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The development of a mindful eating app for adolescents through mixed-methods feedback from adolescents with overweight or obesity

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Introduction: Obesity in childhood and adolescence continues to be a major public health challenge. Mindfulness-based interventions (MBIs) can be great adjuncts to multidisciplinary weight management interventions for adolescents. Delivery of MBI via mobile phones can decrease barriers to engagement. Mindfulness increases present-moment awareness, which may promote self-regulation, which is in turn important for weight management. Several studies have shown that delivering mindfulness training for adolescents via mobile devices may be feasible and acceptable, but this is still a growing area of research. The Unified Theory of Acceptance and Use of Technology (UTAUT) is a framework that has been used to understand why individuals choose to use health apps. This study aims to gather adolescent perceptions about an existing mindful eating mobile app designed for adults, via mixed methods research, and to utilize their feedback to design and develop a mindful eating app for adolescents.

Methods: This was a cross-sectional, mixed methods study. Twenty-five adolescents, 13–17 years old, with a BMI $\geq$ 85th percentile completed a UTAUT-based survey and a semi-structured interview after viewing excerpts from an existing mindful eating mobile app.

Results: Adolescents with overweight/obesity are receptive to using a mindful eating app, with some concerns about Effort Expectancy and Self-Efficacy. Youth endorse that such an app should have reminders, short and colorful videos with captions, and it should be engaging, relatable, and non-judgmental. This information was used to develop a mindful-eating web-based app for adolescents, SAMBA (Study of an Adolescent Mindfulness-Based App).

Conclusions: We developed a mindful eating web-based app for adolescents utilizing feedback from this youth cohort using an existing mobile app as the starting point. Future directions include pilot testing the app and its content.

KEYWORDS

mHealth, mindful eating, mindfulness training, app development, adolescents, obesity, UTAUT, semi-structured interview

1 Introduction

Obesity, which affects 1 in 5 children and adolescents in the US, is associated with increased morbidity and mortality (1, 2). Standard treatment for obesity involves Intensive Health Behavior and Lifestyle Treatment. However, weight loss maintenance remains a challenge, with most interventions followed by significant relapse (3, 4). Strategies to improve weight maintenance include interventions that teach maintenance skills such as self-regulation (5) or extending the length of treatment, which is costly and may benefit from using digital tools as a novel strategy (6).

The practice of mindfulness, which promotes purposeful and nonjudgmental awareness of the present moment, was first introduced to the Western medical field in 1985 by Jon Kabat-Zinn (7, 8). Mindfulness-based interventions (MBI) can enhance multidisciplinary pediatric weight management programs (9). MBIs address the underlying behavioral mechanisms for maladaptive eating (10–12); they support self-regulation for weight loss by reducing habitual eating patterns (emotional eating, external eating), and can improve self-awareness and self-acceptance (10). Adolescents are particularly susceptible to self-regulation challenges and are more likely to eat in response to internal (emotional) and/or external (environmental) cues, as opposed to physiologic hunger and satiety cues (11). MBIs have shown to be acceptable and feasible for children and adolescents with or without parental involvement (13, 14). Recent research has found that MBIs may prevent or improve childhood obesity (15, 16), as well as improve eating behaviors and body image acceptance among children and adolescents (17–20). Furthermore, recent meta-analyses have found that MBIs can be effective for improving youth mental health and well-being (21, 22).

Mindful eating is the practice of bringing present moment intentional awareness and acceptance (mindfulness) to eating-related thoughts, emotions, bodily sensations, and behaviors (23, 24). Mindful eating involves several practices including 1) paying attention to the sensory properties of food, 2) paying attention to bodily hunger and satiety cues (which has overlap with intuitive eating), 3) observing and accepting food-related thoughts and cravings in a non-judgmental way, noticing that they are separate from the self, and how they occur in response to internal or external triggers (25). Mindful eating interventions may help patients improve their relationships with food by disrupting habit loops of maladaptive eating behaviors (10, 26). Mindful eating programs may reduce emotional and external eating among patients with overweight or obesity (27). Even a brief mindful eating program has been shown to lead to less impulsive food choices (28). For youth with obesity, these programs have been shown to improve mindful eating, food cravings and weight control (29).

