Teleaudiology as an Avenue for Transforming the Future of Hearing Care in Australia

By

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ABSTRACT

Teleaudiology refers to the remote delivery of audiological services by leveraging telecommunications and digital technology. This mode of service delivery surpasses geographical and time constraints, as the client and clinician can be in different locations and some services do not necessarily need to be delivered in real time. Teleaudiology can be applied to almost all service types, ranging from hearing assessment to intervention and rehabilitation. Despite the benefits of teleaudiology being well recognised, many clients and clinicians showed hesitation about its use and considered it applicable to a limited variety of services. Infrastructural and legislative constraints further restricted teleaudiology implementation on a larger scale. It was not until the COVID-19 pandemic when hearing healthcare stakeholders were faced with substantial challenges in continuing in-person care and more attention was brought upon the feasibility of utilising teleaudiology to match service demand. Clinical guidelines on teleaudiology use were developed by the professional organisations in some countries (e.g., Australia) to inform safe and effective practice during and beyond the pandemic. Nevertheless, teleaudiology uptake in Australia has been generally slow in spite of the presence of a growing body of evidence on the clinical applications of teleaudiology. A more thorough understanding of stakeholders' perceptions is crucial to further teleaudiology implementation in the post-pandemic landscape.

To address the aim of enhancing teleaudiology service delivery through evaluation of web-based and smartphone-based interventions with the incorporation of hearing healthcare stakeholders' opinions, this thesis presents a series of five studies using mixed methods encompassing three distinct components of teleaudiology service delivery.

Study 1 and Study 3 explored the experiences and perceptions of hearing healthcare stakeholders in Australia towards teleaudiology uptake through the use of online surveys and semi-structured interviews. Findings suggested that certain barriers to teleaudiology uptake still existed, rendering its widespread implementation restricted. That said, recent endeavours in improving teleaudiology uptake were seen and stakeholders generally held positive attitudes towards post-pandemic teleaudiology use.

Study 2 and Study 5 revolved around Oto, a smartphone application (app) developed for tinnitus management. These studies employed a longitudinal feasibility trial and randomised controlled trial design to evaluate Oto's effectiveness and usability. Results indicated that Oto was effective

in reducing tinnitus severity and distress and the effects were relatively long-lasting (up to 9 months). Its usability was also rated high among app users.

Study 4 focussed on remote hearing assessment and examined the performance, ecological validity, and usability of two smartphone-based hearing assessment apps – Hearing Test (Android version) and Mimi Hearing Test (iOS version) – alongside a web-based app, MDHearing Aid in screening for mild and moderate hearing loss. This study revealed generally reasonable performance, ecological validity, and usability of all examined apps, with the Hearing Test app demonstrating most potential for hearing screening purposes in adults.

Overall, this thesis adds to the evidence base and generates significant knowledge to support the viable and effective use of teleaudiology for remote service delivery during and beyond the pandemic. For the potential of teleaudiology to be fully realised, ongoing research and collaborative effort from all stakeholders is needed to tackle current challenges and barriers.

DECLARATION

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university

2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and

3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

No editor was used in the preparation of this thesis.

Signed.....Boaz Mui.....

Date.....06-03-2025.....

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PUBLICATIONS, PRESENTATIONS, AND OTHER ACHIEVEMENTS

Publications

Mui, B., Leong, N., Keil, B., Domingo, D., Dafny, H. A., Manchaiah, V., Gopinath, B., Muzaffar, J., Chen, J., Bidargaddi, N., Timmer, B. H. B., Vitkovic, J., Esterman, A., & Shekhawat, G. S. (2022). COVID-19 and tinnitus: An initiative to improve tinnitus care. *International Journal of Audiology, 62*(9), 826-834. https://doi.org/10.1080/14992027.2022.2104175*

Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2023). Hearing health care stakeholders' perspectives on teleaudiology implementation: Lessons learned during the COVID-19 pandemic and pathways forward. *American Journal of Audiology, 32*(3), 560-573. https://doi.org/doi:10.1044/2023_AJA-23-00001

Mui, B., Lawless, M., Timmer, B. H. B., Gopinath, B., Tang, D., Venning, A., May, D., Muzaffar, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Australian hearing healthcare stakeholders' experiences of and attitudes towards teleaudiology uptake: A qualitative study. *Speech, Language and Hearing*, 1-10. https://doi.org/10.1080/2050571X.2024.2372171

*This article was submitted and published during PhD candidature but has not been included in this thesis due to its lower relevance to the scope of this PhD.

Accepted manuscript

Mui, B., Swanepoel, D. W., Manchaiah, V., Muzaffar, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Validating smartphone-based and web-based applications for remote hearing assessment. *Journal of the American Academy of Audiology*.

Manuscripts under review

Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Digital therapeutics in tinnitus care: A feasibility study of the Oto smartphone application. *Journal of the American Academy of Audiology*.

Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Towards digital solutions for tinnitus: A randomised controlled trial of the Oto smartphone application. *Speech, Language and Hearing*.

Presentations

Oral presentation at Tinnitus Australia's webinar 2022 "Tinnitus Research Update: From emerging treatments to the impacts of COVID". Titled "The Impacts of COVID-19 on People with Tinnitus".

Oral presentation at the Audiology Australia national conference 2023. Titled "Hearing health care stakeholders' perspectives on teleaudiology implementation: Lessons learned during the COVID-19 pandemic and pathways forward".

Three Minute Thesis (3MT) Competition 2024. Titled "Silence! Bring back my peace: A digital approach to tinnitus management". People's choice award in College heat round.

Oral presentation at Flinders University College of Education, Psychology and Social Work HDR Conference 2024. Titled "Towards digital solutions for tinnitus: A randomised controlled trial of the Oto smartphone application".

Media engagement

2nd March 2022. Interviewed by Peter Goers on ABC Radio Adelaide to promote awareness of healthy hearing and tinnitus for World Hearing Day.

18th October 2023. Interviewed by ABC Radio Riverland to share findings from paper titled "Hearing health care stakeholders' perspectives on teleaudiology implementation: Lessons learned during the COVID-19 pandemic and pathways forward".

28th October 2024. Interviewed by David Bevan on ABC Radio Adelaide to share tinnitus research conducted at Flinders University.

Industry internship

September – November 2024. Industry internship with Oto Health Ltd, a co-funder of this PhD.

ABBREVIATIONS

AAMC	Association of American Medical Colleges
AAO-HNS	American Academy of Otolaryngology-Head and Neck Surgery
ABR	Auditory brainstem response
ACT	Acceptance and commitment therapy
AMA	American Medical Association
ANZCTR	Australian New Zealand Clinical Trials Registry
App	Application
ASHA	American Speech-Language-Hearing Association
ASLP-IC	Audiology & Speech-Language Pathology Interstate Compact
ASMR	Autonomous sensory meridian response
BCW	Behaviour change wheel
BTOP	Broadband Technology Opportunities Program
CBT	Cognitive behavioural therapy
CI	Cochlear implant
CONSORT	Consolidated Standards of Reporting Trials
COREQ	Consolidated criteria for reporting qualitative studies
CPD	Continuing professional development
CT	Computed tomography
DHLS	Digital Health Care Literacy Scale
DLSAT	Digital Literacy Self-Assessment Tool
DPOAE	Distortion product otoacoustic emission
eHEALS	Electronic Health Literacy Scale
EMA	Ecological momentary assessment
ENT	Ear, nose, and throat
GP	General practitioner
HA	Hearing aid

HADS	Hospital Depression and Anxiety Scale
HSP	Hearing Services Program
ICBT	Internet-based cognitive behavioural therapy
ICC	Intraclass correlation coefficient
ICT	Information and communications technology
LCME	Liaison Committee on Medical Education
MARS	Mobile App Rating Scale
MAUQ	mHealth App Usability Questionnaire
MRHA	Medicines and Healthcare products Regulatory Agency
MRI	Magnetic resonance imaging
NAL	National Acoustic Laboratories
NASA	National Aeronautics and Space Administration
NBN	National broadband network
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NONPF	National Organization of Nurse Practitioner Faculties
OAE	Otoacoustic emission
PSQI	Pittsburgh Sleep Quality Index
PSSUQ	Post-Study System Usability Questionnaire
PTA	Pure tone audiometry
PTM	Progressive tinnitus management
QOLS	Quality of Life Scale
RCT	Randomised controlled trial
REM	Real ear measurement
RMSD	Root mean square deviation
SCT	Social Cognitive Theory
SD	Standard deviation

