). Moreover, 58% considered this work to have changed their current and future practice. Participants were statistically more likely to report "never" watching online tutorials than "often" (p=0.014), but, of those that did watch such material, 75% agreed that it had a positive impact upon their practice. Most participants created digital content during this period; only 5% produced no such material. An increased use of digital tools was reported by 55% of participants, 92% of whom described this as having a positive effect upon practice and only 8% were unsure (p=0.022). However, in the unstructured discussion, the use of digital tools appears to be associated with mixed outcomes. Men reported significantly more frequent use of digital tools (91% vs. 45% describing this use as often, p=0.038) and spent a larger proportion of time on technique relative to their pre-pandemic habits than women (p=0.065); moreover, a trend indicated that more women than men created digital content in the form of tutorials (p=0.095). The exceptional situation musicians experienced during the pandemic, which introduced new aspects to musical instrument practice, and accelerated changes already underway, could lead to future work that improves practice under "normal" conditions, and exposes discrepancies between certain demographic groups.

KEYWORDS

musical instrument practice, instrumental technique, COVID-19, music education, digital tools

Introduction

Studies of musicians' wellness, practicing routines, and higher education provision during the COVID-19 pandemic-related lockdowns have pointed to a complex situation that, despite obvious disadvantages, has also been described by some musicians as a creative period. Indeed, evidence of musicians' creativity during this period can be seen in a surge of online material, including concert streams, and self-made videos on technique and practice tips.

The impact upon musicians of the COVID-19 pandemic, specifically the lockdown periods during which live concerts and in-person music teaching were prohibited in many countries, has been evaluated in the literature from various perspectives. Despite prevailing negative themes such as musicians' loss of income and reduced wellness, reactions to other effects of the pandemic lockdown, such as the use of technology in music teaching, seem to be more complex, with musicians able to identify both positive and negative aspects. Performing arts professionals reported reduced work and income, reduced wellbeing, and specific challenges, such as those associated with caring responsibilities (Spiro et al., 2021). Musicians reported practicing less, but also described using the lockdown to work creatively, e.g., learn new skills and make social connections (Spiro et al., 2021). A comparison of the pandemic's impact upon the professional lives and wellbeing of mid-career freelancers vs. an older, more experienced cohort showed that, while musicians from both groups described career-related concern and financial stress, the mid-career respondents reported more distress, specifically citing less practice time, less engagement with collaborative music-making, and getting less pleasure from the musical activities they were undertaking (Cohen and Ginsborg, 2021).

A significant body of research focuses on the digitalization of teaching at conservatoire-level during the pandemic, detailing the technical demands, and the resulting impact on teachers and students, including influence on time spent practicing. An investigation into the effect of the shift to online classes and asynchronous learning formats at the Music University of Freiburg showed that some students practiced less during the pandemic compared to a similar group of students pre-pandemic. However, the type of practice was identified as being more self-motivated and more effective at accomplishing goals than pre-pandemic practice, and thus, the experience was not perceived to be wholly negative (Nusseck and Spahn, 2021). The perspective of teachers at French and Swiss conservatoires was investigated specifically in relation to the move to digital teaching. Teachers were able to point to advantages and disadvantages of digital teaching, and described a long-term impact in their pedagogical practice. While the majority of interviewees reported offering some online teaching that exactly replicated what they would do in a classroom, the making and sharing of recordings was important too: the majority had commented on video and audio recordings made by students, and just over half had made video recordings of themselves. The teachers described this situation as having a positive influence upon their pedagogical approach, but also described significant disadvantages, especially not being able to play alongside students (Güsewell and Terrien, 2021). Another study reported fluctuating motivational levels in a group of 12 athletes and musicians, and highlighted various positive and negative issues in these students' relationships with their coaches and teachers during the COVID-19 pandemic (Philippe et al., 2020). A survey at an Italian conservatoire studied changes in the educational program of 20 music students (Schiavio et al., 2021). Negative effects related to technology, such as technical issues, were reported in parallel with positive experiences such having more time to learn about new teaching technology, and eventually enjoying working with these formats. Moreover, the study participants used technology to actively seek connections with their fellow students during the period when in-person group classes did not take place. This points to the high value placed upon social life during studies, but also perhaps to the perceived importance of peer-peer learning that has been shown to exist amongst conservatoire students (Nielsen et al., 2018). Several of the above discussions reflect the pre-pandemic findings and recommendations made by Jørgensen (2015) in a report on a scheme whereby teacher-led pedagogy projects that sought unconventional ways to teach musical instrument practice were trailed at the Norwegian Academy of Music, and evaluated by students and staff. The post-study report describes a willingness to experiment on the part of both students and professors. Issues that were flagged included limitations in existing digital tools for storing and organizing recordings (Jørgensen, 2015). Making and commenting on video recordings of one's own practice has been suggested to be an effective evaluation strategy in musical instrument practice, and a route to independent learning (Jørgensen, 2004), and audio recordings have been used to guide music students' critical reflection of their own practice and promote self-regulated learning (McPherson et al., 2019). Practice strategies that include making and listening back to recordings, and using a metronome, have been associated with a high level of expertise in a study comparing young musicians of varying expertise (Hallam et al., 2012). A British study that surveyed a cohort of 338 amateur, student, and professional musicians reported that the drivers to new technology that support musical instrument performance are significantly higher than entry barriers to using such technology. Most musicians used tuning and metronome applications on mobiles rather than bespoke devices, and recorded themselves approximately once a week, although they did not always listen to their own recordings. Moreover, students listened to recordings of others more often than professionals did (Waddell and Williamon, 2019).