A study of an MBI on mindful eating and resilience found the program to be feasible and acceptable among schoolchildren and

their parents (30). Furthermore, research suggests that MBIs specifically focused on eating behaviors, delivered in clinical settings, may be effective for decreasing emotional eating (31). MBIs may improve eating behaviors and promote weight loss among adults with overweight and obesity, with a large effect on eating behaviors and a moderate effect size on psychological outcomes (anxiety) and body weight (12, 32–34). A randomized anti-obesity feasibility study among adolescent females suggested that a satiety-focused mindful eating intervention may reduce BMI among adolescent females with overweight or obesity (35). However, a recent meta-analysis suggested that the effect of MBI on improving BMI among children with overweight and obesity remains inconsistent and further research is needed (36). Digital tools offer innovative approaches to delivering health interventions to adolescents (37), especially as smartphone use is nearly universal within this population (38). Delivering MBIs via mobile phones may increase accessibility by overcoming barriers to accessing traditional interventions (39, 40). A study of a mindful eating intervention found that a family-based mindfulness-based cooking class could be feasible for youth with overweight and obesity, while also highlighting key barriers to participation, such as cost and busy schedules (41). Mobile interventions may be particularly beneficial for patients with financial, socioeconomic, and geographic barriers to participation in traditional mindfulness programs (42). A randomized trial found a mindful eating intervention for adolescents delivered via smartphones was feasible and efficacious (43). For adolescents, the development of successful mobile health apps requires a user-centered design approach that elicits user feedback through a combination of both quantitative and qualitative methods (44–48).

The Unified Theory of Acceptance and Use of Technology (UTAUT) model has been used widely to predict user acceptance and use of technology (49, 50). Semi-structured interviewing is a valuable tool for eliciting nuanced feedback about mobile health interventions (51, 52). Used jointly, the UTAUT and semi-structured interviews can provide important insight into the acceptance and adoption of mobile health apps (50). Recent research employing the UTAUT model and semi-structured interviews suggests that mobile apps can provide communicative support, reduce distress, and improve well-being and self-care in youth with chronic conditions or long-term illnesses (53, 54). The UTAUT model has been shown to explain a large percent of the variance in acceptance of digital health interventions among adults with obesity and to be helpful in designing consumer health technology to manage adolescent obesity (55, 56). Qualitative analysis from semi-structured interviews has been previously utilized to understand adolescent preferences during the development of mobile health applications for mental health (57) and obesity (58).

Research suggests that mobile health apps may benefit youth, including improving healthy eating habits and weight loss (59, 60); mindfulness-based apps, in particular, may improve awareness of weight-related behaviors in adolescents and young adults (61). Despite the success of mindful eating apps for individuals with obesity, many available apps could improve upon the domains

Abbreviations

MBI, mindfulness-based intervention; UTAUT, The Unified Theory of Acceptance and Use of Technology; SAMBA, Study of an Adolescent Mindfulness-Based Intervention App; FMA, framework matrix analysis; ATA, applied thematic analysis; RCT, randomized controlled trial.

of comprehensive information, engagement, and aesthetics (62); furthermore, very few have been specifically designed for adolescents (61). The Eat Right Now app[®] was developed by Judson Brewer (Mindfulness Center of Brown University), and was shown to reduce craving-related eating and over-eating behaviors and improve weight loss among adults (39, 63).

Given the lack of mindful eating apps for adolescents, and the evidence suggesting positive effects of mindful eating apps in adults and mobile health apps in this population, we aimed to develop a mindful eating app for adolescents. Using the Eat Right Now[®] app as a starting point, we aimed to understand the acceptability and feasibility of a mindful eating app for adolescents. In this study, we elicited adolescent feedback about this mindful eating app via the UTAUT and semi-structured interviews. Specifically, we used results of the UTAUT survey to gauge adolescent interest in a mindful eating app. Results from the semi-structured interviews, analyzed via Framework Matrix Analysis (FMA), provided real-time feedback for the development of a mindful eating app specifically for adolescents, the Study of an Adolescent Mindfulness-Based App (SAMBA). After creating this initial version of the SAMBA app, we further analyzed the qualitative data via applied thematic analysis (ATA), in order to provide depth to the UTAUT findings, and to identify additional user feedback for guiding future testing and iterations of the app.

2 Methods

2.1 Study design

This study was conducted at Hasbro Children's Hospital (Brown University Health) in Providence, RI from July 2022 to May 2023. Participants were recruited from the Pediatric Endocrinology Clinic and the Primary Care Clinic during their regular clinic appointments, by members of the research staff. A convergent mixed methods design was used, with survey and interview data collected concurrently. Data were analyzed independently, and then integrated to identify areas where qualitative themes explained, or expanded on the quantitative results.

