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Seeking best practice for app-based speech perception testing in a longitudinal cochlear implant journey

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Introduction: Speech perception testing has traditionally played a vital role in determining cochlear implant (CI) candidacy and post-operative monitoring of functional benefits. Service delivery through telepractice can play an important role throughout all stages of the CI journey, yet gaps in evaluating speech perception are evident. Here we present a conceptual framework for the development, piloting, and validation of a digital tool to deliver standardized speech perception assessments. The aim was to maintain best practice of hearing health care through ensuring “gold standard” of service delivery for all stakeholders.

Methods: This study had two phases. The first phase implemented an iterative approach to develop the myHEARcheck app to evaluate standardized speech perception in real time with a clinician (synchronous) or self-administered and reviewed by a clinician at a later time (asynchronous). The second phase evaluated the effectiveness and efficiency of the app when used by experienced adult CI users ($n = 23$). Participants were assigned to three groups, all of whom experienced asynchronous use of the app, whereas two groups had in-clinic sound-booth testing, and synchronous testing. Post-assessment interviews were conducted to understand user experience.

Results: The myHEARcheck app was successfully implemented on an iPad to evaluate standardized speech perception synchronously and asynchronously. Word perception results with the app tested synchronously ($\bar{X} = 47\%$) and asynchronously ($\bar{X} = 42\%$) were significantly different from traditional testing ($\bar{X} = 32\%$). Synchronous sentence scores ($\bar{X} = 80\%$) were significantly different from the traditional ($\bar{X} = 88\%$) and the asynchronous ($\bar{X} = 90\%$) scores. Participants reported the app was easy to use, irrespective of prior experience with technology. Some participants indicated the absence of clinician assistance during the asynchronous session was a limitation.

Conclusion: A digital tool, the myHEARcheck app was conceptualized, scoped, built, and implemented to address organizational and psychosocial challenges and barriers to the utilization of health care, including access, affordability, acceptability, and engagement. All participants were able to independently evaluate their speech perception with a high degree of confidence in the use of this approach. The app, as tested, demonstrated the potential for a digital tool to provide a device-agnostic standardized evaluation of speech perception using synchronous and asynchronous telepractice.

KEYWORDS

best practice, cochlear implants, digital health, speech perception, telepractice

Introduction

The cochlear implant (CI) ecosystem for an adult with a moderate to profound hearing loss is an intricate interaction between their psychosocial domain, the organizations involved in providing services and facilitating access and monitoring technology (Psarros, 2023). Decision-making around technological suitability is routinely based on performance on audiological testing and medical suitability. Referral for a CI is largely based on pure tone audiometry and speech perception testing performed by an audiologist in a clinical setting (Zwolan et al., 2020). Increasingly smartphone apps are available to support decision-making in a patient's journey by heightening awareness of hearing function and monitoring changes in hearing either synchronously (i.e., involving a hearing health care professional (HHCP) overseeing data collection) or asynchronously (i.e., with the HHCP actively reviewing results or self-monitoring by the person with hearing loss) (Maruthurkkara et al., 2021; Timmer et al., 2021). Such shifts in approach are consistent with health care for chronic conditions, including diabetes and heart disease, with digital tools, enabling autonomy of care in an efficient, timely way (van den Broek-Altenburg and Atherly, 2025).

Standardized speech perception testing has been a fundamental component of the CI protocol since the emergence of multichannel CI systems in the 1980s (Dowell et al., 1986). Speech perception scores identify and guide decisions regarding CI suitability, and post-surgery scores are used to monitor, guide, and optimize device usage. Further, map verification commonly includes some form of speech perception evaluation. In remote device programming sessions, and in the absence of standardized methodologies, live-voice speech perception testing is generally used (Hemmingson and Messersmith, 2018; Vaerenberg et al., 2014).

The perceived need to increase the availability of diagnostic technologies, such as speech perception, was the premise of this study. The intent was to identify or develop a digital tool that can be used remotely either synchronously or asynchronously prior to CI surgery to identify candidacy and be implemented throughout the post-operative journey to monitor outcomes. Speech perception materials currently available in self-testing apps that utilize a Digit Triplet Test (DTT) (Dillon et al., 2016; Smits et al., 2006) are not consistent with standard word and sentence tests used in clinical protocols, so they are not readily transferable across methodologies of care. The DTT can provide a measure of a speech reception threshold (SRT), which is reported as the difference between the signal presented (speech) and the background noise at which 50% accuracy is attained and is reported in decibels (dB). The smaller the difference, the better the speech perception ability; thus, a low SRT score is indicative of a good speech perception result. Traditionally, in a clinical setting, SRT scores are measured with sentence-level materials. Scores on SRT-tests using different materials, including sentences and the digit triplet test (DTT), have been correlated in a clinical setting (Willberg et al., 2021). Cullington and Aidi (2017) found a significant correlation between DTT scores obtained in the clinic and those when Bamford-Kowal-Bench sentences (Bench et al., 1979) were presented in a simulated home environment using an adaptive technique (Cullington and

Aidi, 2017). Further research is required, however, to determine whether the correlation is observable in a larger sample of CI users using monosyllabic words, as well as sentences, which are more commonly used to determine guidance for CI candidacy (Boisvert et al., 2020). Audiological testing for speech perception without direct streaming has historically been tethered to a soundproof booth to overcome calibration issues minimizing ambient noise and reverberation and preserving the integrity of the stimulus being presented. However, the logistics of conducting testing by telepractice preclude access to a soundproof room at the remote end, an important consideration when considering methodologies for delivering speech perception testing.

The primary barriers to speech perception testing by telepractice are the calibration requirements of the acoustic environment in which self-testing will occur, the relevance and integrity of the stimulus being presented, the applicability to the population being tested, and the potential for variation in its administration. Removal of these barriers through the development of a standardized app to test speech perception through telepractice could serve to mitigate the gaps in a telepractice model for delivering comprehensive CI services (Cullington et al., 2023). Access to a device-agnostic standardized speech perception app enabling self-administered and online evaluation has the potential to address the demands on clinical time and resources arising from an increase in the base of CI recipients. CI clinics would have increased capacity to concentrate on assessing candidature and acute care while providing support and oversight of patients who have already received a CI (Wasmann et al., 2024).

This research was conducted in two phases with the following aims:

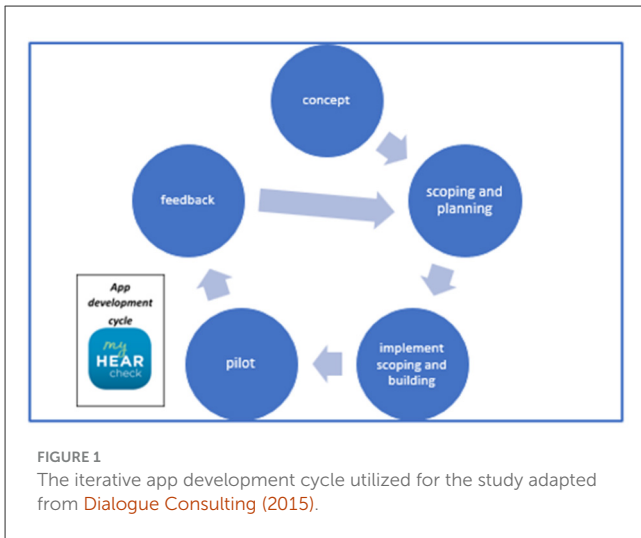
PHASE 1: To develop a digital tool (app) to deliver standardized speech perception testing that could also be administered by the person with hearing loss or by professionals either at a clinic or using telepractice, with or without the use of portable equipment to enable flexible service provision.