The connection between creativity and the use of digital resources, such as recording devices, has been investigated in several studies. Creativity has been suggested to be an important aspect of musical instrument practice, and the use of video "practice diaries" to self-evaluate creativity may improve problem-solving and increase agency in the practicing process (Wise et al., 2017). The creative use of technology to collaborate with other

musicians, evidenced in a group of musicians from various genres, may have been an important factor in building resilience during the pandemic (Fram et al., 2021). The evaluation of digital resources used during the pandemic for music teaching, music making, and communication includes proposed qualities for improving connection and relationship-building in online teaching (de Bruin, 2021), reports of initial artistically positive experiences associated with increased creative time to practice and compose versus long-term fears about the lack of sustainability of digital music making in some cases, especially in an ensemble (Verhulst, 2021), and the creation and analysis of online platforms that generate music by connecting musicians, e.g., composers and performers (Stollery and Black, 2021).

In summary, existing research into musicians' work and lifestyle during the COVID-19 pandemic generally reports reduced wellness, and reduced practice time, which, in some cases, was nonetheless described as being creative, and more efficient than usual practice. Reduced social mixing and inability to play together with colleagues were often reported as significant negatives; proposals to compensate for this *via* digital resources, such as making and sharing recordings, had mixed success. During the COVID-19 pandemic-related concert-free time, there was a surge in online streams, including pre-recorded and archival material, but also many live performances, from solo concerts in musicians' living rooms to orchestras live-streamed from empty concert halls (see, e.g., Barone, 2020; Macdonald, 2020; Paar, 2020), and asynchronized recordings of individual, distanced musicians compiled together to create ensemble works (e.g., this contribution from the Rotterdam Philharmonic Orchestra[1]). This output extended beyond concerts to discussions and demonstrations, especially with technical tips (e.g., by cellist Ferrándes, 2020). Indeed, musicians have discussed using the lockdown, during which there was little or no requirement to practice ensemble repertoire, to work on technique (Gersten, 2020). This is the environment that this paper aims to explore. The study presented here has a different focus to existing studies that have investigated wellness, practice time, and music pedagogy; instead, technique-based practice and use of digital content and tools to aid practice during the COVID-19 pandemic-related concert-free time are considered. A short survey was undertaken to investigate how frequently musicians practiced during the concert-free time. Participants were asked what proportion of practice time was spent on technique, whether they consumed or created digital content related to technique, and how they used digital tools during this period.

Aims

This study aims to investigate how the COVID-19 pandemic influenced aspects of musical instrument/vocal practice. The four main areas of interest are the following behaviors and activities during the concert-free time:

- -The **amount of practice** that musicians were undertaking.
- -The type of practice that musicians were undertaking, especially the **proportion of time spent practicing technique.**
- -The **consumption and creation of audio/video content** related to technique.
- -The **use of digital tools** in the practice room.

The goal was to compare this with pre-pandemic working habits, and determine whether any changes made to practice had a positive and/or lasting effect on practicing methods, and could thus be incorporated into future studies and practicing programs.

Materials and methods

A semi-structured interview was developed and carried out between September and November 2021 in-person or on the telephone with 22 musicians living in Switzerland. A copy of the interview script can be found in the Supplementary material of this paper.

The questionnaire script was followed strictly during each interview, and consisted of a combination of fixed, targeted questions followed by open questions to allow more nuanced discussion. The interviewees were given time to comment freely at the end of each question. All musicians were living in Switzerland during the pandemic, so they experienced the same national measures restricting concert activities, in summary: a first lockdown prohibiting concerts and rehearsals from 16 March to 6 June 2020, a period with no restrictions, limitations to 15 performer/audience members in November/December 2020, a second lockdown from 22 December 2020 to 19 April 2021, limitations to audiences of up to 50 people from 19 April 2021, and lifting of all restrictions on 26 June 2021.[2] The musicians also had available to them the same structure of financial compensation offered by the Swiss government.