SQS	Sleep Quality Scale
STARPAHC	Space Technology Applied to Rural Papago Advanced Health Care
SUS	System Usability Scale
TCQ	Tinnitus Cognitions Questionnaire
TCS	University of Alabama-Birmingham Technology Comfort Survey
TFI	Tinnitus Functional Index
THI	Tinnitus Handicap Inventory
TLST	Telehealth Literacy Screening Tool
TQ	Tinnitus Questionnaire
TRI	Tinnitus Research Initiative
TRT	Tinnitus retraining therapy
TSCHQ	Tinnitus Sample Case History Questionnaire
TSD	Trait Self Descriptive Inventory
UFB	Ultra-fast broadband
UQ-COH	The University of Queensland's Centre for Online Health
WHO	World Health Organization
WHOQOL-BREF	Short version of World Health Organization Quality of Life

CHAPTER 1 – INTRODUCTION

This thesis presents a series of five studies which correspond to the use of teleaudiology in three aspects of hearing healthcare, namely awareness, assessment, and intervention (Figure 1.1). As an overview of the structure of this thesis, the background of the current PhD research is explained in detail by a literature review (Chapter 2), followed by each of the five studies in manuscript format (Chapters 3-7) and a general discussion of all studies (Chapter 8). Details of the five studies are further elaborated in *Thesis outline* (Chapter 1.3).

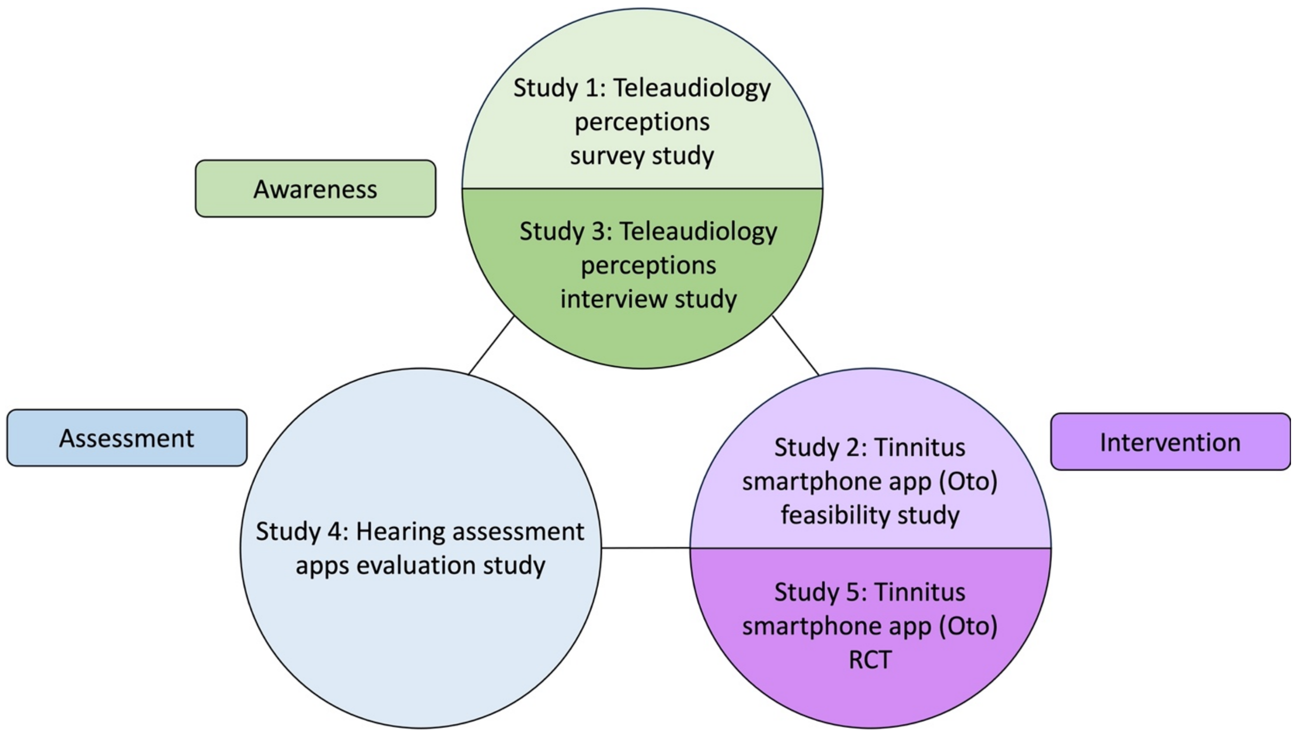

Figure 1.1 Summary of the five studies presented in this thesis and their corresponding aspects of hearing healthcare in terms of teleaudiology use.

1.1 Background of this PhD – overview of key gaps in teleaudiology research and novel contribution to knowledge

By definition, teleaudiology leverages digital technology as a means of remote hearing healthcare service provision to clients who are located differently from service providers (Australian Government Department of Health and Aged Care, 2022b). Although the body of teleaudiology research work has grown over the years, multiple gaps remain in various areas of the literature, some of which will be elaborated in *Literature Review* (Chapter 2) and addressed by the five studies presented in this thesis (Chapters 3-7).

As an initial step in portraying the landscape of teleaudiology practice, attempts in describing the attitudes and perceptions of hearing healthcare stakeholders towards teleaudiology uptake have been primarily directed to clients and clinicians (e.g., Bennett & Campbell, 2021; Eikelboom & Atlas, 2005; Eikelboom et al., 2022; Eikelboom & Swanepoel, 2016). To adopt a more inclusive approach, Study 1 (Chapter 3) and Study 3 (Chapter 5) are the first exploratory studies investigating the perceptions of underexplored stakeholder groups, including students, academics, and industry partners, towards teleaudiology uptake.

Despite the abundance of commercially available smartphone-based and web-based applications (apps) developed for the purposes of performing hearing assessment and tinnitus management, many lack empirical evidence to demonstrate their performance and support their use in clinical practice (Almufarrij et al., 2022; Mehdi, Dode, et al., 2020). To address these gaps in the literature, Study 2 (Chapter 4) and Study 5 (Chapter 7) are the first studies evaluating the effectiveness and usability of a novel multi-modal app-delivered tinnitus intervention (Oto app), and Study 4 (Chapter 6) provides original insights to the currently largely lacking knowledge of hearing assessment app validation with the selection of apps and app performance parameters never evaluated previously.

1.2 Overall aim and research questions of the current PhD research

Combining the above key gaps identified in the literature, the current PhD research aimed to enhance teleaudiology service delivery through evaluation of web-based and smartphone-based interventions which are designed taking stakeholder perceptions into account. This PhD comprises a series of five studies which addressed three distinct components of teleaudiology service delivery. As such, the research questions of the current PhD research are:

1. How is teleaudiology perceived by hearing healthcare stakeholders including clients, clinicians, students, academics, and industry partners in Australia? (Addressed by Study 1 and Study 3)
2. What is the effectiveness and usability of Oto, a smartphone application for tinnitus management, in reducing tinnitus distress? (Addressed by Study 2 and Study 5)
3. What is the performance, ecological validity, and usability of two smartphone-based hearing assessment applications – Hearing Test (Android version) and Mimi Hearing Test (iOS version) – alongside a web-based application, MDHearing Aid in screening for mild and moderate hearing loss? (Addressed by Study 4)

Because of the exploratory nature of Study 1 and Study 3, no hypothesis was developed for these studies. Instead, the findings (themes and subthemes) were organically produced from the responses collected. As for Study 2 and Study 5, it was hypothesised that Oto would be effective in reducing tinnitus distress with high usability. For Study 4, the hypothesis was that the three apps examined would show reasonable performance, ecological validity, and usability in screening for mild and moderate hearing loss.