PHASE 2: To verify the effectiveness and efficiency of the app when used with experienced adult CI users, in both the presence (synchronous) and absence (asynchronous) of an experienced clinician, and assess the comparability of app testing with the “gold standard” traditional testing within a soundproof booth.

PHASE 1

The development process of the myHEARcheck app

The perceived need for the myHEARcheck app was identified through extensive delivery of cochlear services using telepractice in a clinical setting. To ensure that the development of the app would address all requirements, an iterative process as described by Stephens et al. (2015) required scoping and planning, implementation and building, piloting, and feedback. The cycle of development continued until 2020, when it was used in a validation and usability study (Figure 1).



The concept

It was anticipated that key users of the myHEARcheck app would be people with hearing loss, aged 8 years or older, with or without hearing devices, whose testing would take place in collaboration with their HHCP. The lower age limit was defined as the age of the youngest participant in the study who, with appropriate amplification, may have a more robust language level to perform open set speech perception testing and the autonomy to manage the technology required for the asynchronous tasks (Munoz et al., 2012; Uhler et al., 2017). Potential scenarios for use of the myHEARcheck app include the following:

- **Candidacy evaluation:** A person with significant hearing loss (PSHL), an adult (an adult or older child) considering CI after long-term hearing aid (HA) use could be used in collaboration with his or her HHCP to guide decisions regarding CI candidacy.
- **Post-operative monitoring either in clinic or self-initiated:** CI user performs ongoing monitoring of her hearing to mitigate need for regular check-ups at a clinic, which otherwise disrupt her work, educational, or social schedule.
- **Monitoring of functional performance with any type of hearing device(s):** This could be done by a user or potential user of hearing devices with mobility issues or limited geographical access to a sound booth for standardized testing, a person with hearing loss seeking a predominantly self-managed care model, or a HHCP who does not have access to standardized testing facilities to perform speech perception testing.

Scoping and planning

Dialogue Consulting (2015) asserted that scoping and planning must define the purpose, specify goals, identify how the app will work, and the stakeholders who will use the app.

The scoping and planning phase of the app considered the framework proposed by Levesque et al. (2013), which uses an

TABLE 1 Process outline for developing a mobile speech perception app.

Purpose	Deliver standardized speech perception test for adults that can increase access and flexibility of use
Goals	To develop an app that was efficient (timely, accessible, cost-effective etc.), effective (same quality), reliable, and easy to use.
Delivery mode	Synchronous or asynchronous
Dimensions (organization perspective)	Increase approachability to offer opportunities to identify when an individual meets audiological candidacy criterion (earlier identification).
	Increase acceptability of the app by clinicians by preserving the integrity of the “gold standard” of speech perception testing by capturing elements required for effective outcomes. Consideration of test stimuli (words and sentences; gender of speaker), masking and background noise, calibration, presentation levels, and response mode.
	Increase availability and accommodation to enable implementation of the app in a space beyond a sound booth with monitoring to ensure an optimal test environment. Provide availability for all points of the CI journey for evaluation and monitoring. Availability at any time (i.e., not restricted to typical clinical hours due to asynchronous capability).
	Increase affordability by minimizing travel time for delivery of services on outreach. Utilization of “off the shelf” technology potentially accessible by both the organization and the PSHL.
Abilities (psychosocial perspective e.g., PSHL)	Increase availability and affordability to standardized testing regardless of geographical location.
	Improve ability to perceive when they are candidates, to know when to seek care, and feel empowered to engage with CI providers. Provide ongoing monitoring of performance to determine when a review of device programming or device type is required.
	Improve ability to engage through autonomy in testings’ increase in digital empowerment.
	Improve ability to reach the ongoing monitoring of speech perception required prior to and following receiving a CI.

organizational (provider) and psychosocial (population) approach to improving access to health care (Table 1).

To increase the likelihood of a usable app, an app development team was formed that included both key stakeholders within the CI ecosystem (four people with hearing loss and four HHCP) as well as experts in the technological development of hearing apps (Toybox Labs).

Stakeholders identified 21 factors considered necessary to meet organizational and population (psychosocial) requirements for the app. The full details of these factors, including the gold standard in clinic sound booth requirements, potential options for the app, and the decision made regarding the app, can be found in the supplementary data. An abridged version of the factors considered and the solutions defined for the myHEARcheck app are presented in Table 2. The first column identifies the factors to be considered with the “gold standard” italicised. The second column summarizes

TABLE 2 Factors identified in Gold standards sound booth testing and solutions for the myHEARcheck app.

Gold standard sound booth	myHEARcheck App
Platform of technology for mobile access <i>Calibrated audiometer and speakers</i>	iOS only on tablet— <i>most stable at time of development for microphone and speaker structure, compared to smartphones, Android or web based</i>
Test room/ <i>Soundproof booth meeting ANSI standards S3.1 1999 r2008 (professionally calibrated)</i>	Quiet room at any location <i>In built microphone used to check ambient noise and reverberation. Testing cannot proceed unless reverberation and ambient noise checks are passed. Ongoing monitoring. Testing discontinues if ambient noise increases above acceptable levels</i>
Number of speakers/ <i>1 speaker</i>	1 speaker built into the iPad— <i>sufficiently capable of providing relevant signal and SNR</i>
Distance of participant from speaker/ <i>1 meter</i>	<i>Recommend iPad be held 60 cm to place microphone and speaker at consistent distance</i>
Presentation level/ <i>60dB HL (65dB SPL)</i>	<i>65dB SPL (60dB HL) standardized level of testing</i>
Presentation mode/ <i>recorded audition alone</i>	<i>Recorded audition alone—as per standardized testing in sound booth</i>
Materials <i>monosyllabic words, sentences AZ Bio in quiet and noise or BKB in noise</i>	<i>Monosyllabic words The AuSTIN test (BKB like sentences in 4 talker babble noise; Dawson et al., 2013)</i>
Gender of presenter in recordings/ <i>male and female (2 of each)</i>	<i>Female speaker—may have increased complexity with higher F0, however is the standard gender of most testing available in Australia where there is not male and female recording as per the AZBio</i>
Noise stimulus/ <i>4 speaker multitalker babble</i>	<i>4 multitalker babble—used in (AuSTIN test)</i>
Personnel involved/ <i>Clinician and participant</i>	<i>Clinician and participant who are familiar with one another. May have varying levels of experience at the myHEARcheck tool should have good usability across all personnel</i>
Location of tester and participant/ <i>same room</i>	<i>Participant and client either collocated or separate in different room or location; Clinician may be offline at time of participant testing</i>
Training and practice/ <i>May be required initially then not required</i>	<i>Practice list available and recommended prior to asynchronous use and first-time using app</i>
Device worn/ <i>Best aided, CI with and without contralateral hearing aid, with and without acoustic component. Use of preferred program if more than one.</i>	<i>Free field testing wearing individual devices or both devices together. Unaided testing not required for speech perception. Option to do testing with different programs if required</i>
Ear tested/ <i>individual ears and then bilateral (binaural)</i>	<i>Ability to test in all conditions to enable bilateral, bimodal, or unilateral assessment. NOTE: Unilateral HL or SSD participants will require plugging of their better ear given free field testing</i>
Response type/ <i>Participant repeats stimuli</i>	<i>Repetition by participant</i>
Variability between participants/ <i>within subject comparison</i>	<i>Participant results over time will be compared to their own baseline for ongoing monitoring. Changes in performance could indicate device concerns, need for additional investigations e.g., cognitive assessment—or repeat testing later to check stability of results</i>