2.2 Participants and eligibility

Participants were recruited from the Pediatric Endocrinology and Primary Care Clinics at Hasbro Children's Hospital. Participants were required to be 13–17 years old, have overweight or obesity (BMI for age/sex $\geq$ 85th percentile), speak English, and have daily access to a smartphone. Exclusion criteria included medical conditions that would preclude adherence to dietary recommendations (such as inflammatory bowel disease), genetic or endocrine causes of obesity, a diagnosis of type 1 or type 2 diabetes mellitus, severe developmental delay and/or serious cognitive impairment, current use of psychotropic medications which could affect weight, or being non-English-speaking.

Eligibility was determined via chart review by research staff and confirmed by discussion with the participant and their parent. All participants received compensation for their participation in the study.

2.3 Procedure

Informed consent and assent were obtained from all participants prior to the study visit. Each participant met with a member of the research team once over a HIPAA-compliant video platform. Demographic data, including age, school grade, sex, gender identity, race, ethnicity, type of health insurance, BMI (extracted from the Electronic Health Record), and technology use data, was collected in REDCap and de-identified.

Participants reported their current weight-related stage of change by selecting the statement that best described their current weight situation, based on the transtheoretical model for weight management (64): (1) At the moment, I am not doing anything to lose weight, and I have no intention about doing anything over the next 6 months; (2) At the moment, I am not doing anything to lose weight, but I am thinking about doing something over the next 6 months; (3) I have been making an effort to lose weight (by dieting and/or exercising) for less than 6 months; (4) I have been making an effort to maintain my weight (by dieting and/or exercising) for 6 months or more.

Based on subject enrollment order, participants were assigned to review (via videoconference) one of three different subsets of video lessons, video animations, and mindfulness exercises from a commercially available mindful eating application (Eat Right Now[®]), which was designed for and tested with adult participants (39). The goal of this grouping was to keep each interview time-limited and engaging. After playing the clip of each video lesson, video animation, or mindfulness exercise to the participant, the researcher conducted a short semi-structured interview to elicit participant opinions about the app, including likes and dislikes about app features, suggestions for change, and how to adapt the app for adolescents (Table 1). Interviews

TABLE 1 Questions asked of participants in semi-structured interview.

Module type	Questions asked
Lessons and animations	What do you like about this lesson/animation? What did you dislike about this lesson/animation? What would you change about this lesson/animation to make it more helpful?
Interactive exercise	What do you like about this exercise? What did you dislike about this exercise? What would you change about this exercise to make it more helpful?
Audio meditation	Would you use this audio meditation if you had it available on your phone? What would you change about this audio meditation to make it more helpful?
Overall	How often would you use this app? What would help you use it more often? What did you like most about the app? If you had a magic wand, what would you change about this app? Can you think of any specific features or functions you would include or change to make the app more relevant for teens? Can you describe any features or functions in the app that would help you learn?

were audio-recorded, transcribed, and then reviewed for accuracy and appropriate deidentification.

The study visit concluded with a survey that was developed by our group based on the Unified Theory of Acceptance and Use of Technology (UTAUT) constructs. Participants completed the survey online using REDCap electronic data capture tools hosted at Brown University Health (65). The survey included 13 statements, organized in eight constructs assessing Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Attitudes toward Technology, Self-Efficacy, Anxiety, and Behavioral Intention. Participants responded to each statement via a 5-point Likert scale (66). We analyzed average scores for each construct to determine participant perceptions of the app. We assessed the percent of participants that provided favorable ratings for each statement, a 4 or 5/5 (agree or strongly agree), or 1 or 2/5 (strongly disagree or disagree) for the Anxiety construct, which is reverse-coded. An a-priori benchmark of 80% of participants reporting favorable ratings was used to gauge acceptability.

Reliability and validity were also estimated for the UTAUT-based survey, using principal components analysis. Scale validation focuses on correlations. If the questions are all valid measures of the same underlying trait, in this case willingness to use technology for managing mindful eating, then participants who endorse high scores on one question should also endorse high scores on other questions as well— a pattern of positive correlations. Principal components analysis summarizes these correlations in a loading, denoted λ , which can be interpreted like a correlation between an individual question and all other questions on the questionnaire. Values close to 1 represent positive correlations with most other questions, values close to -1 represent generally negative correlations with other questions, and values close to 0 represent no association. This can be used to evaluate whether or not all questions are equally relevant to participant attitudes, which reflects internal structure validity. This provides information on how to interpret what scores represent, as well as which questions are most insightful to individual attitudes.