The following definitions were given to the interviewees before the interview. "Concert-free time" was defined as the periods of complete lockdown or periods when no in-person concerts could take place (but, for example, concert streams with ensembles were possible). "Usual" practice was defined as that undertaken during a typical working period pre-pandemic. Participants were recruited in the following way: an e-mail invitation to participate that was sent to local ensembles and professional music associations. Positive respondents were asked whether they met the following criteria:

1 https://www.youtube.com/watch?v=3eXT60rbBVk

2 For a summary of historical COVID19 measures in Switzerland, see: https://www.bag.admin.ch/bag/en/home/krankheiten/ausbrueche-epidemien-pandemien/aktuelle-ausbrueche-epidemien/novel-cov/massnahmen-des-bundes.html#757183649

residency in Switzerland during the pandemic, and a regular professional performance schedule (participants were allowed to decide for themselves whether their performance schedule was "regular," if they questioned this further, they were asked to consider whether a significant amount of their average monthly income came from performance activities). From 23 responses, one was discarded due to residency outside of Switzerland. The remaining 22 respondents were interviewed. In addition to noting instrument type and student/professional status, a short demographic survey also recorded whether the participant taught, and if they have school-aged children. This demographic data is summarized in the Supplementary material Table S1 to allow the reader to connect the quotes in "Demographic trends" with the demographic data. Participants have been assigned the codes P1 to P22.

Results

The results from the interviews are given below. "Main survey results" reports the responses to the semi-structured interview, "Demographic trends" describes some tendencies according to the participants' demographics and "Additional comments" presents selected comments from the respondents' free feedback that they were allowed to give at the end of each question.

We performed all statistical analyses using STATA version 16.1 for Windows (Stata Statistical Software; StataCorp LP, College Station, TX, United States). For the results reported in "Main survey results", we used multinomial logistic regression to estimate the odds of each answer relative to the other answers (i.e., relative risks). For the results reported in "Demographic trends," we used Fisher's exact and ordered logistic regression (for ordinal variables) and logistic regression (for binary variables) to evaluate the differences in the distribution of the answers to the different questions as a function of student/professional status (students vs. non-students), having school-aged children (children vs. no children), teaching activity (teach vs. do not teach), and gender (female vs. male). For these latter analyses, we only considered the questions that were answered by all 22 participants.

Main survey results

The survey results are presented in the four main sections of the survey, respectively: Amount of practice, Type of practice, Online content, and Digital tools. For some questions, participants who responded in a certain way were asked to answer a follow-up "sub-question." This is delineated in the text below. The descriptive statistics are summarized in Table 1. The results of the statistical tests are presented in the Supplementary material.

Amount of practice

The participants were asked how the amount of time they spent practicing during the concert-free time compared with their usual, pre-pandemic routine. The amount of practice during the pandemic-related concert-free time was reported as different to usual by 91% of participants and usual for only 9% of participants (significantly different odds, $p = 0.002$, see Table S2 in the Supplementary material). Specifically, 41% of participants reported practicing less, and the same percentage said they would describe their practice as "fluctuating," i.e., they agreed with the statement: "*there were periods when I practiced a lot more than usual, and periods when I practiced a lot less than usual*." Nine percent of participants reported practicing more than usual.

Type of practice

Technique practice was defined to be "*etudes, studies, exercises, scales, repertoire excerpts with a technical goal, general technical work on sound/intonation,* etc." When asked to consider the proportion of practice time spent on technique, 55% of respondents reported this to be larger than usual, 36% "the same" and 9% "smaller." The odds of answering "larger than usual" were significantly higher than the odds of answering "smaller than usual" ($p = 0.019$, see Table S3 in the Supplementary material).

Sub-question: Those who reported a larger proportion of practice time spent on technique were asked whether they agreed, disagreed or were not sure whether the following statements were true:

> 'This has had a positive impact on my technique'
> 'This has changed how I practice now, and will practice in the future'

Seventy-five percent (of those who reported a larger proportion of practice time spent on technique) agreed with the former statement and 58% with the latter statement. The odds of agreeing with the former statement were significantly higher than the odds of disagreeing with it ($p = 0.037$, see Table S4 in the Supplementary material). There were no significant differences in the odds of the answers to the latter statement (see Table S5 in the Supplementary material).

Online content

The participants were asked if they had watched or read online content relating to technique. This was defined within the questionnaire as including masterclasses, tutorials, podcasts, blogs, and articles, but excluding concerts. Fifty-nine percent of respondents reported never watching or reading such content, and all this group said that this was in line with their usual habits. Thirty-two percent of respondents reported watching or reading such content "sometimes," of which 14% reported this to be "the same" and the remaining 86% "more" than their usual habits. Nine percent of respondents reported watching or reading such content "often," all of whom described this as "more" content than their usual habits. The odds of answering "never" were significantly higher than the odds of answering "often" ($p = 0.014$, see Table S6 in the Supplementary material). There were no significant differences in the odds of whether the use of the online content

TABLE 1 Practice habits during the pandemic-related concert-free time compared with usual habits pre-pandemic.