1.3 Thesis outline

In order to systematically address the aforementioned research questions, a series of five studies were conducted. Those studies included:

1. Study 1 (Chapter 3) was a survey study which aimed to explore how teleaudiology was perceived by the hearing healthcare stakeholders in Australia. Their previous experiences with teleaudiology were also investigated. Stakeholders included in this study were clients, clinicians, students, academics, and industry partners. A collection of five online surveys was created, with one survey designed specifically for each stakeholder group, and distributed nationwide in Australia.
2. Study 2 (Chapter 4) served the purpose of a longitudinal feasibility study, aiming to investigate the feasibility of utilising a multi-modal smartphone app (Oto) in tinnitus management in terms of trial acceptability, deliverability, and effectiveness. This study formed the basis for a comprehensively designed randomised controlled trial (RCT) (Study 5) by shedding light on trial parameters such as the feasibility of recruitment, retention rate, and intervention implementation. These findings informed several modifications in the methodology of Study 5. Besides, user feedback was collected in Study 2 on app usability, satisfaction, perceived effectiveness, and user experience to improve app functionality targeting users' preferences and needs.
3. Study 3 (Chapter 5) was an extension of Study 1 and these studies shared similar aims, in which Australian-based hearing healthcare stakeholders discussed their views and opinions on teleaudiology implementation and uptake. This study employed semi-structured interviews to further collect more in-depth qualitative data which might otherwise not be captured extensively in Study 1. Findings from Study 1 and Study 3 will provide invaluable insights to evaluate, inform, and improve current hearing healthcare service delivery via teleaudiology.

4. Study 4 (Chapter 6) aimed to examine the performance, ecological validity, and usability of two freely available smartphone-based hearing assessment applications – Hearing Test (Android version) and Mimi Hearing Test (iOS version) – and a web-based application, MDHearing Aid, in screening for mild and moderate hearing loss using conventional in-person audiometric testing as gold standard for comparison. Hearing sensitivity data were garnered in both sound-controlled laboratory setting and naturalistic home environment to assess the replicability of hearing assessment results as well as the apps' applicability to clinical utilisation.
5. Study 5 (Chapter 7) was informed by the findings from Study 2 and employed a two-arm parallel-group RCT design to evaluate the effectiveness and usability of the Oto app in reducing tinnitus severity and distress. Long-term effectiveness of Oto was measured using data collected at four timepoints (up to nine-months) since baseline. Results obtained from Study 2 and Study 5 will constitute research evidence for the evaluation and consideration of incorporating the app into remote tinnitus care delivery.

The above five studies are presented in this thesis in the format of scientific journal publication manuscripts. Study 1 has been published by the *American Journal of Audiology*. Study 3 has been published by the *Speech, Language and Hearing*. Study 4 has been accepted by the *Journal of the American Academy of Audiology*. The remaining two studies are currently under peer review. Given that some of the studies examined matters of similar nature, a small amount of repetition can be found in the introduction sections of the manuscripts.

CHAPTER 2 – LITERATURE REVIEW

2.1 Outline of literature review

This chapter is rooted in the core component constructing this PhD: teleaudiology. A literature review has been conducted for the purposes of elucidating this topic from multiple perspectives and identifying key research gaps.

This literature review describes the definition of teleaudiology, history of telehealth, tools and models of teleaudiology service delivery, scope of and rationale for teleaudiology implementation, COVID-19 pandemic and its influence on teleaudiology uptake, and recent development of the Australian Teleaudiology Guidelines.

In addition to this chapter, each study (Chapters 3-7) presents an individual literature review most pertinent to its context, aim, and research question in the *Introduction* sections of each chapter. Hence, to avoid duplication, this chapter serves as an overall introduction of teleaudiology, and will not be covering certain specific aspects in detail.

2.2 Teleaudiology

2.2.1 Definition

Telehealth, also known as telemedicine, eHealth ("e" denotes electronic), or mHealth ("m" denotes mobile), refers to the remote delivery of healthcare services via electronic communication and digital means (Australian Government Department of Health and Aged Care, 2022b). Teleaudiology is a branch of telehealth in which audiological services are provided by clinicians to clients who are in a different physical location. Audiology Australia defines teleaudiology as "the use of telecommunications and digital technology to provide access to audiological services for clients who are not in the same location as the clinician" (Audiology Australia, 2020, p. 1). The American Speech-Language-Hearing Association describes the clinical use of teleaudiology more explicitly as "the delivery of services using telecommunication and Internet technology to remotely connect clinicians to clients, other health care providers, and/or educational professionals for screening, assessment, intervention, consultation, and/or education" (American Speech-Language-Hearing Association, n.d.-d, para. 1).

2.2.2 History and advancement of telehealth

Technology has come a long way and evolved drastically since its first use for medical purposes in history. Before the existence of digital technology, humans have used technologies available at that time to relay messages across long distances, including those containing medical and health information (Rushbrooke & Houston, 2014). Humans realised the importance of connectivity and attempted to conquer the obstacle of distance by utilising different tools. One of the earliest records of distance health communication was the use of bonfires in the Middle Ages to transmit information about the bubonic plague across Europe (Zundel, 1996). Medical information such as diagnosis of diseases and direction for treatments was relayed by postal systems since the 1700s (Craig & Patterson, 2005; Rushbrooke & Houston, 2014).

It was not until the 1800s a closer resemblance of digital technology emerged: the telegraph. Invented by Samuel Morse in the mid-1800s, the telegraph could transmit messages within and across continents (Rushbrooke & Houston, 2014). It was used widely in the American Civil War to report casualty and order medical supplies (Craig & Patterson, 2005). Eikelboom (2012) reported the possible beginning of telehealth in Australia in 1874 when a conflict was initiated by the Kaytetye people at the Barrow Creek station in Central Australia. Several individuals were injured and a telegraph was sent to Adelaide to seek medical advice and connect a dying individual with his wife who was 2000 kilometres away over the telegraph wire.

The telegraph was eventually replaced by the telephone in the late-1800s and physicians were among the first to adopt it in their practice (Zundel, 1996). Other than human voice, amplified sounds from a stethoscope and even electrocardiograms and electroencephalograms could also be transmitted by the telephone (Craig & Patterson, 2005).

The next advancement in technology which created a new means of distance health communication was the invention of radio communication in the early 1900s. Radio was utilised to provide medical advice to sailors when in-person medical assistance was unavailable at sea, and it is still being used presently in militaries (Rushbrooke & Houston, 2014). Also in the early 1900s, the Australian Royal Flying Doctors notably leveraged radio to relay medical information over long distances (Rushbrooke & Houston, 2014).

The invention of the television in the 1950s enabled telehealth to further evolve as diagnosis could be made based on visualised medical information rather than merely audio description. Closed-circuit, interactive television was first used in the 1960s in the USA to conduct remote consultation and diagnosis, transmit medical records and laboratory data, and facilitate training and education (Craig & Patterson, 2005).

Another significant technological advancement which positively influenced telehealth was the introduction of satellite communication in the midst of the space race in the 1960s (Rushbrooke & Houston, 2014). Satellite technology was applied by the National Aeronautics and Space Administration (NASA) in its manned space flight program. The effects of zero gravity on astronauts' health was monitored by measurement of heart rate, respiration rate, body temperature, and so forth and any in-flight medical emergencies were supported by earthbound physicians (Bashshur et al., 2000). Success in such program paved the way for the application of satellite technology in the provision of telehealth services in rural and remote areas. NASA later was involved in the Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) program in which general medical services were offered to the people of the Papago Indian Reservation in Arizona via satellite communication (Rushbrooke & Houston, 2014).

Towards the end of the 20th century, telehealth has once again become an area of interest due to the development of the Internet. Factors such as more affordable digital devices (laptops, tablets, and smartphones), better Internet connectivity and speed, and the emergence of online teleconferencing software enabled telehealth services to be more accessible than ever before and gave professionals, patients, and researchers an opportunity to discover and evaluate the potential benefits of telehealth again (Rushbrooke & Houston, 2014).

2.2.3 Tools used in teleaudiology service delivery

Teleaudiology adopts a range of digital tools for remote service delivery. Among the tools that are still in use at present, telephone has the longest history and it can be used to serve multiple functions such as hearing device fitting follow-up and counselling (Eikelboom et al., 2021). Rapid development of the Internet and invention of technological tools gave rise to the use of computers and smartphones in teleaudiology service delivery. Videoconferencing, text messages, emails, and instant online chats are some common modes of communications in teleaudiology (Eikelboom et al., 2021). Smartphone applications (apps) and websites can also be used for specific purposes such as hearing device fitting and finetuning (Ross, 2020) and tinnitus management (Mehdi, Dode, et al., 2020).