The values of the loadings were used to estimate reliability, interpreted as representing the percentage of total variation in scores that is meaningful. Reliability of 0.70, or 70% meaningful variation, is often considered acceptable. Lastly, the correlation between summed scores on the UTAUT and the two questions about Behavioral Intention was estimated to represent concurrent validity. If the UTAUT validly represents willingness to use a mindful eating app, then participants who endorse higher scores on the questionnaire will also endorse greater willingness to use the app when directly asked, a positive correlation. Using this approach allowed us to investigate this empirically. A Bayesian estimation procedure was used because the sample size is modest ($N = 25$ participants).

All data was de-identified before analysis.

2.4 Framework matrix & applied thematic analyses

Framework matrix analysis (FMA) and applied thematic analysis (ATA) were used to analyze qualitative data from the

interview transcripts. Considering the time-consuming process of ATA in the context of app development (67), we conducted FMA first, as it provided real-time feedback for the design and initial development of our mindful eating web-based app (SAMBA). Together with the results from the UTAUT survey, which gauged adolescent interest in a mindful eating app, the results from the FMA of the interview transcripts informed the development of the initial version of the SAMBA app. Once app development was underway, we again analyzed the interview transcripts, via comprehensive ATA, to gain a more nuanced perspective on the app's successes and potential areas of improvement for future iterations of the app.

First, all 25 audio-recorded participant interviews were transcribed by members of the research team. Full review of the transcripts yielded inductive (based on the researcher's interests) and deductive (based on interview responses) FMA codes. A research assistant entered summaries of participants' comments, relevant quotes, and key decisions regarding app development into the framework matrix. After the framework matrix was built, matrix contents were reviewed by the principal investigator and deemed accurate and complete. Data helped inform app design and development (67).

After FMA was complete, we used the framework matrix to create a second codebook for ATA. Two coders reviewed the ATA codebook and independently coded the first transcripts, then met to review their coding, finalize the codebook and add additional inductive codes. With the finalized codebook, the two coders then independently coded all 25 transcripts. After the initial coding was completed, the two coders met to review 5 (20%) randomly selected transcripts to review codes and resolve discrepancies. The master coded transcripts were entered into NVivo software (version 14.0). Concordance was calculated at 90%, demonstrating a high consistency between the coders.

3 Results

3.1 Participant characteristics

In total, 25 participants completed the research study, including providing demographic and technology use information, and completing the semi-structured interview and UTAUT questionnaire. Fifteen (60%) identified as male. In terms of race and ethnicity, 5 identified as African-American (20%), 4 identified as white (16%), and 15 (60%) identified as Hispanic or Latino. Seventeen (68%) had severe obesity, defined as a BMI percentile at $\geq 120\%$ of the 95th percentile. All 25 participants reported owning a smartphone and using apps. Detailed demographic information is summarized in Table 2. When asked about their weight-related stage of change, 2 (8%) were contemplating changing their behaviors, 3 (12%) were preparing to change their behaviors, 16 (64%) were actively changing behaviors, and 4 (16%) were in the maintenance stage of behavior change.

TABLE 2 Demographics and characteristics of adolescents at enrollment.

Characteristic	n (%)
Age, mean years $\pm$ SD	14.6 $\pm$ 1.5
Gender	
Male	15 (60)
Female	8 (32)
Non-Binary	2 (8)
BMI	
Absolute	36.4 $\pm$ 7.8
% BMI of 95th percentile	128.3 $\pm$ 39.4
Severe obesity	17 (68)
Race	
African American	5 (20)
White	4 (16)
Other	16 (64)
Ethnicity	
Hispanic or Latino	15 (60)
Not Hispanic or Latino	10 (40)
Insurance status	
Public	10 (40)
Private	15 (60)
Smartphone ownership	25 (100)
Smartphone use	
Weekly	1 (4)
1–5 $\times$ /day	7 (28)
>5 $\times$ /day	17 (68)
App use	25 (100)
Internet browser use	23 (92)
Weight-related stage of change	
Precontemplation	0
Contemplation	2 (8)
Preparation	3 (12)
Action	16 (64)
Maintenance	4 (16)

3.2 Unified theory of acceptance and use of technology (UTAUT) survey

Findings from the UTAUT survey are summarized in Table 3. The Performance Expectancy, Social Influence, Facilitating Conditions, and Attitudes toward Technology constructs received average scores between 4 and 5/5, indicating that most participants responded “Agree”, or “Strongly Agree” to the questionnaire statements for these constructs. However, the Effort Expectancy and Self-Efficacy constructs had lower average scores, between 3 and 4. Over 80% of participants selected either “Agree” (4/5) or “Strongly Agree” (5/5) with at least one statement from each construct, including Behavioral Intention, with the exception of the Self-Efficacy construct. The Anxiety construct, which was reverse coded, received an average score of 2.27 [1.62, 3.07], indicating that most participants responded “Disagree” (2/5) or “Neither Agree nor Disagree” (3/5) to these statements. These results suggest that adolescents are motivated and think a mindful eating app would be helpful, but they may lack confidence in their ability to use it. Overall, the high levels of agreement for these constructs support the development of a mindful eating app for adolescents.