(Continued)

TABLE 2 (Continued)

Gold standard sound booth	myHEARcheck App
<i>Scoring/percent correct words and dB SRT</i>	<i>Sentences, words, phonemes, vowels, and consonants percent correct</i>
<i>Utilization of results/monitor individual outcomes, evidence base for candidacy and optimization of technology</i>	<i>Identification of potential for CI candidacy; ongoing monitoring of post-operative performance over time</i>
<i>Test interval/Preoperatively and 1, 3, 6 then, 12 months post op</i>	<i>Schedule as collaborated with participant</i>
<i>Significance of difference/calculation between preoperative and post-operative testing; and follow outcome trajectory</i>	<i>Test-retest reliability with the AuSTIN test established. Test-retest reliability between use of AuSTIN in traditional test setting and with the use of the myHEARcheck app in both synchronous and asynchronous test conditions (to be established)</i>
<i>Privacy/participant privacy always maintained</i>	<i>Password coded logging into App for both participant and facilitator; Secure storage of data on cloud requiring password coding</i>

the solution that was agreed by stakeholders for inclusion in the myHEARcheck app based on the evidence and technology available at the time of development.

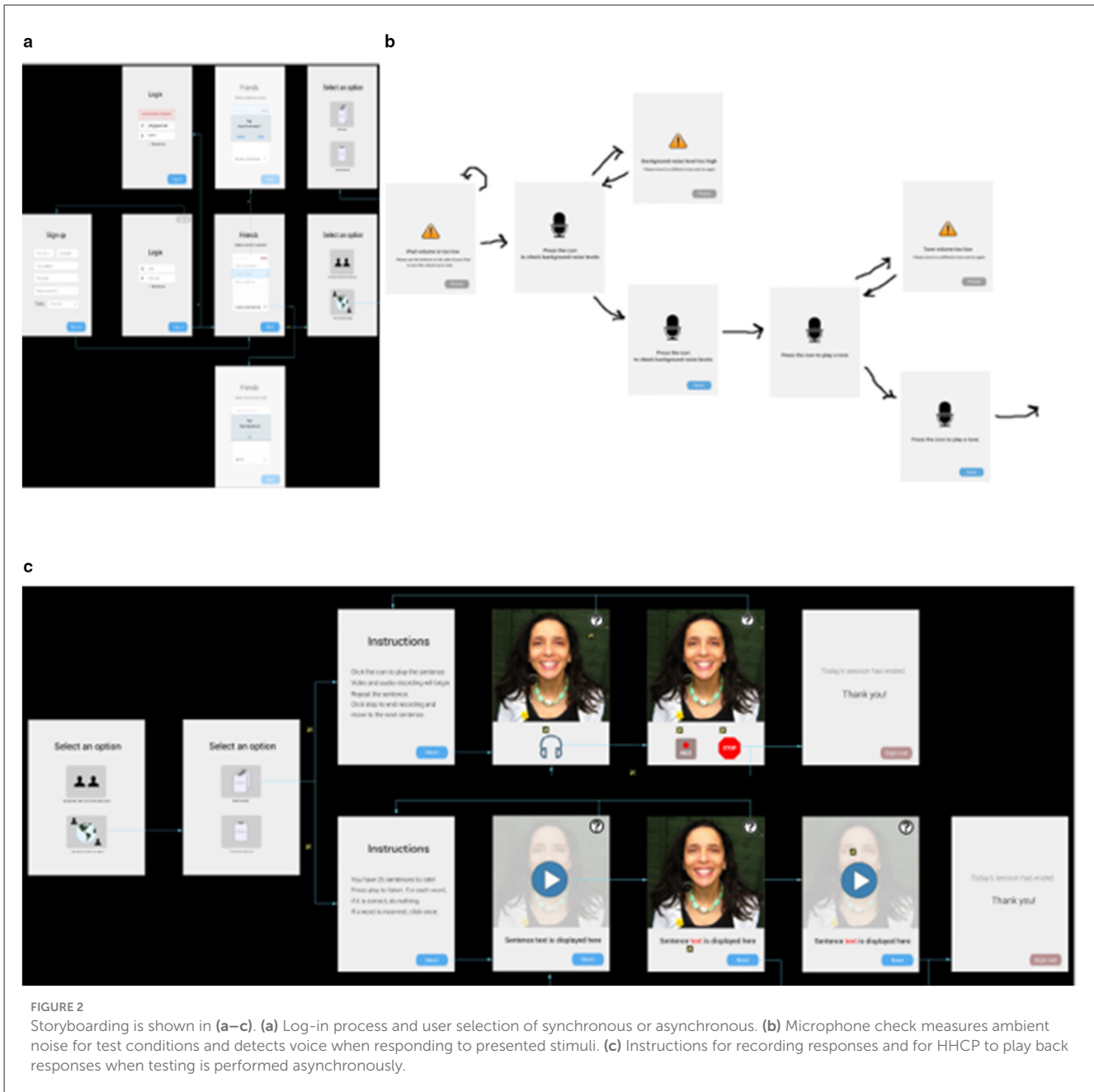
These options were discussed with stakeholders, as were key factors for decision-making regarding inclusion. The final column indicates the features chosen for the myHEARcheck app, based on the evidence available for the decision-making process.

Implementation and building

“Storyboarding” with a series of screenshots of the potential flow for the myHEARcheck app emulated the experience either synchronously or asynchronously for all potential stakeholders. An example of a storyboard is shown in Figures 2a–c (key factors of consideration were the ability to decide whether the app was to be presented synchronously or asynchronously) (Figure 2a); whether the setting was quiet enough to administer the test, whether the participant’s voice was detected by the iPad (Figure 2b), and the set-up needed to ensure asynchronous test results were captured and sent to the assigned clinician for scoring.

Pilot and feedback

The pilot phase was an iterative process conducted over three stages. Feedback and outcomes measured at the conclusion of each stage informed stakeholders and developers, enabling them to make continuous improvements. The usability, reliability, value, security, aesthetics, and functionality of the app were rated at each stage as “acceptable”, “neutral”, or “additional work required”, following a model for the development of medical apps as described in Hensher et al. (2021). Tasks for each of the stages included synchronous tests in the presence of a clinician, asynchronous tests without a clinician being present, and baseline evaluation using the AuSTIN test in the sound booth. Participant evaluations to ensure aesthetics, value, and security were prioritized before final release of the app.



Participants in the myHEARcheck pilot included those with normal hearing and those with hearing loss since the performance of normal hearers on speech perception tests under noisy conditions is frequently used as a guide for assessing performance and degree of difficulty (Holder et al., 2018). Table 3 summarizes the procedures followed during each of the three stages and outcomes, which, in turn, informed the decision-making and actions of developers and stakeholders using an iterative approach to further design the app.

The pilot determined that a key limitation of the use of an adaptive measure for sentence testing was the degree of difficulty in establishing the starting level of the SRT test, particularly when used in the asynchronous testing mode. Completion of a DTT was intended to set the initial starting level for testing; however, many of the pilot participants found the DTT too difficult to complete and were unable to access the SRT stimuli. Adjustments

to the DTT were implemented to address the difficulties identified; however, they could not be resolved in the timeframe of the study. For this reason, the stakeholders and developers chose to use a fixed signal-to-noise ratio (SNR) of 10 dB with four-speaker babble in the study to evaluate the effectiveness and efficiencies of the myHEARcheck app.