2.2.4 Teleaudiology service delivery models

The timing of delivering teleaudiology services can vary based on factors such as clinician's and client's preferences, Internet connectivity, and resource availability. Figure 2.1 depicts the synchronous and asynchronous models of service delivery via teleaudiology. Synchronous, or real-time, delivery of teleaudiology services most closely resembles conventional in-person consultation (Eikelboom et al., 2021). Communication and exchange of medical information occurs in real time during consultation usually by telephone or videoconferencing (American Speech-Language-Hearing Association, n.d.-d). For instance, pure tone audiometry (PTA) testing and hearing aid (HA) fitting can be performed remotely using the synchronous model (Novak et al., 2016; Swanepoel, Koekemoer, et al., 2010). In circumstances where Internet connectivity is unstable or when clinician and client are unable to agree on a mutually available time for consultation, teleaudiology services can be delivered in an asynchronous, or store-and-forward, manner. In the asynchronous model, medical data such as images, videos, test results, and other kinds of information are saved either in local drive or on the cloud and sent for interpretation and review at another time (American Speech-Language-Hearing Association, n.d.-d). Home-based otoscopy is an example of asynchronous teleaudiology service delivery. Videos captured by a smartphone otoscopy device were sent to physicians for examination at a later time (Erkkola-Anttinen, Irjala, Laine, Tahtinen, et al., 2019). A hybrid model which consists of both synchronous and asynchronous service delivery is also feasible, e.g., a combination of remote consultations and sharing and review of stored HA usage data between consultations (American Speech-Language-Hearing Association, n.d.-d). Regardless of their differences, all models of teleaudiology service delivery are thought to potentially increase the accessibility of hearing healthcare services for underserved communities across the world (Swanepoel, Clark, et al., 2010).

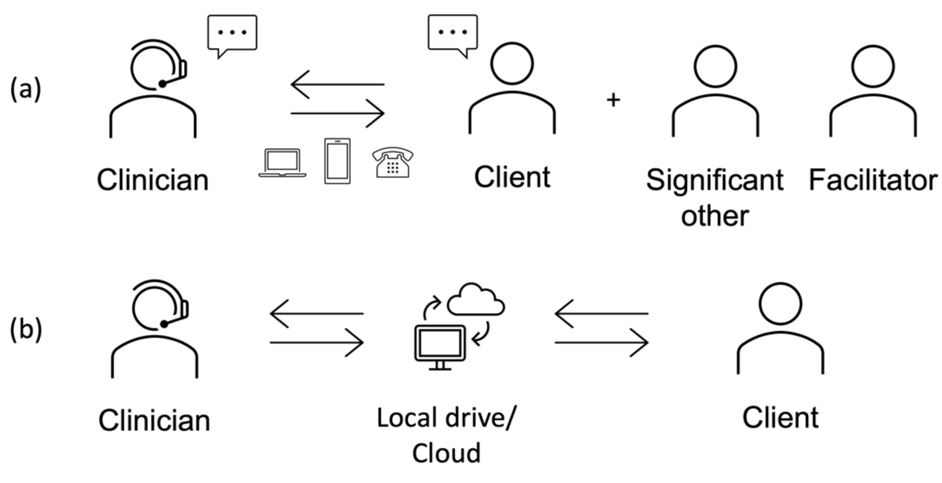

Figure 2.1 (a) Synchronous model and (b) asynchronous model of service delivery via teleaudiology.

Similar to conventional in-person audiology services, many teleaudiology services are driven by clinicians. Nevertheless, teleaudiology gives rise to the possibility of self-led management in which clients are actively involved in the management of their audiological conditions and wellbeing (Eikelboom et al., 2021). Typical examples of self-led teleaudiology services include the use of HA smartphone apps to adjust HA settings and address individual listening needs in real-life situations, and the use of apps and websites to obtain educational information as well as to complete an online program to manage conditions such as tinnitus (Beukes et al., 2019; Ross, 2020). Self-led management aligns with patient-centred care which is a widely advocated approach in audiological practice (Brice & Almond, 2022). Moreover, previous studies have demonstrated that patients' adherence to intervention and rehabilitation, their satisfaction, health outcomes, emotional wellbeing, and quality of life can be improved when self-led management is incorporated in care delivery (Convery, Hickson, et al., 2019; Convery, Keidser, et al., 2019). Such benefits brought about by self-led teleaudiology services highlight their importance in the teleaudiology service delivery model and therefore should receive attention equivalent to that of clinician-led services. With a gradual shift in clients' generation from the Silent Generation (who were born from 1928 to 1945 when digital technology was less prevalent) to the baby boomers (who were born from 1946 to 1964 when digital technology became more common than the previous generation), an increase in clients' technological confidence and autonomy is likely to predict an increase in the use of self-led teleaudiology services (Ross et al., 2022).

Teleaudiology has the same and perhaps higher capacity in engaging third parties when compared to in-person services. Involvement of significant others (e.g., family members, friends) in audiological rehabilitation has the potential to improve health outcomes (Scarinci et al., 2021). Having a significant other attending teleaudiology consultation may provide additional support to the client and more importantly, the remote format of service delivery overcomes geographical boundaries. The client and significant other no longer need to be in the same physical location to attend consultation together as long as they have adequate Internet connectivity and suitable devices. The same benefit applies to the involvement of practitioners from other disciplines (e.g., an ear, nose, and throat (ENT) specialist or a speech pathologist) and even other clients who participate in the same audiological rehabilitation program (Eikelboom et al., 2021). On the other hand, there is a potential for disengagement with the presence of third parties due to various reasons, such as the lack of safe space to share sensitive health information and privacy concerns (Houser et al., 2023).

2.2.5 Scope of teleaudiology services

Information and communication technology can be applied to a plethora of services in the audiology spectrum. In the literature reviews by D'Onofrio and Zeng (2021), Frisby et al. (2021), and Muñoz et al. (2021), they similarly categorised teleaudiology research articles into the following groups based on the type of services delivered: hearing screening, diagnostic testing, intervention and support, and hearing health promotion.

2.2.5.1 Hearing screening

Hearing screening refers to the testing usually conducted prior to diagnostic testing. A pass/fail criterion is used to indicate the need for further diagnostic testing in which the type and degree of hearing loss is identified. Hearing screening can also be conducted regularly between diagnostic testing to monitor changes in hearing thresholds (Eikelboom et al., 2021).

Most of the literature that investigated how teleaudiology could be applied to hearing screening used computer-based, tablet-based, or smartphone-based audiometric tests including PTA and speech tests. Seren (2009) compared the hearing thresholds obtained from a web-based hearing screening system to those from conventional in-person hearing screening in 36 adults. The author found that the air conduction hearing thresholds measured by both methods differed by less than 2 dB and thus the web-based system could act as a screening tool easily accessible by the public. Dillon et al. (2018) evaluated the accuracy of Sound Scouts, a computer-based hearing screening app, in 491 children aged five to 14 years with normal hearing and hearing loss and 50 adults with normal hearing. The app utilised tests of tones in noise, speech in quiet, and speech in noise. The sensitivity and specificity of the app was found to be sufficiently high for children from age five to 14 but the type of hearing loss was only correctly identified in two-thirds of cases where a child failed the screening. The reliability of tablet-based hearing screening apps with gamification feature was assessed in several studies and they all concluded that the apps could be considered reliable and cost-effective tools for hearing screening in adults and school-age children (Rourke et al., 2016; Samelli et al., 2017; Samelli et al., 2020). Similarly, smartphone-based hearing screening apps were able to yield results comparable to conventional audiometry in the studies by Eksteen et al. (2019) and Swanepoel et al. (2014).

A small number of studies evaluated the feasibility of using distortion product otoacoustic emissions (DPOAEs) in remote synchronous hearing screening. DPOAEs are sounds generated by the cochlea at specific frequencies when two pure tone stimuli are presented in the same ear simultaneously (Katz et al., 2015). The presence/absence of DPOAEs can indicate whether there is an underlying hearing loss and estimate the frequencies affected should there be a hearing loss. Remote DPOAE testing has been demonstrated to produce results comparable with conventional testing in adults, children, and infants and therefore could be a valuable addition to remote hearing screening programs (Ameyaw et al., 2019; Ciccia et al., 2011; Krumm et al., 2007).