Percent (#participants)

Amount of practice compared to usual			
More	Less	The same	Fluctuating
9% (2)	41% (9)	9% (2)	41% (9)
Proportion of practice time spent on technique compared to usual			
Larger	Smaller	The same	
55% (12)	9% (2)	36% (8)	
Subquestions: if answer above was "Larger," agreement with the following statements			
This has had a positive impact on my technique			
Agree	Disagree	Not sure	
75% (9)	8% (1)	17% (2)	
This has changed how I practice now, and will practice in the future			
Agree	Disagree	Not sure	
58% (7)	25% (3)	17% (2)	
Frequency of watching/reading online content related to technique			
Often	Sometimes	Never	
9% (2)	32% (7)	59% (13)	
Amount of content compared to usual habits			
More	Less	The same	
36% (8)	0	64% (14)	
Breakdown: those who answered "Often" above			
100% (2)	0	0	
Breakdown: those who answered "Sometimes" above			
86% (6)	14% (1)	0	
Breakdown: those who answered "Never" above			
0	0	100% (13)	
Subquestions: if answer above was "More," agreement with the following statements			
Watching/reading this content has had a positive impact upon how I practice			
Agree	Disagree	Not sure	
75% (6)	0	25% (2)	
The majority of this content was produced by my peers			
Agree	Disagree	Not sure	
25% (2)	75% (6)	0	
Participation in streamed/pre-recorded online activities			
Concerts only	Tutorials only	Both	None
50% (11)	18% (4)	27% (6)	5% (1)
Frequency of use of digital tools (metronome, tuner, recording device) during practice			
Often	Sometimes	Never	
68% (15)	27% (6)	5% (1)	
Use compared to usual habits			
More	Less	The same	
54% (12)	5% (1)	41% (9)	
Breakdown: those who answered "Often" above			
67% (10)	0	33% (5)	
Breakdown: those who answered "Sometimes" above			
33% (2)	0	67% (4)	

(Continued)

TABLE 1 (Continued)

Percent (#participants)					
Breakdown: those who answered "Never" above					
0	100% (1)	0			
			Subquestion: if answer above was "More," agreement with the following statement		
			Using these digital tools has had a positive impact upon how I practice		
			Agree	Disagree	Not sure
			92% (11)	0	8% (1)

was more, the same, or less than usual (see Table S7 in the Supplementary material).

Sub-question: Respondents who reported watching/reading more online content than usual were asked if they agreed, disagreed or were unsure if they agreed with two follow-up statements:

> The majority of this content was produced by my peers (musicians around the same age as me, undertaking similar activities to me).
> Watching/reading this content has had a positive impact upon how I practice.

As seen in Table 1, 75% of respondents who had reported watching/reading more online content disagreed that the majority of this content was produced by peers, 15% agreed with this statement, and no respondents were "unsure." Seventy-five percent agreed that this content had a positive impact upon how they practiced, 15% said they were "unsure" whether they agreed with the statement, and no respondents answered "disagree." No relative risk reached statistical significance for these two questions (see Tables S8 and S9 in the Supplementary material).

The interviewees were asked about the type of content they had created themselves: 27% reported having taken part in streamed or pre-recorded concerts and created video tutorials, masterclasses, or blogs. Fifty percent of respondents had taken part in concerts only, 18% in tutorials only, and only 5% had done neither. The odds of having created streamed or pre-recorded concerts were significantly higher than the odds of not having created such content ($p = 0.016$, see Table S10 in the Supplementary material). In contrast, the odds of having created or not video tutorials, masterclasses, or blogs did not significantly differ from each other (see Table S11 in the Supplementary material).

Digital tools

In response to whether the participants had used digital tools such as a recording device, metronome, or tuner, 68% described this use as "often," with only 5% reporting "never," and 27% "sometimes." The odds of answering "often" were significantly higher than the odds of answering "never" ($p = 0.009$, see Table S12 in the Supplementary material). Fifty-four percent described this as being "more" than their usual habits (67% of whom had answered "often" above, and 33% "sometimes"), 5% reported "less" (answered "never" above) and the remaining 41% "the same" (33% of whom had answered "often" above, and 67% "sometimes"), as shown in Table 1. The odds of answering "more" were significantly higher than the odds of answering "less" ($p = 0.017$), and the odds of answering "the same" were significantly higher than the odds of answering "less" ($p = 0.037$, see Table S13 in the Supplementary material).

Sub-question: Those who reported more use of digital tools during the pandemic were asked whether they agreed with the statement *This has had a positive impact upon how I practice*. Ninety-two percent of those who had reported more use of digital tools agreed with this statement, 8% was not sure, and no one disagreed. The odds of agreeing with this statement were significantly higher than the odds of being unsure/disagreeing ($p = 0.022$, see Table S14 in the Supplementary material).

Demographic trends

Despite the small sample size, some demographic trends may be indicated by the data. These are summarized in Table 2.