In terms of internal validity of the survey, the loadings (which range from -1 to 1) representing common association between an individual question and all other questions, were large ($\lambda > 0.5$) except for facilitating conditions ($\lambda = 0.01$). This is because all teens endorsed this question, which indicates it provides no meaningful information. The association with behavioral intention was positive [correlation > 0.15 , 95% CI (0.07, 0.27)], which supports the validity of the survey, meaning that those who endorse the constructs say they would be more likely to use the app. Reliability was appropriate [0.70, 95% CI (0.50, 0.85)], suggesting that similar youth would get similar scores using this questionnaire.

3.3 Framework matrix analysis

FMA supported the findings from the survey in that participants overall were receptive to a mindful eating mobile app. It also pointed to additional app features that adolescents consider important, which were not present in the app that was presented to them during this study, as it was developed for an adult audience (39).

Analysis of inductive codes “attitude and tone” and “user flexibility” found that youth overall found the app relatable and encouraging; however, they disliked content containing moralizing language about food and weight. They also preferred the self-directed exercises that provided many choices.

Analysis of the deductive codes “easy to understand” and “educational” revealed that adolescents found the app educational and easy to understand. Analysis of the deductive codes “engaging” and “visually appealing,” contained mixed responses. While some youth found the app engaging, others wanted shorter videos, captioning, and more visual engagement. Similarly, while some youth found the app visually engaging, others provided suggestions to increase engagement, including text message reminders, introduction videos, gamification features, and teen-specific examples.

3.4 SAMBA app features guided by FMA findings

Given that adolescents disliked moralizing language about food and weight, we avoided the use of such language in the SAMBA app. The SAMBA app was designed to include directions for following certain exercises depending on each person’s daily experience, and at their own pace, since adolescents preferred self-directed exercises that provided choices,

Youth preferences highlighted the need for shorter videos, captioning, and more visual engagement; SAMBA’s lesson videos include captions, have an abundance of visual aids, and are shorter and more colorful than those in apps designed for adults, such as Eat Right Now[®]. We followed participants’

TABLE 3 Overview of descriptive statistics and constructs used in UTAUT survey.^a

UTAUT construct survey statement	Average score [1–5, mean (95% CI)]	Loadings ^b	N (%) endorsing agree (4/5) or strongly agree (5/5) (R) ^a endorsing disagree (2/5) or strongly disagree (1/5)
Performance Expectancy			
Using a mindful eating app will help me develop a healthier relationship with food	4.20 [3.45, 4.70]	0.73 [0.34, 1.12]	24 (96)
Using a mindful eating app will improve my chances of eating healthier	4.29 [3.55, 4.75]	0.23 [−0.19, 0.65]	23 (92)
Using a mindful eating app will help me be healthier overall	3.94 [3.16, 4.53]	0.69 [0.31, 1.14]	16 (64)
Effort Expectancy			
Learning how to use a mindful eating app will be easy for me	3.47 [2.67, 4.18]	0.24 [−0.19, 0.65]	12 (48)
I will find a mindful eating app easy to understand, use and navigate	3.81 [3.02, 4.44]	0.43 [0.01, 0.83]	22 (88)
Social Influence			
My parents will think it is a good idea for me to use a mindful eating app	4.67 [4.06, 4.04]	0.76 [0.38, 1.17]	22 (88)
Other people who are important to me will think it is a good idea for me to use a mindful eating app	3.94 [3.16, 4.53]	0.57 [0.15, 1]	16 (64)
Facilitating Conditions			
I have what I need (smartphone, time, skills) to be able to use a mindful eating app	4.80 [4.26, 4.98]	0.01 [−0.43, 0.42]	25 (100)
Attitudes Toward Technology			
Using a mindful eating app is a good idea to help me eat healthy	4.58 [3.94, 4.91]	0.51 [0.14, 0.97]	24 (96)
Self-Efficacy			
I am confident that I will be able to use a mindful eating app	3.86 [3.06, 4.47]	0.66 [0.25, 1.14]	19 (76)
Anxiety			
I think using a mindful eating app could make me worry or hurt my feelings (R)	2.27 [1.62, 3.07]	−0.69 [−1.16, −0.29]	15 (60)
Behavioral Intention			
I will use a mindful eating app if I have access to it	Reliability 0.70 [0.50, 0.85]	Concurrent validity 0.15 [0.07, 0.23]	20 (80)
I will participate if there is a study to use a mindful eating app for teams		0.19 [0.11, 0.27]	19 (76)