2.2.5.2 Diagnostic testing

A diagnostic test battery consists of various tests assessing different locations along the auditory pathway. Result from each test complements one another to pinpoint the type and degree of hearing loss. The literature shows that a majority of in-person diagnostic tests can be adapted to remote delivery and the tests are discussed below.

Otoscopy is generally the first part of the diagnostic test battery. It is a clinical procedure in which the external ear canal, tympanic membrane, and part of the middle ear are examined. Any observed abnormality may indicate an underlying pathology and/or a hearing loss and a need for referral to other medical professionals, e.g., an ENT specialist. It is crucial to ensure images and videos recorded by otoscope/video-otoscope have high quality so that an accurate diagnosis can be made. Mandavia et al. (2018) evaluated the accuracy of a smartphone otoscope used by an ENT trainee and a general practitioner (GP) trainee in flagging referrals to an ENT centre by an asynchronous model (i.e., images were stored and forwarded to an ENT specialist for assessment). When compared to the use of standard otoscope by an ENT specialist, the smartphone otoscope was able to achieve the same diagnosis in 99 out of 104 ears and all 52 participants received the same decision on whether they required a referral. In another study by Erkkola-Anttinen, Irjala, Laine, Tahtinen, et al. (2019), the accuracy of smartphone otoscope operated by parents instead of medical professionals was examined. When training was provided, the parents were able to record videos with sufficient quality for physicians to detect or exclude acute otitis media and the parents’ experiences were positive. Recent technological development enabled artificial intelligence algorithms to be incorporated in smartphone otoscopy and its accuracy was reported to be equivalent, or even superior, to standard otoscopy (Cha et al., 2019).

Similar to hearing screening, audiometric tests (PTA and speech tests) play a significant role in the diagnosis of hearing loss. Diagnostic PTA measures air conduction and bone conduction hearing thresholds at frequency intervals mostly between 250 and 8000 Hz. With speech tests in which communication difficulties are quantified, intervention options can be recommended accordingly.

A number of studies have demonstrated that computer-based remote PTA (air and bone conduction) has adequate accuracy and reliability for diagnostic purposes, even though its performance may become suboptimal when ambient noise levels are high (e.g., Swanepoel & Biagio, 2011; Whitton et al., 2016). Newly introduced smartphone-based automated audiometry and machine learning not only preserve the reliability of teleaudiometry, but also provide a more portable option, expand the scope of test to masking and speech recognition testing, and even potentially predict a full audiogram based on a few measured hearing thresholds (Barbour et al., 2019; Pitathawatchai et al., 2022; Sandström et al., 2020). Regarding remote speech tests, no significant difference was observed between scores obtained from speech perception testing conducted by clinicians remotely and conventional testing in soundproof booths (Ribera, 2005; Whitton et al., 2016). Blamey and Saunders (2015) reported the development of a self-led online speech perception test and it had a high correlation with conventional audiograms in the better ear. The authors nonetheless suggested that caveats such as a hearing loss too mild for speech perception to be affected or too severe that speech was inaudible, and unfamiliarity with English language or Australian accent could restrict this test's usability.

Another component of the diagnostic test battery is acoustic immittance testing which includes tympanometry and acoustic reflex testing. Tympanometry assesses the function of the tympanic membrane and middle ear by measuring the acoustic immittance with varying pressure in the external ear canal, while acoustic reflex testing measures the presence/absence of the stapedius muscle reflex when a sound stimulus is presented (Katz et al., 2015). Both tests typically share the same equipment and a probe is placed in the ear for the presentation of sound stimuli. Several studies support the use of remote tympanometry with the assistance of a trained facilitator on the client's side to ensure proper probe insertion. Both synchronous and asynchronous models of delivery were shown to be successful with a high agreement (greater than 75%) with conventional in-person tympanometry (Kleindienst, 2014; Lancaster et al., 2008; Ramkumar et al., 2018). There is currently no literature dedicated to evaluating the feasibility of conducting acoustic reflex testing remotely (Eikelboom et al., 2021). However, given its similarity in procedure and required equipment to tympanometry, it is reasonable to suggest that acoustic reflex testing can be performed via teleaudiology with appropriately trained personnel.

Even though auditory brainstem response (ABR) is not routinely used in clinical setting, its objective nature makes it particularly useful for populations who may be incapable of giving voluntary responses in behavioural testing, e.g., PTA. ABRs are neural responses in the auditory nervous system evoked by sound stimuli and such responses can be used for hearing threshold estimation (Katz et al., 2015). Several studies revealed similar efficiency and accuracy between real-time tele-ABR with the support of trained facilitators and conventional in-person ABR testing in infants (Hatton et al., 2019; Ramkumar et al., 2013b). In addition, tele-ABR significantly decreased loss to follow-up rates and travel costs associated with in-person assessments, and it was rated a satisfactory experience by parents (Dharmar et al., 2016; Hatton et al., 2019).

2.2.5.3 Intervention and support

Once an individual is diagnosed with a hearing loss and/or other audiological conditions which can affect everyday communication and quality of life, intervention options and follow-up support should be discussed. Current literature supports the delivery of conventional in-person intervention and support services such as HA and cochlear implant (CI) fitting and finetuning, audiological rehabilitation, and tinnitus management via teleaudiology and in general the outcomes of both methods are comparable.

Real ear measurements (REMs) are an important step in the HA fitting process in which the output of the HA is verified and matched against a prescribed target tailored to the user’s hearing thresholds. REMs require placement of a probe tube in the ear close to the tympanic membrane and measurements of the sound level in the ear canal are made (Dillon, 2012). REMs performed remotely with the assistance of trained facilitators in probe tube placement were shown to have no clinically significant difference from those performed in-person (Ferrari & Bernardez-Braga, 2009; Novak et al., 2016). Novak et al. (2016) concluded that remote HA fitting in 181 patients was successful as reflected by high HA usage and patient satisfaction, and significant improvement in self-reported communication abilities and quality of life in most patients. In another large-scale study conducted by Pross et al. (2016), 42,697 veterans were prescribed HAs (1,009 via teleaudiology and 41,688 via in-person fitting) and the self-reported hearing outcomes and satisfaction were similar between both methods.

Apart from HAs fitted by clinicians, the introduction of self-fitting HAs which allow the users to perform hearing assessment, programming, and finetuning solely by themselves may reduce the cost and increase accessibility (Eikelboom et al., 2021). Sabin et al. (2020) reported that the HA benefit and speech perception in noise between the self-fitted individuals and those who were fitted by clinicians were comparable. It is noteworthy that most self-fitting HA studies focus on individuals with mild to moderate hearing loss and exclude those with more severe hearing losses.

The support from hearing healthcare professionals is nonetheless recommended prior to self-fitting due to their expertise in identifying medical contraindications, e.g., a conductive hearing loss (D'Onofrio & Zeng, 2021).

Following HA fitting, the devices may need to be finetuned from time to time when needs arise, e.g., when the user’s hearing thresholds or communication needs have changed. Remote HA finetuning during an online appointment with or without facilitators was found to be feasible and perceived by HA users positively (Angley et al., 2017; Tao et al., 2021). Some HA manufacturers developed their own smartphone apps which enable the users to finetune their devices instantaneously to address their communication issues in diverse listening environments outside the clinic. Some of those apps also allows users to communicate with clinicians in real time and receive in-situational support, as well as to engage family members in remote appointments conducted through the apps and therefore can benefit the users (Froehlich et al., 2020; Rumley & Ratanjee-Vanmali, 2019).

Individuals whose hearing losses are too profound to be aidable by HAs may benefit from the use of CIs. Similar to HAs, the feasibility and reliability of remote CI programming (or mapping) were examined in several studies. The literature predominantly supports the use of remote CI mapping in adults and children due to its capability of producing test results and audiological outcomes equivalent to those from in-person mapping, high patient satisfaction, and cost-effectiveness (Luryi et al., 2020; Ramos et al., 2009; Schepers et al., 2019). Nevertheless, Hughes et al. (2012) noted challenges of communicating with the CI users when the ambient noise level was high and the CI processor was connected to the programming interface (thus making the CI microphone inactive). Alternative communication strategies such as sign language and visualisation of instructions via videoconferencing should be adopted.