Participants with children, and those who teach reported practicing less than their counterparts during the concert-free time: less practice was reported by 55% of participants with children (vs. 27% of participants without children), and 50% of those who teach (vs. 17% of those who do not teach). Students reported practicing more than non-students: 14% (vs. 7% of non-students) reported practicing more, and 71% (vs. 27% of non-students) practiced in fluctuating amounts. When organized according to gender, the results show men practicing more than women: 18% of men (vs. 0 women) reported practicing more, 18% less (vs. 64% of women), and 55% a fluctuating amount (vs. 27% of women). No statistical test reached significance for any of these effects (see Table S15 in the Supplementary material).

In terms of proportion of practice time spent on technique, gender also appears to divide the participants, with 73% of men spending more time on technique than usual (vs. 36% of women), and no men (vs. 18% of women) spending a smaller proportion of practice time on technique. Students reported spending a larger proportion of practice time on technique than non-students (71% vs. 47%). None reported spending a smaller proportion of time on technique (vs. 13% of non-students) and 29% reported the same

TABLE 2 Demographic breakdown: Practice habits during the pandemic-related concert-free time compared with usual habits pre-pandemic habits.

Percent (#participants)

Subgroup	% of population (#participants)	More	Less	The same	Fluctuating
Amount of practice compared to usual					
Students	32% (7)	14% (1)	14% (1)	0	71% (5)
Non-students	68% (15)	7% (1)	53% (8)	13% (2)	27% (4)
Children	50% (11)	0	55% (6)	9% (1)	36% (4)
No children	50% (11)	18% (2)	27% (3)	9% (1)	45% (5)
Teach	73% (16)	6% (1)	50% (8)	13% (2)	31% (5)
Do not teach	27% (6)	17% (1)	17% (1)	0	66% (4)
Female	50% (11)	0	64% (7)	9% (1)	27% (3)
Male	50% (11)	18% (2)	18% (2)	9% (1)	55% (6)
Subgroup	**% of population (#participants)**	**Larger**	**Smaller**	**The same**	
Proportion of practice time spent on technique compared to usual					
Students	32% (7)	71% (5)	0	29% (2)	
Non-students	68% (15)	47% (7)	13% (2)	40% (6)	
Female	50% (11)	36% (4)	18% (2)	46% (5)	
Male	50% (11)	73% (8)	0	27% (3)	
Subgroup	**% of population (#participants)**	**Yes, created concerts**			
Participation in streamed/pre-recorded online activities—concerts					
Students	32% (7)	100% (7)			
Non-students	68% (15)	67% (10)			
Subgroup	**% of population (#participants)**	**Yes, created tutorials**			
Participation in streamed/pre-recorded online activities—tutorials/masterclasses					
Female	50% (11)	65% (7)			
Male	50% (11)	27% (3)			
Teach	73% (16)	56% (9)			
Do not teach	27% (6)	17% (1)			
Subgroup	**% of population (#participants)**	**Often**	**Sometimes**	**Never**	
Frequency of use of digital tools (metronome/tuner/recording device) during practice					
Students	32% (7)	100% (7)	0	0	
Non-students	68% (15)	53% (8)	40% (6)	7% (1)	
Female	50% (11)	45% (5)	45% (5)	9% (1)	
Male	50% (11)	91% (10)	9% (1)	0	

amount (vs. 40% of non-students). No statistical test reached significance for any of these effects (the gender effect approached significance, $p = 0.065$; see Tables S16 and S16.1–4).

For the questions regarding frequency of watching online content related to technique, and how this content compared to usual pre-pandemic habits, no discernible trend can be seen, and accordingly the statistical tests were far from significance (see Tables S17, S17.1–4, S18, and S18.1–4).

Most participants were active in creating their own online content in the form of concerts or tutorials; only 5% created no such content. Regarding the demographic breakdown, no statistical test reached significance for any of these effects; however, students appeared to be more likely to have created concert streams than non-students (100% vs. 67%, see Table S19.1 in the Supplementary material). Moreover, teachers were more likely to have created online tutorials than non-teachers (56% vs. 17%, see Table S20.3 in the Supplementary material), and there appears to be a trend whereby women were more likely to have created online tutorials than men (65% vs. 27%, $p = 0.095$, see Table S20.4 in the Supplementary material).

A frequent use of digital tools during practice was seen in the student population (100% reported using such tools often vs. 53% of non-students). Similarly, a larger proportion of men reported

regular use of digital tools than women: 91% of men reported "often" vs. 45% of women, 9% of men vs. 45% women reported "sometimes" and 0 men vs. 9% of women reported never. The odds of using digital tools more often were significantly higher for men than for women ($p = 0.038$, see Table S21.4 in the Supplementary material). Regarding the question of how this use of digital tools compared to pre-pandemic practice, no statistical test reached significance (see Tables S22 and S22.1–4).

Additional comments

After each question in the survey, respondents were given the opportunity to expand their answers with additional comments that they considered relevant. Below, selected comments that represent this feedback have been grouped according to recurring themes. Participants have been labelled with codes P1 to P22, and references to instrument and demographic information can be seen in the Supplementary material Table S1.