PHASE 2

Evaluation of effectiveness, efficiencies, and implicit factors of the myHEARcheck app

Recommendations from the third stage of the pilot were incorporated into the myHEARcheck app prior to recruiting

TABLE 3 Stages 1, 2, and 3 of the myHEARcheck app pilot study with stakeholders, procedures and outcomes.

Stage 1	Stakeholder	Procedure	Outcome
	<p>Facilitators: 2 students</p> <p>Participants</p> <ol style="list-style-type: none"> Adult (23 years) normal hearing Adult (24 years) normal hearing Adult (47 years) with HL bilateral CI user Child (8 years) with normal hearing Adult (72 years) HL using hearing aids <p>Clinician: 1 audiologist</p>	<p>Provide synchronous testing, observe asynchronous session</p> <p>Speech perception testing in sound-booth, and with app in both synchronous and asynchronous conditions.</p> <p>Qualitative rating of use of app.</p> <p>Sound booth speech perception testing.</p>	<ul style="list-style-type: none"> Synchronous word scores much higher than sound booth and asynchronous word scores. Asynchronous sentence scores generally much lower than both sound booth and synchronous. Digit Triplet Test hard to execute – very timing consuming and increased the complexity of the task Participants report background noise for words very difficult. Usability and reliability requiring additional work
<p>Action taken end of stage 1 pilot:</p> <ul style="list-style-type: none"> Adjustments to background noise algorithm required to increase difficulty of the sentence task and reduce difficulty of the word task. Consideration of removal of the Digit Triplet Test and implementation of the fixed signal to noise ratio (SNR) for both the synchronous and asynchronous testing. Next stage of testing to use both the adaptive and fixed SNR methods to determine noise level Developers improved graphics to prompt required action 			
Stage 2	Stakeholder	Procedure	Outcome
	<p>Facilitators: 2 students</p> <p>Participants</p> <ol style="list-style-type: none"> Adult (84 years) HL CI+HA user Adult (18 years) HL bilateral CI user Adult (18 years) HL CI+HA user Adult (35 years) normal hearing <p>Clinician: 1 audiologist</p>	<p>Provide synchronous testing, observe asynchronous session</p> <p>Speech perception testing in sound booth, and with app in both synchronous and asynchronous conditions.</p> <p>Qualitative rating of use of app.</p> <p>Sound-booth speech perception testing</p>	<ul style="list-style-type: none"> Asynchronous word scores extremely difficult for users of the CI due to background noise levels being too high. Adaptive algorithm not functioning correctly for words or sentences. Some confusion regarding when to start recording responses to stimuli in the asynchronous condition leading to some responses not being measured and need to restart the process.
<p>Action taken end of stage 2 pilot:</p> <ul style="list-style-type: none"> Decision to use a fixed 10dB SNR to enable consistency in task. This is a clinically acceptable means of measuring word and sentence scores. Additional changes to interface for indicating when recording of asynchronous responses have commenced and finished. 			
Stage 3	Stakeholder	Procedure	Outcome
	<p>Facilitators: Audiologist</p> <p>Participants</p> <ol style="list-style-type: none"> Adult (39 years) normal hearing Adult (25 years) normal hearing 	<p>Provide synchronous testing, observe asynchronous session.</p> <p>Speech perception testing with app only in both synchronous and asynchronous conditions.</p> <p>Qualitative rating of use of app.</p>	<ul style="list-style-type: none"> Adults with normal hearing recruited to check the usability and the reliability of the app alone. Due to the adaptive measures being removed a near normal score was expected with the 10dB SNR. Usability and reliability issues resolved.
<p>Action taken end of stage 3 pilot:</p> <ul style="list-style-type: none"> Developers had taken on additional projects and had other commitments. Issues with algorithm adjustments had taken longer than anticipated. Final check before research project recommended to ensure all functionality in place. 			

further participants to evaluate the effectiveness, efficiencies, and implicit factors of the app.

Participants

A total of 23 PSHLs who were current and experienced CI users were recruited from a large CI clinic. All PSHLs had served as volunteers in previous research projects at that institution (see details in Table 4). Informed consent was obtained in accordance with established National Health and Medical Research Council Guidelines (NHMRC, 2007) and relevant Human Research Ethics Committee approval. All participants had been using hearing devices for between 3 and 63 years. CI use ranged from 0.5 to 12 years. Ten of the recipients had received bilateral sequential CIs, nine used a hearing aid and CI (bimodal), and the remaining four used their CI only, with no hearing device fitted in the contralateral ear. All participants had experience with at least one CI for an

average of 5.52 years (range 1–12 years) as shown in Table 4. All participants were familiar with speech perception testing using a traditional approach with recorded materials presented in a sound booth (Condition 1 of the study). All but one of the participants lived within 50 km of the CI clinic.

A clinician experienced in administering and scoring speech perception tests was recruited to conduct the testing and support the Condition 3 testing as required.

Study design

A quasi-randomized recruitment process assigned participants to one of three study groups according to the order of their enrolment. The first participant was assigned to Group 1, the second to Group 2, the third to Group 3, and the fourth to Group 1, and so on, until 24 subjects were recruited in total. This pragmatic approach enabled a timely recruitment

TABLE 4 Study participant details.

Participant	Age	Gender	Group	Device(s)	Length first CI use (years)
M1	73	M	1	Bilateral CI	11
M2	75	M	2	Bimodal	4
M3	68	M	3	Bimodal	4
M4	76	M	1	Unilateral CI	6
M5	56	M	2	Bimodal	1
M6	61	M	3	Unilateral CI	12
M7	74	F	1	Bilateral CI	3
M8	76	M	2	Bimodal	4
M9	66	M	3	Bilateral CI	5
M10	72	M	1	Unilateral CI	5
M11	60	F	2	Bilateral CI	8
M12	68	M	1	Bimodal	7
M13	70	M	3	Bilateral CI	7
M14	78	F	2	Bilateral CI	5
M15	61	M	3	Bilateral CI	11
M16	72	F	1	Unilateral CI	2.5
M17	64	M	2	Bilateral CI	10
M18	60	M	3	Bilateral CI	3.5
M19	70	F	1	Bilateral CI	3.5
M20	68	M	2	Bimodal	4
M21	81	M	3	Bimodal	5
M22	70	F	1	Bimodal	2
M23	77	M	2	Bimodal	4

Participants were assigned to study groups 1, 2, or 3 according to their order of enrolment.

process. Quasi-randomization was considered feasible as the study group inclusion criteria ensured a relatively homogenous group of participants who were from the same clinic (e.g., post-lingually severe hearing loss, adult, more than 12 months of CI usage, experience with CI speech perception testing and research involvement) (Laird et al., 2024). Additionally, this design was suitable for the acute nature of the study and the distribution of the testing across groups. All baseline tests, speech perception testing, and initial interviews were conducted on the same day over a maximum time frame of 2 h.

All participants completed baseline testing with the visual analog scale (VAS) to better assess and understand their experience with technology and its importance as they perceived it in their daily lives.

Groups 1 and 2 completed all three speech perception testing conditions, and only Group 3 completed Condition 3 to provide insight into the experience required before completing the myHEARcheck app asynchronously:

Condition 1: Traditional speech perception testing conducted in a sound booth using the AuSTIN test (Dawson et al., 2013) followed by the (Consonant–Nucleus–Consonant word test (Peterson and Lehiste, 1962). For both tests, materials were presented through a fixed speaker 1 m from the participant in

the free field at 65 dB SPL with a fixed SNR of +10 dB. Test materials were administered and scored by the clinician.