Besides amplification devices, individuals with hearing loss can participate in audiological rehabilitation programs to learn communication strategies and repair communication breakdowns with communication partners, e.g., family members, friends, colleagues, etc. One example of such programs is the Hear-Communicate-Remember intervention developed by an Australian research group (Meyer et al., 2020). This five-week training program was designed for family caregivers of individuals with dementia and hearing loss and it contains four online learning modules including communication strategies and HA management skills. This program could be delivered by an audiologist, speech-language pathologist, or psychologist remotely. Six dyads of individuals with dementia and hearing loss and their caregivers were involved in this study. The caregivers were mostly satisfied with the learning materials and reported improved knowledge about how to facilitate HA use and communicate better with their family member. They also expressed concerns about poor Internet connectivity and their unfamiliarity with technology which could be ameliorated by appropriate instructions and training. Another UK-based research group developed C2Hear, a self-guided multimedia educational program for new HA users (Ferguson et al., 2016; Gomez & Ferguson, 2020). The program comprised a series of online videos addressing the practical and psychosocial issues of audiological rehabilitation. In both randomised controlled trials (RCTs), the participants who undertook this program had significantly greater improvement in self-efficacy and knowledge of HAs than those who only received a booklet on HAs (control group) (Ferguson et al., 2016; Gomez & Ferguson, 2020).

Tinnitus is a prevalent condition affecting approximately 10% to 15% of the adult population (Baguley et al., 2013). It is commonly manifested as the perception of a ringing or buzzing sound in the absence of an external sound stimulus, but description of other types of sounds have also been reported (Baguley et al., 2013). Tinnitus is a heterogeneous condition which can have numerous causes and it is often associated with hearing loss (Lockwood et al., 2002). People with tinnitus can find it debilitating with its extensive impacts on hearing, communication, social relationships, mental health, and sleep quality (Mantello et al., 2020). There is currently a variety of intervention/management options which aim to lower the impacts of tinnitus and research for a cure is still underway (Zenner et al., 2017). Some studies investigated the feasibility of delivering tinnitus intervention/management in the form of counselling and education via teleaudiology. For example, both clinician-guided and self-guided Internet-based cognitive behavioural therapy (ICBT) for tinnitus has been shown repetitively to significantly alleviate tinnitus distress and tinnitus-associated comorbidities such as depression and anxiety (Beukes, Baguley, et al., 2018; Jasper et al., 2014; Kaldo et al., 2013; Nyenhuis, Zastrutzki, et al., 2013). In addition, there are an abundance of commercially available tinnitus smartphone apps that claim to help manage tinnitus but the effectiveness of only a few of them have been evaluated and they predominantly are able to lower tinnitus distress (Mehdi, Dode, et al., 2020).

The number of identified smartphone apps related to tinnitus intervention and support varied across reviews. For example, Mehdi, Riha, et al. (2020) identified 87 apps whereas Nagaraj and Prabhu (2020) identified as many as over 200. Irrespective of such variation in the number of apps identified, there remained a dearth of research validating the effectiveness of those apps and existing studies were prone to methodological limitations (Mehdi, Dode, et al., 2020). A majority of tinnitus smartphone app validation studies lacked control groups (e.g., Henry et al., 2017; Inkster et al., 2018; Tyler et al., 2018) and only one study adopted an RCT approach (Fitzpatrick et al., 2017). Many studies had a small sample size (less than 25 participants) (e.g., Henry et al., 2017; Paul & Eubanks Fleming, 2018; Perreau et al., 2021) and this limitation might have rendered the findings insignificant. Moreover, the study by Kim et al. (2017) combined tinnitus smartphone app usage with Ginkgo biloba prescription which could have confounded the results and the stand-alone effectiveness of the app was indeterminable. Among the tinnitus smartphone app validation studies identified, the longest study duration was four months and no attempt has been made to investigate the effects of the apps in a longer term (Schlee et al., 2022). It is apparent that much more attention and effort are required in validating tinnitus smartphone apps under a well-designed research structure (e.g., with control groups and longer study duration) so that more effective intervention options are available to people affected by tinnitus and they can access such interventions wherever and whenever they need.

2.2.5.4 Hearing health promotion

Only three studies focussing on hearing health promotion were identified and all of them described the use of smartphone apps to monitor the sound level of music or video played in the device (Knoetze et al., 2021; Paping et al., 2022; Paping et al., 2021). In two of those studies, the same Netherlands-based research group evaluated the music listening habits of 311 adolescents by comparing app-measured objective data to self-reported data on listening frequency, duration, and sound level (Paping et al., 2022; Paping et al., 2021). They revealed a slight to fair agreement between the two groups of data and thus self-reported measures were deemed inaccurate and unreliable. They proposed regular use of smartphone apps to monitor music listening habits in order to minimise the risk of developing recreational noise-induced hearing loss. Another study by Knoetze et al. (2021) explored the use of sound-level monitoring earphones in combination with a sound-level monitoring smartphone app to raise awareness of healthy listening and change the listening behaviours in 40 young adults. A majority of participants indicated that the smartphone app was helpful in reviewing their own listening behaviours and a significant drop in sound intensity and sound dose was observed.

2.2.6 Rationale for implementing teleaudiology

As reported in the Global Burden of Disease study initiated by the World Health Organization (WHO) in 2019, the global prevalence of hearing loss of any degree was estimated to be 20% (1.57

billion people) (Haile et al., 2021). Those with a moderate or greater hearing loss (≥35 dB) in the better ear comprised 5% (430 million people) of the global population. It was projected that with an ageing population, the number of people with hearing loss will surge to 2.45 billion by 2050. Due to its high prevalence, hearing loss was the third largest cause of disability after low back pain and migraine in terms of number of years lived with disability, and it was the leading cause of disability among people older than 70 years (Haile et al., 2021). The Australian population had a prevalence of hearing loss slightly lower than the global prevalence as it was estimated to be 15% (3.95 million people) in 2019-20 (Hearing Care Industry Association, 2020). Of those with a hearing loss, 2.6 million people (10% of Australian population) had mild hearing loss while the remaining 1.35 million (5% of Australian population) had a hearing loss of moderate or higher severity. By 2066, the number of people with hearing loss in Australia is projected to reach 7.8 million which is almost a two-fold increase from 2019-20 (Hearing Care Industry Association, 2020).

Unaddressed hearing loss is known to impact multiple aspects of life including speech and language development in children, communication ability, cognition, education, employment, and mental health (World Health Organization, 2021). In addition, hearing loss can cause substantial economic impact on society and the estimated global cost attributed to unaddressed hearing loss is $980 billion annually. This includes healthcare costs, educational costs to provide support to children with hearing loss, costs of lost productivity, and societal costs (World Health Organization, 2021). In Australia, the total financial cost of hearing loss in 2019-20 was estimated as $20.0 billion in which $1.0 billion was the health system costs and $16.2 billion was the productivity costs (Hearing Care Industry Association, 2020). Apart from financial costs, the value of reduced wellbeing as a result of hearing loss was estimated as $21.2 billion in 2019-20 (Hearing Care Industry Association, 2020). An upward trend in the total cost of hearing loss was discovered from 2017 to 2020 which suggested that hearing loss was and possibly still is a growing problem in Australia (Hearing Care Industry Association, 2020).

Although it would be ideal to provide hearing healthcare services to every individual with hearing loss, access to such services remains uneven within and across countries. Nearly 80% of people with hearing loss reside in low-income and middle-income countries where hearing healthcare services are very limited or absent (Swanepoel, Clark, et al., 2010; World Health Organization, 2021). Accessibility of HAs in developing countries is particularly low, with only 10% of those who can benefit from using a HA are actually using one in the WHO African Region (World Health

Organization, 2021). Global shortage of hearing healthcare clinicians is another contributing factor to the service delivery gap. The availability of audiologists in 78% of countries in the WHO African region is as low as less than one audiologist per million population (World Health Organization, 2021). Even in developed countries (e.g., Australia) where there are more than 10 audiologists per million population, most of the audiologists are based in metropolitan areas, rendering provision of hearing healthcare services in regional and rural areas inadequate (Victorian Government Department of Health and Human Services, 2018; World Health Organization, 2021). The increasingly high prevalence of hearing loss and paucity of hearing healthcare clinicians underline the importance of remote service delivery to underserved populations. As supported by research evidence, teleaudiology is a viable approach that can complement conventional in-person service delivery to improve accessibility, reduce the cost and time required for clinicians and clients to travel, and help mitigate the multifaceted impacts of unaddressed hearing loss globally.