Amount of practice

The following quotes describe how time spent practicing was reduced by energy and time constraints caused by teaching and family commitments:

> *P16*: I felt I was locked in a room with a computer, camera, microphones [because of online teaching] and afterwards there was absolutely no energy or interest to practice for myself.

> *P4*: The experience of practice was different for those who have children and those who don't have children…we were spending a lot of time with our kids and maybe not practicing as much.

Descriptions of fluctuating practice, as seen below, were typical:

> *P17*: There were periods where I didn't practice at all, and periods where I practiced regularly, about 3 hours a day.

Some comments showed participants to be relaxed and positive about the idea of practicing less than usual:

> *P15*: Before the pandemic I had to practice almost every day to feel like I was doing well…but, actually, [I learnt that] taking care of my instrument [voice] also means resting sometimes.

Type of practice

Some respondents related an increased proportion of practice time spent on technique to not needing to prepare concert repertoire, or, as seen in the last example, practicing repertoire in a more technical way rather than preparing it for a performance, and spoke positively about this time:

> *P22*: I had no specific things that I had to rush-practice for, so I had time to [work on technique].

> *P19*: I had wanted to improve some [technical] things for a long time, and…finally I had the time to do it.

> *P3*: Even when I did not practice technical stuff, I would practice pieces in quite a technical way.

The following comment describes a more ambiguous situation in which technical practice was viewed as having helped the participant but, nonetheless, overall technical level was perceived to have dropped:

> *P4*: [Because I was practicing so little] I felt like my level was less good, even though I was doing technique exercises… that probably kept me on a better level than I would have been otherwise.

In contrast to the technical work described above, other respondents used the time to work on repertoire, either learning new pieces, or playing old pieces for their own enjoyment. For example:

> *P8*: I practiced perhaps less, but …I had time that I could spend slowly on the pieces that…I had always wanted to play.

Further evidence of productivity and creativity during this time can be seen in several participants learning new instruments, practicing different types of music than usual, or getting involved in other aspects of musical life. For example:

> *P6*: I started playing Arabic instruments during the pandemic.

> *P14:* I was practicing other styles of music, pop and rock,… which was a type of technical work.

> *P15*: I did a lot of interviews for podcasts via Zoom…it was not about music making but about the business of music making and kind of activism as well.

Online content

The period when streamed concerts were allowed was reported by several participants to have boosted the amount of practice undertaken:

> *P3*: In the first lockdown when there were no streams I definitely practiced less. In the second lockdown, when the

> rules were a bit different, for example, when orchestras could do streams without an audience, then I practiced more.

The following quotes describe positive and more ambiguous feelings towards the results and the process of making video recordings for students:

> *P18*: Every week I made a video for my students about Peter and the Wolf…it worked really well…

> *P16*: Space is incredibly important for me, for teaching and for playing together, and having no space [because we were doing everything online or through recordings] really messed me up…In the end the effect was positive because you can learn from every new situation, but I'm happy that I don't **have** to do it now

Respondents who reported producing online tutorials and masterclasses spoke positively about this process both when they listened back to the results, and when they did not. For example:

> *P22*: I did a practice blog once a week every week during the pandemic…you practice way more intensely [with a live camera recording]…occasionally I would go back and [watch] the video…just to compare the progress for myself…but I didn't regularly do that…maybe once or twice a month.

> *P19*: I was getting paid [to make masterclasses in video form]…mostly [about] technical things. [I had often been told by teachers to record myself but] I didn't take the time to actually do that. When I had to send some videos [for these masterclasses] then of course I was checking the videos first, and then I realised some things [about my playing], so it helped.

Digital tools

Recording devices featured regularly in the discussion about which types or digital tool participants used most during lockdown. The corresponding feedback shows a complex relationship, for example:

> *P6*: [I made recordings of myself and watched them in slow motion], it's better than a mirror because it's delayed.

> *P7*: Recording can be a fantastic tool. It makes you hear and see yourself from the outside, which gives you a kind of clarity…but it can make you afraid of playing the next note. It can be too objective [especially with limited quality microphones]… In many ways it made me love playing a lot less…and for a period of time changed the way I played to a way that sounded better on a recording but not in real life.

One participant described the use of a metronome not only as a tool to keep time, but also to keep focus:

> *P3*: I definitely practice more concentrated [with a metronome]…keeping me focused on what I'm doing.

Several participants described investing in new technology during the pandemic, including specific software programs:

> *P13*: We used a [programme for practicing ensemble pieces where each person records their part with a metronome] as a tool to improve…a programme of really difficult music… it was an amazing discovery how effective it could be to practice with this kind of digital tool…we would never have thought to have used it…we will use it again [and have found another programme with even better sound quality].

Discussion

There follows a discussion according to the four focal points of this study, a summary of the study's limitations, and proposals for future work.