^aThe statement labeled (R) is reverse-coded.^bBayesian PCA loadings (range −1 to 1).

suggestions to add customizable text reminders, and thus the SAMBA app sends five text reminders per week. We included two introduction videos that must be watched before the video lessons. We also included personalization features, including the opportunity to choose between two different characters who are wearing different clothes, have different gender and different body weight. In terms of gamification, the SAMBA app also allows participants to accrue experience points, XP, for their app use (i.e., completion of audio meditations, video lessons, mindful eating exercises). As their XP increase, youth progress through different experience levels based on their XP accrual: beginner, intermediate, advanced, and pro-mindful eater, and these levels are displayed on the main screen (Figure 1). For the pilot study to test the app, our plan is to offer prizes if participants accrue enough XP reflecting that they have used the app as intended. The app also includes teen-specific examples to increase engagement (i.e., the lesson videos include examples pertinent to school experiences, as opposed to work experiences which would match an adult audience).

3.5 Applied thematic analysis

During review of the master coded transcripts, three themes emerged. These themes embodied the participants' opinions about the app's visual engagement and interactivity, ease of use, and the overall tone of the app.

3.5.1 Mindful eating apps should be engaging, interactive, and visually appealing

Many participants described the app's design as an important factor in their willingness to engage with an app. We identified where participants described the app as *boring* vs. *engaging* and *visually appealing*. In particular, participants described the importance of engaging visuals, including colorful animations and backgrounds, instead of direct speech or text.

Well, I did like the way it [was] portrayed– it helped us visualize it. You know, it's better to get shown something rather than told something. [Participant 9, 13 years old]

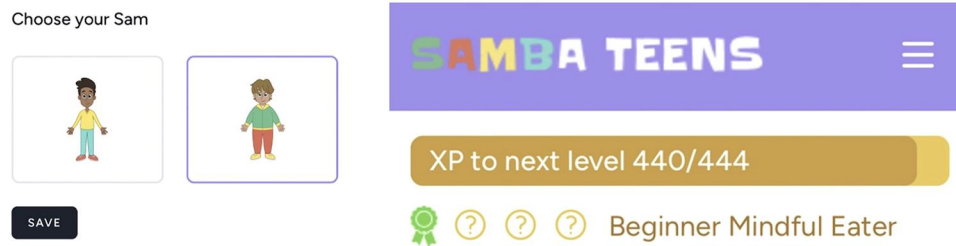


FIGURE 1

Representation of SAMBA mindful eating app personalization features (choice of preferred character, Sam) and gamification features [accrual of XP (experience) points and completion of levels (i.e., Beginner Mindful Eater)]. As shown, SAMBA features colorful and engaging graphics throughout the app.

Furthermore, many participants reported the need for an *interactive app with gamification and examples*. Participants suggested gamification options including rewards systems (points, badges, prizes), minigames, and pop quizzes.

I'd add certain structures to it, where you're supposed to watch a certain amount of videos at once, just so you don't forget about it. Like the way to check if the person's understanding the video, that would help, because I think the message behind the videos sometimes got a little lost. [Participant 26, 14 years old]

While design and interactivity were common themes described by the majority of participants, participants also expressed that this should be balanced by lessons that are *simple with ample explanation*.

It was both thorough but simple enough to get the gist of it. And it wasn't too much for people to understand, I guess. So, it still gives you a tidbit of what they expect from the app and what you're going to have, but it doesn't throw too much info at you so you're like, "I don't want this at all." [Participant 12, 16 years old]

3.5.2 Mindful eating apps should be flexible, adaptable, and easy to use

Several participants suggested that clear *instructions* were important in encouraging participation. Although they appreciated flexibility and did not want to feel controlled, some expressed that structure and step-by-step directions would prevent users from feeling overwhelmed with options.

...the other ones were more like, "this is what you're doing wrong. You should be doing this." but it doesn't really tell you how to get from point A to Point B... It's like, this is what you're doing wrong, and this is what you should be doing, but there's no helpful tips. [The Gears lesson] had more instructions instead of- I don't want to call it criticisms, because they're not really criticisms. It's just

showing you two sides of one coin instead of showing you the process of flipping the coin. [Participant 19, 16 years old]

Participants highlighted the importance of an *easy-to-understand* app that teaches you how to engage in mindfulness training.