Condition 2: The iPad delivering the myHEARcheck app was shared between the clinician and the participant in a quiet room in synchronous conditions. The built-in calibration of the app required noise levels of ≤ 35 –40 dB and a reverberation time of ≤ 0.4 –0.6 s. A traffic light system was used, where green indicated a suitable listening environment, amber denoted borderline conditions, and red indicated the limits had been exceeded, at which point testing would be paused until the environment was optimized by adjusting the environment accordingly (NSW Department of Education, 2016¹).

The iPad was positioned 60 cm from the participant during the presentation of the stimuli and then passed to the clinician, who scored responses directly before passing the iPad back to the participant following each presentation. During testing, the clinician did not inform the participant of the outcome following each presentation/scoring sequence.

Condition 3: The participant completed testing with the myHEARcheck app asynchronously in the same quiet room as in

1 <https://apps.apple.com/au/app/listenapp-for-schools/id981300043>; <https://www.vichealth.vic.gov.au/sites/default/files/Guidelines-Creating-Healthy-Living-Apps.pdf>

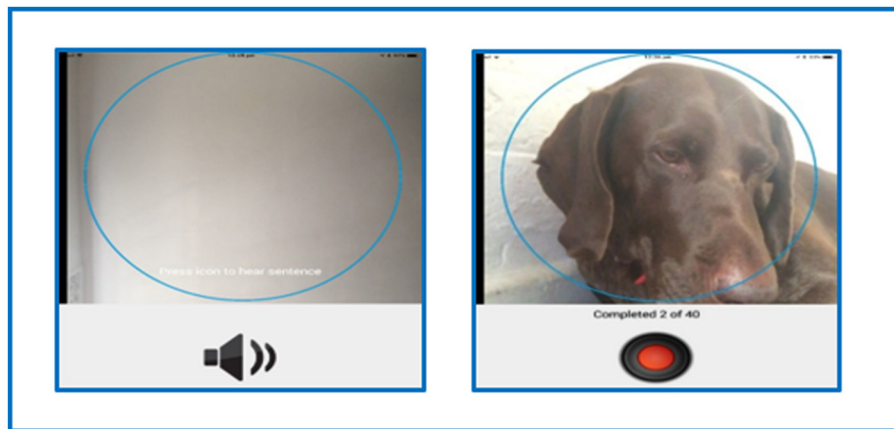


FIGURE 3 Guidance for positioning of iPad for completion of asynchronous tasks.

TABLE 5 Study Design for all three groups.

Test interval/ Materials	Baseline	Test session	Post test session (immediately after)	Post test session (6 months later)
Participants	<ul style="list-style-type: none"> • Speech Spatial Qualities 12 (SSQ-12) (Noble et al., 2013) • Assessment of Quality of Life -8D (AQoL) (Maxwell et al., 2016) • Technological expertise ratings Likert scale 	<ul style="list-style-type: none"> • Word and sentence testing • Rating of ease of difficulty after each test 		
Group 1 <i>n</i> = 8		Condition 1 Sound booth Synchronous app Asynchronous app	<ul style="list-style-type: none"> • Telehealth usability questionnaire (TUQ) (Parmanto et al., 2016) • Semi structured interview e.g. role of telehealth in CI journey, use of the APP 	<ul style="list-style-type: none"> • Semi structured interview e.g. role of telehealth in CI journey, use of the APP
Group 2 <i>n</i> = 8		Condition 2 Synchronous app Sound booth Asynchronous app		
Group 3 <i>n</i> = 7		Condition 3 Asynchronous app		
Clinician		Administration of Sound booth and Synchronous app testing	Universal Design Performance measure (UDP) (Center for Universal Design, 2000)	

Condition 2 (i.e., without the presence/oversight of a clinician). Participants sat on a chair with the iPad on a stand 60 cm away. The iPad was set to full volume, in accordance with its calibration. The built-in calibration as described above to optimize room acoustics was used. Additionally, if the participants' voice level was too soft, a message would be displayed to adjust the vocal level or optimize orientation to the iPad. Ideal positioning of the iPad was guided by a circle display (Figure 3) to maximize the delivery of the speech stimuli and the capture of participants' responses, which could also serve to optimize the clinician's ability to score the response at a later time.

Participants were encouraged to do at least one test run before completing the word and speech perception testing tasks.

Groups 1 and 2 completed all three conditions. Group 3 completed only the asynchronous Condition 3 to understand the

impact of previous experience using the app on their ability to complete tasks.

The order of presentation for Conditions 1 and 2 were balanced for Groups 1 and 2, as outlined in Table 5, to ensure that any order effects in the test outcomes could be identified.

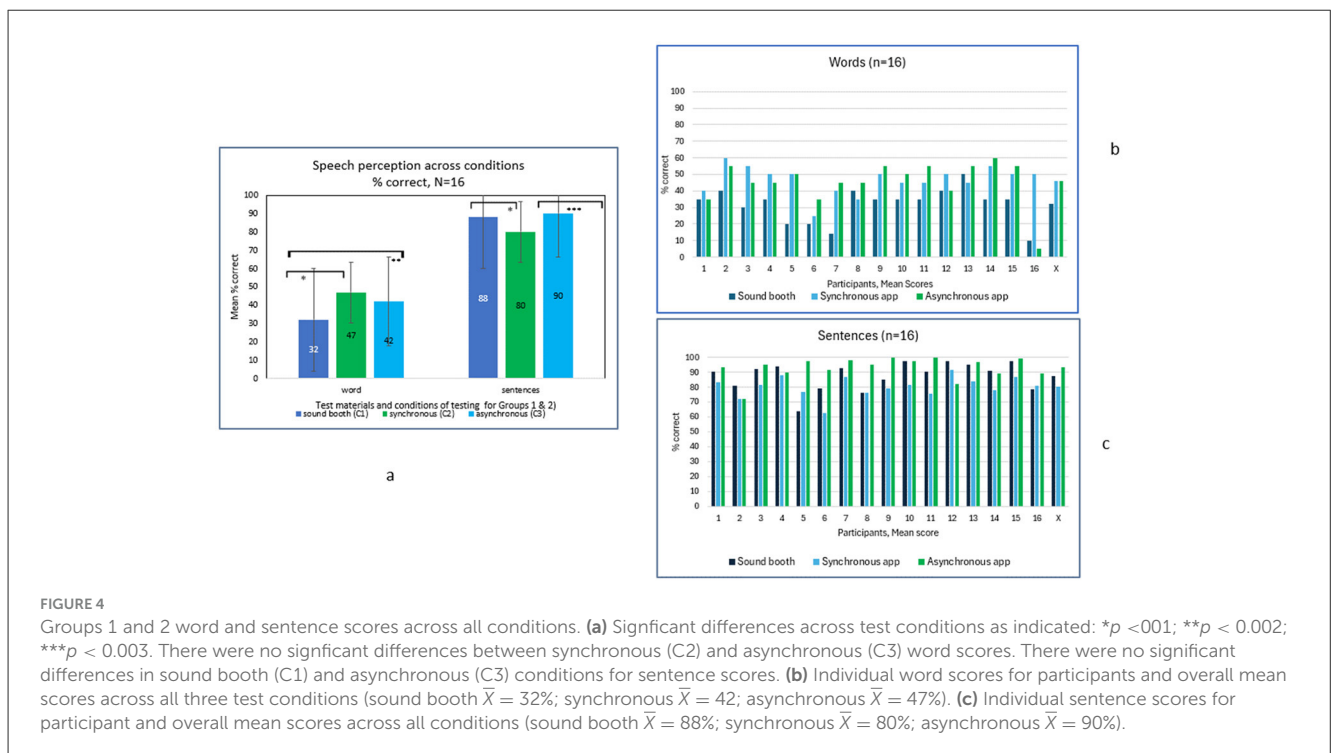
Participants used their best aided listening condition, that is, they wore the hearing devices outlined in Table 4 using their preferred program for each device.