Amount of practice

In this study, 91% of participants reported a change in amount of practice compared to their pre-pandemic habits. Most of the 22 participants described this change as practicing less or in fluctuating amounts (41% in both cases). Although some comments showed this to be a negative experience, mostly due to the time pressure and extra workload associated with family life or giving online teaching (as documented in Spiro et al., 2021), some people described experiencing this positively as a rest and a chance to work differently on their instrumental practice.

A demographic breakdown appears to support the participants' comments that having school-aged children and teaching both reduced the amount of practice (55 and 50% reported less practice, respectively). Students, on the other hand, reported more practice than non-students (14% reported more, 14% less, 0% the same and 71% fluctuating practice compared with 7, 53, 13, and 27% in non-students, respectively). The large amount of fluctuating practice in students may reflect the fluctuating motivational levels reported in Philippe et al. (2020). The difference between men and women (18% of men reported practicing less compared to 64% of women) appears to support the finding that women in Switzerland were more likely to reduce their working hours than men (Steinmetz and Monsch, 2021).

However, perhaps due to small sample size, none of the above findings were proved to be significant.

Type of practice

Fifty-five percent of participants spent a larger proportion of practice time on technique compared to their usual, pre-pandemic routine, and this result was found to be significant. This supports the participants' comments that they used the time to undertake technical work that they would not otherwise have had time to do. The additional comments regarding learning new repertoire, or even learning new instruments reflects the mixed experiences of musicians during the pandemic, and points to moments of productivity and creativity, as documented in Nusseck and Spahn (2021) and Schiavio et al. (2021).

The demographic breakdown showed students spending more time on technique than non-students (71 and 47% reporting more, respectively) and men spending more time on technique than women (73 and 36% reporting more, respectively). These results were not shown to be significant (although the gender effect approaches significance, $p = 0.065$), possibly due to small sample size, but may be linked to the relatively larger amount of practice time reported in these groups above. The majority of those who increased the proportion of technique-practice agreed with the statements that it has had a positive impact on their technique (75% agreed, statistically more likely compared to those who answered "disagree"), and changed how they practice now and will practice in the future (58% agreed). It is notable that the latter statement received less agreement than the former, i.e., some participants acknowledged a positive change in practice that they nonetheless do not plan to incorporate into their future routine. This could be an acknowledgement, in line with the collected statements, that, once concert life resumes, repertoire practice becomes a priority again.

Online content

Fifty-nine percent of respondents reported "never" watching online content related to technique, such as masterclasses (a statistically significant majority compared to "often"). However, 75% of those who did report an increase in watching this content felt that it had a positive impact upon their own instrumental practice. The proliferation of material on YouTube and other platforms could be considered anecdotal evidence of the production of online content being accelerated by the lockdown periods. Indeed, almost all (95%) respondents in this study engaged in making some kind of audio/video content themselves, in the form of pre-recorded/streamed concerts and tutorials for students. This shows the productivity of a population a majority of whom were out of work or undertaking a reduced amount of work during this period, supporting reports of increased creativity despite the reduction in paid work (Spiro et al., 2021). In the demographic breakdown, teachers were seen to be particularly active in making online tutorials (25% created tutorials only, 31% tutorials and concerts, compared with 0 and 17% for non-teachers, respectively). This is supported by results in a British survey that show instrument teachers being more receptive to use of digital technology than non-teachers, and reporting increased use and a greater willingness to try new technology (Waddell and Williamon, 2019). The comments in our survey and in the literature (Güsewell and Terrien, 2021) show nuanced feedback from teachers that acknowledges both advantages and disadvantages of distanced learning *via* such content.

Digital tools

Most respondents (68%) reported using digital tools often, and more than in their pre-pandemic practice (54% of respondents). Those who reported increased use of such tools described the experience almost unanimously (and with statistical significance) as improving their technique. However, individual comments point to a more complex relationship, particularly with recording devices, which have elicited both positive and negative feedback. Increased engagement with digital tools was also seen in the respondents purchasing specific software to facilitate new practicing and teaching methods. A particularly frequent use of digital tools was, unsurprisingly, seen in the student population. Notably, there was a statistically significant difference between men and women's use of digital tools, with 91% of men vs. 45% of women reporting using such tools often. This difference is especially pertinent considering the significant reported improvement associated with such tools. These results seem to support the existence of a digital learning gap between women and men, that has been reported as existing from childhood, e.g., in the context of music education (Colley et al., 1997), and in the context of national and international attempts to unpick the underlying causes of this imbalance (Davaki, 2018). Our results are supported by a survey of digital learning technology in individual settings undertaken on a cohort of 338 amateur, student, and professional musicians in Britain (Waddell and Williamon, 2019). After demographic corrections were made to the data, men reported more usage of audio and video recording, and audio playback devices in musical instrument practice. Moreover, men reported a significantly higher tendency to seek out new technology to aid musical instrument practice, to enjoy learning it, and to enjoy using it. However, although these differences were significant, they were not large. Moreover, there was no significant difference in general (i.e., not music-specific) skills in computer and mobile devise usage, and thus the authors suggest that the established trend of greater digital confidence amongst men and boys may be waning, and the gender gap narrowing, as has been reported elsewhere in the case of music students (Colley and Comber, 2003). However, the above studies were carried out before the COVID-19 pandemic, and it is possible that the pandemic has reversed apparent progress,

especially given the reduced working times reported by women during this period (Steinmetz and Monsch, 2021).