...it walks you through everything. Instead of just telling you, "You need to do this, that, and that," it gives you ways to do that. And kind of guides you through it. [Participant 6, 17 years old]

Similarly, participants wanted an app that was both *visually appealing* and *simple* enough to use easily.

Nothing about [the app] was confusing at all. It wasn't an app that's easy to get lost in. [Participant 14, 17 years old]

3.5.3 Mindful eating apps should be relatable, non-judgmental, and helpful

Participants described the importance of an app that is *honest* and *relatable*—one that acknowledges the realities and challenges of food cravings.

I like how it doesn't hide from the fact that people crave foods and stuff like that. And he was basically saying it's better to accept [that] than act like it's not there. And he was also saying, like, when you have cravings, you see changes in your body. Your mind and your body change once you have cravings. [Participant 5, 15 years old]

Multiple participants resonated with the lessons' messages about mindful eating, cravings, and the challenges of breaking habit loops related to food.

It made me think of how I used to use food as a stress relief. And I almost relate to how that person felt when... about what they were talking about. I understood personally; it related to a personal experience. [Participant 19, 16 years old]

Participants described the app and the messages, examples, and stories within the lessons as *relatable*. They described the app as one that acknowledges the challenging nature of improving one's relationship with food and eating.

It kind of just, like, goes through the stages of how people sometimes mess up, and they'll be like, "Well, I can't do it anymore," and then they'll realize their faults and try again.
[Participant 12, 16 years old]

The themes of visual engagement, usability, and positive app tone revealed during ATA supported our findings from the FMA. In particular, findings from the ATA and FMA both highlighted the importance of visual appeal, engagement, usability, and non-judgmental tone in a mindful-eating app. The ATA also revealed the need to include gamification, relatable examples, and thorough explanations. While the FMA informed the development of the SAMBA app, given its rapid turnaround time, the ATA findings are important data that may influence future iterations of the app.

4 Discussion

4.1 Principal results

Results from the UTAUT-based survey showed that a mindful eating app is acceptable to adolescents overall, with high scores for Performance Expectancy, Social Influence, Facilitating Conditions, and Attitudes Toward Technology. However, the survey results also identified potential challenges in terms of Effort Expectancy and Self-Efficacy. Qualitative analysis supported and contextualized the survey findings. Advanced thematic analysis showed adolescents to be receptive to a mindful eating app, and also identified themes pointing to essential features for successful youth engagement.

Similarly to prior work, given that the FMA methodology has a faster turn-around time, it was used in real time to inform app design and development, whereas final insights from ATA were available after app development (67). Importantly, analysis of the semi-structured interviews using FMA and ATA yielded consistent results, an approach for analyzing qualitative data that has been described in past research (67). Specifically, both FMA and ATA codebooks elicited similar themes regarding the importance of an easy-to-use, engaging, and visually appealing app for adolescents.

While the FMA codebook summarized the participants' individual interview responses about the app and shaped the development of the SAMBA app, the ATA codebook identified broader themes. In addition to the major themes elicited by analysis of the semi-structured interviews, participants provided constructive suggestions regarding visual engagement, gamification, and the addition of teen-specific examples.

Participants' answers to the UTAUT survey constructs demonstrated that they believe that a mindful eating app may improve their relationship with food and help them be healthier.

Overall, participants agreed that they have the resources and time to use this type of app, and that they (and their parents) would have a positive perception of this technology. However, participants cited lower agreement with the Effort Expectancy and Self-Efficacy constructs, indicating that they may find a mindful eating app confusing or intimidating, or they anticipate potential challenges with learning to use a mindful eating app. Qualitative themes that emerged from thematic analysis suggested several potential features that may mitigate youths' lack of confidence in successfully using such a digital tool. Specifically, youth endorsed that a mindful eating app for adolescents needs to have a specific design, allowing it to be engaging, interactive, and visually appealing; it should also have a specific structure and flow, allowing it to be flexible, adaptable, and easy to use, and finally, it should have content that is relatable, non-judgmental, and helpful.

Pilot testing of health apps, such as the SAMBA app, should include exit interviews to assess for specific barriers to Effort Expectancy and Self-Efficacy that may affect youth engagement with apps and their content. This would inform user feedback-driven iterations of the SAMBA app to optimize adherence and clinical outcomes.