On completion of each condition of speech perception testing, participants rated the level of difficulty of the task on a 10-point Likert scale, with 0 indicating "no difficulty" and 10 indicating that the task was "extremely difficult".

Following completion of all the speech perception conditions assigned to the participants, they were

TABLE 6 Statistical plan for evaluating effectiveness, efficiency and implicit factors of myHEARcheck app.

Research question	Statistical procedure (95% confidence; $p < 0.05$)
Effectiveness	
1. Are results obtained synchronously with the myHEARcheck app (Condition 2) comparable to those measured traditionally in a sound booth (Condition 1)	Paired <i>t</i> -tests between Condition 1 and Condition 2 (Group 1 and 2 data only)
2. Are results obtained asynchronously with the myHEARcheck app (Condition 3) comparable to those measured traditionally in a sound booth (Condition 1)	Paired <i>t</i> -tests between Condition 1 and Condition 3 (Group 1 and 2 data only)
3. Are results obtained using the myHEARcheck app synchronously (Condition 2) and asynchronously (Condition 3) comparable	Paired <i>t</i> -tests between Conditions 2 and Condition 3 (Group 1 and 2 data only)
4. Does having previous experience with using the myHEARcheck app impact its use in asynchronous testing conditions	One-way ANOVA across groups for words and sentences administered in Condition 3 (Group 1& 2 compared with Group 3 data); Fishers Least Significant Difference test
Efficiency	
5. Can participants easily complete speech perception testing with the myHEARcheck app? How usable is the myHEARcheck app?	Mean scores across all domains of the TUQ compared to VAS degree of difficulty
6. Did self-rated technical experience impact performance with the myHEARcheck app?	Correlation of speech perception scores and ratings of technical experience
7. Did internet speed impact the usability of the myHEARcheck app?	Correlation of the internet speed and asynchronous word scores
8. Do clinicians find the myHEARcheck a usable tool for participants as rated on the UDP?	Average of the three different ratings provided over the study
9. Does the participants SSQ-12 overall and Speech rating impact their performance on the myHEARcheck app presented asynchronously?	Correlation coefficients of SSQ-12 ratings and Condition 3 scores
Implicit factors	
10. Did technology use and importance changes for participants after COVID 19?	Descriptive statistics showing ratings on technological importance pre and post COVID-19
11. What is important to participants in the CI model of care	Interview thematic analysis



interviewed by the HHCP and rated their satisfaction with the myHEARcheck app using Technical Usability Questionnaire (TUQ).

Asynchronous scoring of myHEARcheck was performed by the researcher by downloading the recordings of each subject on an iPad and scoring according to the accuracy of the responses

as described for Conditions 1 and 2. Scores for test Conditions 2 and 3 were stored in a password-protected.xml file. Once video recordings had been reviewed and scored, they were deleted, consistent with privacy protocol. Only numerical data for the scores remained.

Statistical plan

The statistical plan for Phase 2 of the study was designed to identify the effectiveness, efficiencies, and any implicit factors impacting the use of the myHEARcheck app. As shown in Table 6, a mixed-methods approach was used to understand the key research questions across the three test conditions and the three groups.

Results

The effectiveness, efficiency, and implicit factors identified when using the app were analyzed across the different groups and conditions. All statistical analyses, including quantitative measures are outlined in Table 6. Analyses include a series of paired *t*-tests, one-way ANOVA, correlation coefficients, and descriptive statistics were performed using Minitab Version 20.3 (Minitab, 2021). Qualitative theme analysis was used to understand the implicit factors of using the telepractice approach.

Effectiveness

The effectiveness of the app at measuring speech perception either synchronously or asynchronously and compared to traditional sound booth testing was evaluated for Groups 1 and 2. A series of paired *t*-tests compared word and sentence scores.

Word scores using the app synchronously ($p < 0.001$) and asynchronously ($p < 0.002$) were significantly better than the scores obtained from the traditional evaluation in the sound booth (Figure 4a). There was no significant difference between word scores obtained using the app in the synchronous and asynchronous conditions ($p = 0.65$).

Sentence scores using the app synchronously were significantly poorer compared to scores obtained in the sound booth ($p < 0.001$) or scores obtained using the app asynchronously ($p < 0.03$). There was no significant difference between sentence scores measured in the sound booth and asynchronously with the app ($p = 0.39$).

Variability within and between subjects in scores across the test conditions is shown for words in Figure 4b and sentences in Figure 4c.

Word score variability is evidenced in the descriptive statistics for the sound booth: mean = 32 (median 35%, min 10%, max 50%); synchronous condition: mean = 47% (median 50%, min 35%, max 60%); and asynchronous condition: mean = 42 (median 45%, min 5%, max 80%).

Variability was less evident for sentence scores, which may have been impacted by a ceiling effect (sound booth: mean 88% (median 91%, min 76%, max 97%); synchronous: mean 80% (median 81%, min 73%, max 91%); asynchronous: mean 90% (median 95%, min 72%, max 100%)).

The effectiveness of the app when being used asynchronously without prior experience was evaluated by comparing outcomes on this task for Groups 1 and 2, who experienced all speech perception conditions, with Group 3, who experienced speech perception testing only under Condition 3 using the myHEARcheck app asynchronously.

One-way ANOVA was used to compare word scores and sentence scores measured with the myHEARcheck app in the asynchronous condition for the three groups, grouped according to whether they had previous experience with the app (Condition 2) and speech perception in the sound booth (Condition 1) as part of the study (Figure 5). There was no significant difference in word scores measured asynchronously across the three groups ($F = 0.81$; $p = 0.46$), confirmed by Fisher's least significant difference (LSD) test performed at a 95% confidence interval indicating that previous experience testing did not impact word-level results. Experience using the app for sentence-level testing, however, led to significantly better scores for Groups 1 and 2 ($n = 16$) than for Group 3 ($n = 7$) ($F = 4.9$; $p = 0.02$). Fisher's LSD test confirmed this at the 95% confidence level.