Limitations

The main limitation of this study is the small sample size, particularly in analyzing demographic data, especially when there were multiple choices in response to a specific question. Although we recorded which instrument the respondents played, the sample size (even when grouped by instrumental family) was too small to make related assertions. In addition, this survey was undertaken in autumn 2021; thus, the time that had passed since the pandemic-related concert-free time might have introduced some errors due to inaccurate memory of the participants; e.g., looking more favorably upon this period in retrospect than while it was underway. The self-reporting required in this study may also have introduced some discrepancies, e.g., exaggerating positive or negative responses due to self-conscious behavior during the interview. Since the original call for participation was sent by email, it is possible that the selected respondents were more technologically-aware than the general population.

Future work

The changes that the period of pandemic-related concert-free time induced in musical practice were in many ways exceptional, and it is expected, or at least hoped, that musicians will not experience such restrictions again. The window for making analyses of this period is closing, as reliability in self-reporting practices during this period reduces with time. However, certain aspects of musical instrument practice that were unique to this period, or trends that were accelerated by it, may provide interesting future case studies under "normal" working conditions, and lead to recommendations for future musical practice. For example, although the minority of respondents reported watching online content, those who did watch it considered it to have had a positive impact upon technique. It may thus be interesting to investigate this effect more closely, and to consider how to broaden the reach of such media, by changing the content, and promoting it differently to musicians. Future work may also involve investigating what aspects of such content musicians find useful, and why, perhaps following up this discussion with an intervention to assess improvements in practice efficiency or performance associated with specific types of content. Similarly, despite the reported perceived benefits of peer-peer learning and engagement (Nielsen et al., 2018), and the efforts made towards online connection during the pandemic (Schiavio et al., 2021), the respondents seemed only rarely to have watched online material produced by their peers. Again, an increased awareness and promotion of such material, may be beneficial to the community. The significant reported improvement in using digital tools appears currently to be benefiting men more than women. Further studies, investment, and promotional work would also be important here to narrow this gap, and to improve these tools further.

Conclusion

The following main conclusions can be drawn from this study. Firstly, the COVID-19 pandemic-related restrictions significantly changed the amount of practice that musicians undertook, mostly resulting in a reduction or fluctuation in practice habits. Secondly, the pandemic-related concert-free time appears to have had the effect of increasing the proportion of practice time musicians spent on technique. Thirdly, the pandemic did not have a significant effect upon the amount of online content related to technique that musicians watched during the pandemic. However, consuming such content seems to be beneficial to technique. The production of online content, in the form of streamed concerts or tutorials, was prevalent amongst musicians during this time. Finally, the use of digital tools such as metronomes, tuners, and recording devices is widespread amongst musicians. This use increased during the pandemic and was considered beneficial to instrumental technique. Men are more likely to use such tools in their practice than women.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

EF conducted the interviews and drafted the first version of the manuscript. PG conducted the statistical analyses and participated in the writing and critical revision of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.846953/full#supplementary-material

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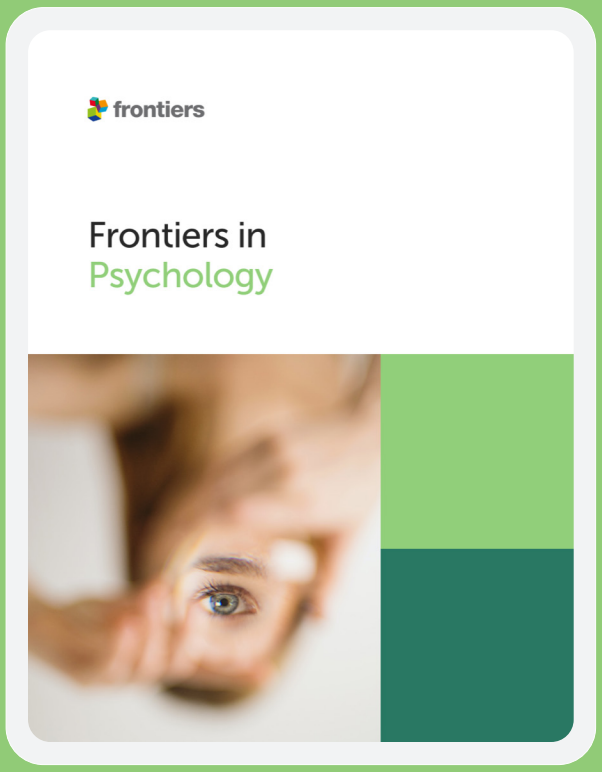
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