4.2 Future directions

The SAMBA web-based app, a mindful eating app for adolescents, was developed with the incorporation of adolescent feedback from this study. As a next step, we had planned to test the SAMBA app in an NIH-funded pilot randomized controlled trial (RCT), to assess the feasibility of app use by adolescents and its effect on eating behavior. Unfortunately, the web-based app was hacked and due to the high cost of launching it again, plans were halted. Instead, we plan to proceed stepwise, and to first test the core curriculum (didactic video lessons, audio meditations) for acceptability and feasibility. For this, we plan to use either text messaging or e-mail to deliver links to our didactic videos and audios, which are hosted on a streaming platform, or to use one of the existing robust online platforms that are designed to centralize the delivery of educational content. This approach of utilizing text messaging, e-mail, or an existing platform as opposed to a brand-new web-based app would allow for a much lower cost, shorter timeline, and increased robustness against real-world challenges such as hacking.

With the rising clinical use of glucagon-like peptide receptor (GLP-1s) agonist medications for weight management in adolescents, the practice of mindful eating remains highly relevant (68, 69). Recent literature has highlighted the need for a focus on nutritional interventions to optimize GLP-1 efficacy (70–72). GLP-1s slow down gastric emptying and intestinal motility and thus can cause early fullness, and they are frequently associated with side effects including nausea, vomiting, bloating, and abdominal pain (73). Interventions focused on eating practices, such as mindful eating, may be able to promote medication compliance and decrease side effects by

encouraging youth to pay attention to their bodily cues of hunger and satiety. Following these body cues can lead to eating smaller, more frequent meals, at a slower pace, and stopping before feeling full, which may be less likely to be associated with gastrointestinal side effects (70, 71). The practice of mindful eating remains highly important, and may be beneficial, when used in conjunction with obesity medications such as GLP-1s. Based on our clinical experience and the literature, the proportion of adolescents with obesity seen in weight management clinics who are eligible and interested in taking GLP-1s as an adjuvant to intensive health behavior and lifestyle treatment has been rapidly increasing (74). Thus, we plan to test the SAMBA app on adolescents who are preparing to start GLP-1s. Other future directions include adapting our mindful eating curriculum for youth with type 1 diabetes mellitus, as this population may also benefit from mindful eating practices given their increased risk for weight gain (75–77) and food-centric management.

4.3 Limitations

The limitations of this preliminary study include a relatively small sample size of 25 participants from a single urban institution, which does not allow us to draw conclusions about app perceptions by gender or severity of obesity, and which may limit generalizability of findings to the general population. We did not include non-English-speaking participants (as the app and its curriculum are only available in English at this time) or older adolescents (greater than 17 years old), as we wanted to focus on middle adolescence, which is different developmentally and socially from late adolescence (18–21 years) (78).

All participants attended a clinical weight management program, and thus may be more motivated than the general adolescent population, as reflected in their answer to the weight-related stages of change questionnaire. Participants viewed excerpts from a mindful eating app and answered a questionnaire endorsing the behavioral intention to use the app, which is different from actually using the app in their daily lives. A future pilot randomized controlled trial (RCT) will seek to address these limitations by assessing the acceptability and feasibility of the core SAMBA curriculum vs. a control, followed by a larger RCT.

4.4 Conclusions

Tailored mindful eating apps should continue to be studied as a potential intervention for adolescents seeking to improve their relationship with food, as an adjunct to multicomponent weight management interventions. Mindful eating apps designed and developed for adolescents, such as SAMBA, should prioritize non-judgmental and relatable features that encourage interactivity with the app.

As technology changes and app use increases among adolescents, prospective studies should continue to assess feasibility of app use within this population. Research measures

such as the UTAUT model can help evaluate what influences youth to adopt and use technology, and qualitative analysis can provide depth to those findings. Competing timelines and high costs for app development, unexpected challenges which are becoming more commonplace, such as hacking, and research implementation present challenges to creating and studying health apps including mindful eating apps. Creative solutions are needed to address these challenges to developing and studying digital MBIs for adolescents.

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 humans were approved by Brown University Health Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MS-G: Project administration, Writing – review & editing, Funding acquisition, Investigation, Formal analysis, Supervision, Writing – original draft, Data curation, Methodology, Conceptualization, Resources. MT: Writing – review & editing, Project administration, Methodology, Data curation. AM: Writing – review & editing, Methodology, Data curation. JT: Formal analysis, Writing – review & editing. RR: Writing – review & editing. EJ: Writing – review & editing, Supervision. BJ: Writing – review & editing, Supervision, Formal analysis.

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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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