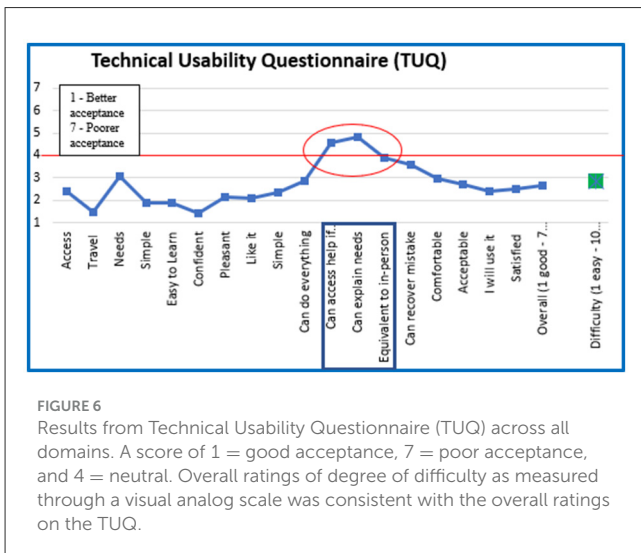
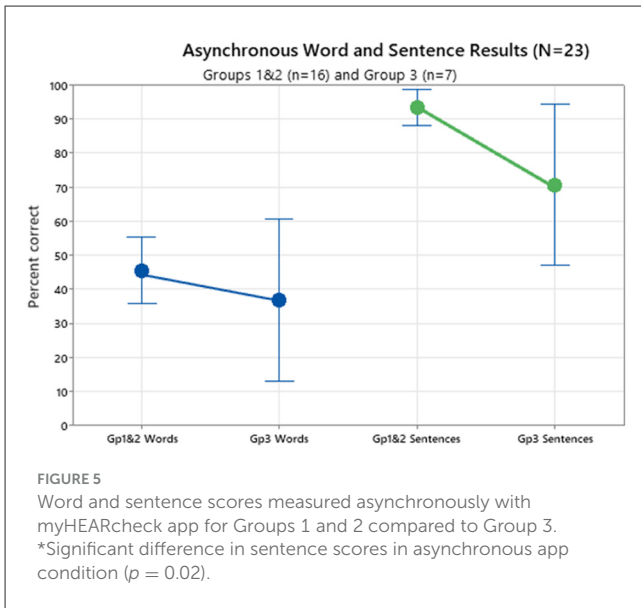
Efficiency

The efficiency of the app was evaluated by assessing the participants and the clinician's usability such as internet speed on the execution of the app and their perceptions regarding the value of the technology for their CI management.

All participants were required to rate their technical expertise on a scale of 1 (poor) to 10 (excellent) prior to the speech perception testing. After each test condition, participants rated the degree of difficulty for that condition on a scale of 1 (easy) to 10 (very difficult). Despite the trend for "degree of difficulty" being reported as lower by participants with a higher rating of technical experience, there was no significant correlation between prior technical experience and the difficulty ratings ($p = 0.07$) (Figure in supplementary materials 3).

Usability was measured across a range of domains with the TUQ. Participants rated statements ranging from 1 (strongly agree) to 7 (strongly disagree) about the characteristics of the app. A rating of 1 was consistent with good acceptability of the app, whereas a rating of 7 indicated poor acceptability, and a rating of 4 indicated a neutral position. Participants rated the majority of domains "agreeable". Three areas rated as neutral or poorer related to the personal experience, for example, the ability to access help if needed and that the experience was equivalent to an in-person session. The average degree of difficulty with the tasks as measured using a VAS was compared to the overall TUQ ratings, as shown in Figure 6. An overall rating of 3 out of 10 (with 10 being the most difficult and 1 being easier) suggests that the use of the VAS ratings was potentially a simple and effective means of validating the experience of using the app in relation to ease of use.

Usability of the app by a clinician was captured using the Universal Design Performance (UDP). The UDP was administered at three intervals across the data collection period. Given the random group allocation of participants, the HHCPs



experienced the use of the myHEARcheck app under all three test conditions.

The UDP evaluated the myHEARcheck app in relation to:

1. Equity for use among the varied population.
2. Flexibility of methodology allowing for different pace and accuracy of use.
3. Simplicity and intuitiveness not unnecessarily complex but intuitive with feedback and prompts.
4. Perceptibility with instructions that accommodate the needs of those with sensory limitations.
5. Tolerance for error by minimizing the consequences of unintentional actions.
6. Low physical effort and can be used efficiently and comfortably with a minimum of fatigue.
7. Usability unhindered by a user’s mobility, size, positioning, or dexterity.

The average ratings across the three separate episodes of completing the UDP, as shown in Table 7, demonstrated that the myHEARcheck app would benefit from improved instructions and improvements in its simplicity, intuitiveness, and tolerance for errors. In all other areas (i.e., equity, flexibility, physical effort, and size), the ratings were positive.

Execution of the app relied on internet connectivity and speed. There was no correlation between internet speed and the degree of difficulty perceived by participants ($r = 0.28$). Although there was some variability in the speed and strength of the connectivity, all sessions using the app could be completed. Further information can be found in Supplementary material.

Implicit factors

Participants were interviewed twice. The aim of the follow-up interview was to determine whether perspectives and attitudes had changed in qualitative aspects of the use of the app, telepractice in general, and whether there was a shift in some of their self-rated perspectives on their experiences with the technology and their willingness to use this in a range of situations.

The initial interviews were conducted in person. Due to COVID-19 restrictions, the second interviews were conducted using videoconferencing through Zoom. Interview details can be found in Supplementary materials. A shift in perspective on the use of telepractice in CI management was observed between Interviews 1 and 2. Prior to the pandemic, 83% of participants indicated they would not (39%) or might consider (44%) the use of telepractice, whereas 17% said they would use telepractice as part of their CI management. A strong reversal of perspective occurred at Interview 2, during the pandemic. Only 23% said they would not (6%) or might (17%) consider telepractice, with 77% indicating they would be willing to use telepractice for CI management. However, 33% of participants indicated they would require assistance to complete this task.

Discussion

This two-phase study was conducted to explore the methodologies and application of a novel model of HHC using telepractice. A digital tool, the myHEARcheck app, was conceptualized, scoped, built, implemented, and evaluated. The overall aim of the development was to address organizational and psychosocial challenges and barriers to use of health care, including access, affordability, acceptability, and engagement. The intent was to assess whether the application of this tool could extend a care model for a CI journey that enabled autonomy of a PSHL through asynchronous use of the app. Organizationally, myHEARcheck could potentially equip all HHC clinicians with a standardized speech perception tool to improve the reach and flexibility of service delivery. Currently, remote standardized measurement of speech perception is reliant on direct audio input (DAI) with CI users needing to return to their clinic for formal testing (Nassiri et al., 2022) Specifically for CI clinics, this could enable clinicians to monitor their implanted recipient caseload without the inherent limitations of the need to access installed infrastructure such

TABLE 7 Universal design performance measures for use of the myHEARcheck app as rated by the HHCP.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1. Equitable					
2. Flexibility					
3. Simple and intuitive					
4. Perceptible information					
5. Tolerance for error					
6. Low physical effort					
7. Size and space for approach and use					

as soundproof rooms, which are an inherent limitation on the number of patients who can be monitored during any timeframe.

Key stakeholders from organizational and psychosocial fields collaborated in the co-design and development of the app, aiming for an evidence-based telepractice approach to emulate a “gold standard” of clinical care. Iterative refinements were made to the app based on user insights and observations during implementation through the pilot phase. The use of apps is becoming increasingly common in chronic health care to enable monitoring of conditions and as a tool to share information with HCPs (Timmer et al., 2021; Winberg et al., 2021; Yadav et al., 2022). Accordingly, the myHEARcheck app was designed to be used by a PSHL in the presence or absence of a clinician, irrespective of device type or configuration. Speech perception scores and functional ratings in this study demonstrated the usability and feasibility of the myHEARcheck app. Nevertheless, the significant differences and disparity among scores obtained using the app, and those obtained within a traditional sound booth setting may circumvent comparisons of scores for ongoing monitoring. Test-retest of the app over time may have provided insights as to whether the myHEARcheck app could be used for this purpose.