2.2.7 COVID-19 pandemic and its impacts

The COVID-19 pandemic is thought to have begun in December 2019 when the first case of COVID-19 was reported in Wuhan, China (World Health Organization, 2020a), as illustrated in Figure 2.2. Since then, the virus spread across the globe quickly and the first case of COVID-19 was detected in Australia on 25th January 2020 (Australian Government Department of the Prime Minister and Cabinet, 2024). Because of its widespread impacts, the WHO declared COVID-19 a pandemic on 11th March 2020, and the Australian government banned international travel and implemented the first national lockdown in the same month (Australian Government Department of the Prime Minister and Cabinet, 2024). The pandemic continued to escalate, resulting in global cases rocketing from 1 million to 10 million from April to June 2020 and further increased to 100 million in January 2021, in which mortality reached 1 million in September 2020 (Hsieh et al., 2021). Towards the end of 2020, vaccine production commenced and the national vaccination program was rolled out in Australia in February 2021 (Australian Government Department of the Prime Minister and Cabinet, 2024). As the world was gradually transitioning to living with COVID-19, international borders fully opened in July 2022 and the WHO declared end of COVID-19 as a global health emergency in March 2023 (Australian Government Department of the Prime Minister and Cabinet, 2024). By that time, global confirmed cases and deaths had exceeded 761 million and 6.8 million, respectively (World Health Organization, 2023).

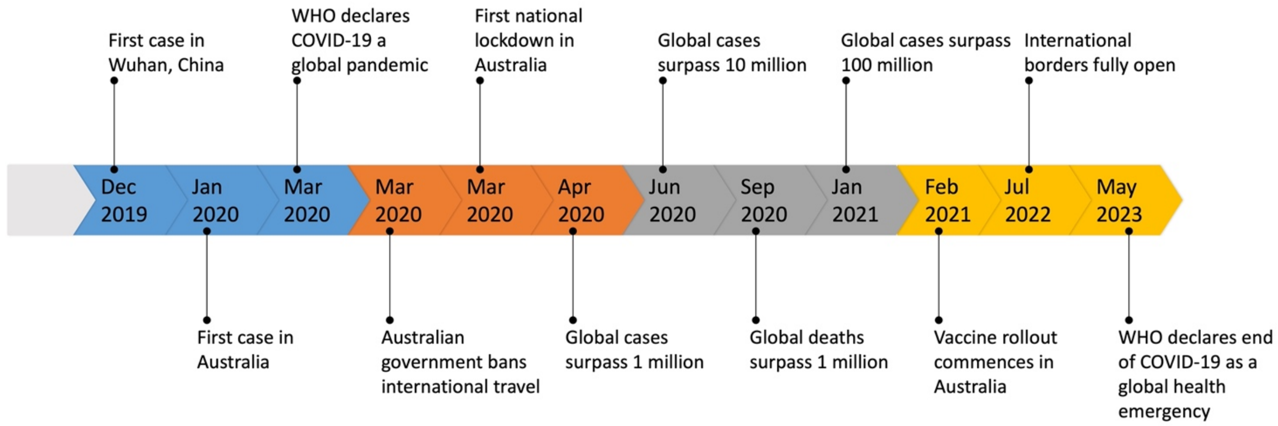

Figure 2.2 Timeline of the COVID-19 pandemic.

The impacts of this pandemic are undeniably profound in many ways. Broadly speaking, some of these impacts include economic loss amounted to 2 trillion dollars in a year during the pandemic, worsened psychological wellbeing (e.g., anxiety, depression, and suicidal ideation), and social implications such as discrimination and racism (Kaye et al., 2021). With regard to healthcare systems, to mitigate the risk of infections, lockdown measures and social restrictions were in place to minimise physical contact. As a result, healthcare service delivery was substantially disrupted (Haileamlak, 2021). Such disruption was particularly evident in lower income countries (World Health Organization, 2020b). Overall, healthcare service utilisation was reported to have decreased by 37% globally during the pandemic, with a greater reduction among people with milder illness (Moynihan et al., 2021). Audiology services were no exception and many audiology clinics had to pause their provision of in-person services (Coco, 2020). Nevertheless, certain selective services such as telemedicine had shown increase in utilisation amidst the pandemic, and so did teleaudiology use (Mann et al., 2020).

2.2.8 Perceptions and uptake of teleaudiology before the COVID-19 pandemic

Before the COVID-19 pandemic, hearing healthcare clinicians generally held positive attitude towards the use of teleaudiology and yet there was an unmatched uptake of teleaudiology in clinical practice. In an international survey study which involved 269 audiologists from 28 countries, despite most audiologists being familiar with teleaudiology and would be comfortable to use it if trained, only 15.5% of them had experience using it (Eikelboom & Swanepoel, 2016). Although willingness in utilising teleaudiology was observed in other studies, audiologists could be selective depending on the type of service delivered and patient population. They were willing to answer questions about hearing and HAs remotely, and most unwilling to perform CI mapping, consult new HA users, and conduct diagnostic assessment via teleaudiology (Rashid et al., 2019; Singh et al., 2014). Specifically pertaining to the use of smartphone in hearing healthcare, audiologists expressed most willingness to use smartphone apps to schedule appointments and allow their patients to adjust HA volume and switch between HA programs, whereas making permanent changes to HA amplification settings by patients themselves received the least willingness (Kimball et al., 2018). Technologically savvy adult patients below 65 years old were deemed most suitable for teleaudiology, while first-time patients, children below 12 years old, and people with disabilities were deemed most unsuitable (Rashid et al., 2019; Singh et al., 2014). Many audiologists believed that adopting teleaudiology would improve service accessibility and pose minimal effect on the quality of clinician-patient interactions (Rashid et al., 2019; Singh et al., 2014). Audiologists' views on how teleaudiology would affect the quality of care were more divided as some of them thought it would be improved while others thought it would be minimally affected (Rashid et al., 2019; Singh et al., 2014). In spite of the immense willingness and perceived benefits, the uptake of teleaudiology remained scarce and it could be attributed to several potential barriers. Some of the major barriers were inadequate infrastructure and technology for clinicians and patients, lack of training, notions of compromised quality of care, licensure, and reimbursement issues (Ravi et al., 2018).

Apart from clinicians' perceptions, patients' views on teleaudiology also plays a crucial role in its clinical uptake. It was found that almost two decades ago, 75% of surveyed audiology patients were unaware of telehealth and only 40% were willing to use it (Eikelboom & Atlas, 2005). Male patients who were aware of telehealth and had used the Internet for health purposes had higher willingness to use telehealth (Eikelboom & Atlas, 2005). There has been very limited research on patients' attitude towards teleaudiology ever since, however most of the patients who used teleaudiology reported high satisfaction and appreciated its benefits such as improved service accessibility, convenience, flexibility to undertake the intervention at any time they wanted, and reduced stress level associated with attending the appointments in a clinical environment (Beukes, Manchaiah, et al., 2018; Ratanjee-Vanmali et al., 2020b). Uptake of teleaudiology could likely be maintained by patient-centred care, understanding and engaging audiologists, user interfaces tailored to patients' needs (e.g., large font and high colour contrast for older populations), and training and technical support (Ratanjee-Vanmali et al., 2020b; Rothpletz et al., 2016). Patients' preference for face-to-face appointments was suggested as a barrier to using teleaudiology (Eikelboom & Atlas, 2005).

One study attempted to garner other hearing healthcare stakeholders' opinions on teleaudiology before the COVID-19 pandemic (Darzi et al., 2016). The authors surveyed 253 individuals in six WHO regions, including individuals with disability and their caregivers, health professionals, administrators, and policy makers. Surprisingly, only 40% of them thought teleaudiology was a feasible and acceptable means of providing audiological rehabilitation services.