Prior experience in using the app was found to be necessary for asynchronous testing, as demonstrated by results from the Group 3 participants, who had significantly lower scores in sentence testing using the app compared to the Group 1 and 2 participants, who had had prior experience with the app. The study design entailed sentence testing presented prior to words, hence the lack of familiarity with the app which might have contributed to this result. It is unlikely that superior scores for Groups 1 and 2 with the sentences were due to a practice effect as the AuSTIN test materials used (Dawson et al., 2013) have high test-retest reliability, and lists were randomly presented on each occasion.

Test stimuli and methods of execution were identified during Phase 1 in the scoping, building, and implementation phase of the study. The initial intent was to have an adaptive application of the SNR to measure a SRT to reduce the likelihood of a ceiling effect (Dawson et al., 2013). Difficulties with the implementation of the algorithm included the fact that it needed to ensure consistency in adjustments of background noise, and the stimuli were identified during the pilot phase of the study, leading to considerable variability in the results. The decision was made to keep a fixed SNR of +10dB across all three test conditions. This could explain Phase 2 sentence scores generally exceeding 70%, suggesting a potential ceiling effect.

The use of the myHEARcheck app led to significantly higher word scores compared to scores obtained in the sound booth. This could have been due to variability in the positioning of the iPad from the participant in order to simplify the task during app use (e.g., if the presentation level was louder when the participant was closer to the iPad speaker). Word-level testing involves less linguistic redundancy and is more reflective of a bottom-up processing approach, increasing task complexity. Sentence-level tasks include both a top-down and a bottom-up approach, increasing contextual clues, which potentially simplified the tasks and made participants less inclined to move the iPad in an attempt to have better access to the stimuli. This observation is strengthened by the asynchronous mean sentence-level results, which were significantly higher than the synchronous test results, where the clinician was involved in the testing. Although clear instructions were given for the use of the myHEARcheck app for asynchronous testing, this variability would otherwise be mitigated by some of the DAI procedures used in other applications that enable self-managed evaluation of speech perception (Maruthurkkara et al., 2021).

Results from the TUQ and VAS suggested participants found the myHEARcheck app easy to use irrespective of their technical expertise and the importance they placed on technology in their daily lives. Most participants indicated a preference for having personal support from a professional on the TUQ, with the main concern being the potential need for assistance during asynchronous testing. Interviews immediately following the research sessions were consistent with this finding, with participants stating that in-person sessions could provide the emotional support, understanding, and guidance they required. The use of apps in health care must factor in the personal and social values of users to shape needs and intents for successful adoption into a model of care (Yadav et al., 2022).

The use of both quantitative and qualitative methods aimed to provide insights and a more holistic understanding of the cohort in the study and identify factors to facilitate the use of telepractice (including digital tools). Patient-reported outcome measures (PROMs), such as the AQoL-8D and the SSQ-12, were included in this study in light of the increasing recognition of their importance for supplementing speech perception to understand hearing function as it relates to the psychosocial needs and status of PSHLs (Hughes et al., 2024; Neal et al., 2022). Participant ratings on the AQoL-8D for the “sense” domain (including hearing and sight) that fell below the normal range

tended toward lower scores on the asynchronous speech perception tasks. These trends suggest the psychosocial status of participants may provide insights into performance on quantitative measures such as speech perception, adding a holistic view of overall function (Neal et al., 2022).

Additionally, PROMs can provide insights into the personal and social values that underpin attitudes toward and acceptance of telepractice and digital tools in health care (Yadav et al., 2022). For instance, PROMs may highlight patient preferences for privacy, convenience, or trust in technology, which influence their acceptance of telepractice. Observations and interview data collected in this study identified factors that were considered important in CI care models; their absence can act as barriers to the use of telepractice. Emotional support, understanding of technology, and guidance for the development of expectations are evidently the themes that need to be understood more explicitly when considering methodological changes to clinical service models in a CI journey. This understanding is increasingly important as CI systems introduce capabilities of autonomy of care and self-management (Maruthurkkara et al., 2021). Personalization of self-management tools must be considered given individual differences across the population (Convery et al., 2016).

Transitioning CI service delivery models is achievable, but genuine collaboration between CI users and HHCPs needs to extend beyond simply granting app access. Building substantial trust is essential for users—so they feel assured that the app can meet their support needs and confident that their information will be used effectively (Winberg et al., 2021). Monitoring and sharing of app results between CI users and clinicians can provide the link to the care model that they experienced and valued in the earlier phases of their CI journey (Cullington et al., 2018).

Currently, technology access is largely controlled by organizations, with clinicians determining which CI users may use particular technologies (Bennett and Campbell, 2021). One factor that will weigh heavily on organizations to shift models of care is the projected increase in caseload, which will place severe pressure on organizations to continue to regularly monitor their clients in clinic. Between 2025 and 2034, an estimated 7.38% growth in CI globally in both unilateral and bilateral surgeries is predicted (Custom Market Insights, 2025). Evidence-based change management approaches through ongoing evaluation of a self-managed care model and its inclusion in service provision could help mitigate barriers preventing an optimal CI journey.

The sensitivity of digital self-management tools to accurately reflect what intervention is required is limited to the information it provides, and in the case of this app, it is a speech perception score that can be compared to previous results and results over time. A speech perception score in isolation may not be sensitive enough to determine when and what type of intervention is needed. Gaps in sensitivity and specificity may exist in apps that can “miss” important indicators due to their development not being evidence-based, lack of expertise in interpreting results, or poor validation (Akbar et al., 2020). The myHEARcheck app was developed on the foundation of a strong evidence base and required the involvement of clinicians for sending the test to

PSHLs and reviewing the results; however, the validity remained unproven, even though the feasibility of execution of the test was demonstrated.

Limitations of this study

A key limitation of this study was the impact of the COVID-19 pandemic on recruitment, where a smaller sample for achieving statistical power was used than recommended. This prevented the inclusion of participants who had experienced telepractice in their CI care model so that different user experiences could not be evaluated. Although consistency of participant data collection was improved by involving a clinician, the addition of other clinicians might have provided a broader perspective on the use of the app. Moreover, clinicians have traditionally posed a barrier to the use of telepractice in audiological services (Bennett and Campbell, 2021), so this will be an important subject for future study. Other limitations have to do with the design of the app. While the myHEARcheck app was intended to be an adaptive test, like the AuSTIN test (Dawson et al., 2013), the algorithm did not function properly in pilot versions. Due to time constraints, a fixed SNR of +10 dB was used for the study version of the app. The beta version of the app was limited by minimal user instructions and clinician scoring methods and by the fact that it used an iPad rather than other digitally integrated tools such as smartphones (DiFabio et al., 2022). Finally, test-retest reliability at the time of data collection and at different intervals could have informed the viability of using the app for ongoing monitoring of CI users over time.

Conclusion

This study presented the development of the myHEARcheck app, a stand-alone, hearing device-agnostic application designed to broaden accessibility for individuals using various hearing technologies (such as bimodal devices) and to ensure functionality when streaming technology is unavailable. Evaluation of the myHEARcheck app on a cohort of experienced adult CI users showed all participants could independently evaluate their speech perception with a high degree of confidence, thereby providing an efficient (timely, accessible, cost effective) and effective (same quality, reliable, and easy to use) telepractice option for speech perception testing. However, disparities in results across test conditions, which would limit direct comparison with a traditional sound booth and app testing, suggests that implementation of this tool would require further iterative refinement.

Data availability statement

Deidentified 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 Royal Victoria Eye and Ear Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. CM: Conceptualization, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. GL: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. RC: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work 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/fauot.2025.1727969/full#supplementary-material>

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