2.2.9 Perceptions and uptake of teleaudiology during the COVID-19 pandemic

After the onset of the COVID-19 pandemic in 2019, lockdown measures and social restrictions were imposed in an attempt to impede virus transmission. In regions where audiological services were considered inessential, face-to-face services were discouraged and many hearing healthcare providers looked into the possibilities of delivering services via teleaudiology (Coco, 2020). Eikelboom et al. (2022) collected responses from 337 audiologists from 44 countries and revealed a significantly larger proportion of audiologists regarding teleaudiology as important during the pandemic (rose from 44% before to 87% during the pandemic). Since the beginning of the pandemic, there was a 20% increase in the use of teleaudiology and it was expected to increase by a further 20% post-pandemic. A similar trend of increased uptake was observed among Australian practice, although the authors were tentative on the continuous use of teleaudiology after the pandemic (Bennett, Kelsall-Foreman, et al., 2022a). Findings from the UK were inconsistent, as one study reported a surge in the uptake of teleaudiology from 30% to 98%, whereas another study with a larger sample size reported a maximum uptake rate of 51% during the pandemic (Parmar et al., 2022; Saunders & Roughley, 2021). Furthermore, 86% of audiologists in the UK expressed interest in continuing practicing teleaudiology after COVID-19 restrictions are lifted (Saunders & Roughley, 2021). Geographical differences in the uptake of teleaudiology were apparent. In developing countries such as Jordan, Egypt, Saudi Arabia, and other Arab countries, around 60% of audiologists were familiar with teleaudiology and only 25% used teleaudiology (Elbeltagy et al., 2022; Zaitoun et al., 2022). Less than half of the audiologists regarded teleaudiology practical under the context of COVID-19 and only 16% held positive attitude towards using teleaudiology (Elbeltagy et al., 2022). Many of them were unsatisfied with teleaudiology and believed their patients shared the same perception mostly due to lack of equipment, experience, and guidelines, uncertainty about test reliability, data privacy concerns, and reimbursement issues (Elbeltagy et al., 2022; Zaitoun et al., 2022).

Some of the factors which encouraged the use of teleaudiology during the COVID-19 pandemic remained the same as before the pandemic, such as convenience, flexibility, reduced travel costs, and minimal impact on the quality of care (Eikelboom et al., 2022; Saunders & Roughley, 2021). Likewise, infrastructural and technological limitations, concerns about patients' technological literacy, preferences for in-person appointments, and perceived superior quality of care brought about by in-person appointments remained as barriers to adopting teleaudiology during the pandemic (Bennett, Kelsall-Foreman, et al., 2022b; Eikelboom et al., 2022; Elbeltagy et al., 2022). However, a few additional motivating factors emerged as a result of the pandemic. Australian audiology clinic owners and managers attributed the increased utilisation of teleaudiology during the pandemic to continuity of care and the need to keep their business running and ensure the safety of staff and patients (Bennett, Kelsall-Foreman, et al., 2022b). Availability of funding from the government to support the use of teleaudiology in some countries also encouraged hearing healthcare providers to consider incorporating this approach in their routine clinical practice (Eikelboom et al., 2021; U.S. Department of Health and Human Services, 2022a). Additionally, Audiology Australia, the leading Australian professional body in audiology, launched the Australian Teleaudiology Guidelines in July 2022 (Audiology Australia, 2022b). Funding from the Australian Department of Health and inputs from hearing healthcare providers and consumers were integrated in the development of these Guidelines. It is hoped that these Guidelines will offer support for both service providers and consumers on the safe and effective delivery of teleaudiology services.

Patients' attitude towards the use of teleaudiology during the COVID-19 pandemic was primarily positive. In a hospital in the UK where provision of in-person cognitive behavioural therapy (CBT) for tinnitus was disrupted, 113 patients were offered audiologist-guided online CBT and 80% of them accepted (Aazh et al., 2021). Of those who declined, unfamiliarity with technology, lack of suitable devices, and believing in-person sessions were more useful were mentioned as the main reasons. It is notable that patients who declined teleaudiology in average had more severe hearing losses and thus they might perceive online communication insurmountable. Subtitles generated automatically during videoconferencing were suggested to possibly motivate this population to try teleaudiology (Aazh et al., 2021). In another study where 246 Australian hearing healthcare clients were surveyed, an overwhelming number of them (74%) were not offered teleaudiology option during the pandemic (Bennett & Campbell, 2021). A majority of those who were offered teleaudiology and accepted it found the experience enjoyable and were satisfied with clinicians' familiarity with technology and quality of care. Some of the clients who were offered teleaudiology but declined it suggested similar reasons as the above study, including difficulty hearing over the phone and perceived lower usefulness of teleaudiology appointments. In addition, they stated that some clinics were unwilling to send items such as HA batteries (Bennett & Campbell, 2021).

2.2.10 Australian Teleaudiology Guidelines

There was no national standard of practice for teleaudiology in Australia before the COVID-19 pandemic. It was until the pandemic when social restrictions were in place and many face-to-face audiology services were disrupted, some audiology clinics began to recognise the convenience of teleaudiology and explore the feasibility of incorporating it in their clinical practice (Coco, 2020). Commissioned and funded by the Australian Department of Health, Audiology Australia developed the Australian Teleaudiology Guidelines in line with the key initiatives from the Roadmap for Hearing Health (Australian Government Department of Health and Aged Care, 2019). The guidelines underwent three phases before their official launch. Phase 1, i.e., the development phase, started in February 2021. Draft guidelines were developed with the inputs from hearing healthcare practitioners regarding their experiences of teleaudiology. The draft was then reviewed by hearing healthcare practitioners, consumers, and providers in Australia and overseas. During phase 2 (testing phase), the revised guidelines were tested by hearing healthcare practitioners and their feedback was sought for further modification of the guidelines. In the final phase (implementation phase), the Australian Teleaudiology Guidelines were launched, promoted, and embedded in clinical practice.

The purposes of the guidelines are to support the delivery of hearing services safely and effectively through teleaudiology, and to enhance access to high quality hearing care across Australia (Audiology Australia, 2022b). The guidelines emphasise that teleaudiology services can be delivered safely and effectively by audiologists and audiometrists with or without a trained assistant on the client's side and should at least have the same quality as in-person services. A client- and family-centred approach should always be adopted when deciding whether teleaudiology is appropriate for the client and for the type of service provided. The guidelines recommend using a synchronous model of service delivery whenever possible as real-time interaction and communication with the client and the third party is preferable. Videoconferencing with live captioning is also preferred to audio-only options to facilitate communication with all clients, especially those with more severe hearing impairment or from a non-English speaking background. The guidelines encompass general considerations, practice operations guidance, and clinical guidance for teleaudiology. However, due to the fact that there are many options available to deliver hearing healthcare services via teleaudiology, the guidelines do not provide recommendations for specific devices, equipment, platforms, software, or apps. Hearing healthcare practitioners and providers can make their own judgments and decisions however they see fit in accordance with the professional and ethical standards.

CHAPTER 3 – HEARING HEALTHCARE STAKEHOLDERS' PERSPECTIVES ON TELEAUDIOLOGY IMPLEMENTATION: LESSONS LEARNED DURING THE COVID-19 PANDEMIC AND PATHWAYS FORWARD (STUDY 1)

3.1 Contribution to overall PhD aim

As seen from *Literature Review* (Chapter 2), exploration of hearing healthcare stakeholders' perceptions towards teleaudiology has focussed heavily on clinicians and clients. Nonetheless, perceptions of other key stakeholders such as students, academics, and industry partners have almost never been explored. They may provide unique perspectives on the matter of teleaudiology uptake which may not be reported by clinicians and clients. In order to devise the best strategies for implementing teleaudiology, the significance of including the voices of all key stakeholders should not be overlooked. This chapter presents the first survey study to shed light on the opinions and needs of students, academics, and industry partners regarding teleaudiology. Overall, this chapter aims to answer **research question 1** – How is teleaudiology perceived by hearing healthcare stakeholders including clients, clinicians, students, academics, and industry partners in Australia?

3.2 Statement of co-authorship and author contributions

This chapter contains materials from the publication indicated below. The signed co-authorship approval form can be found in Appendix 1.

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B. Mui and G. S. Shekhawat were involved in the study conceptualisation and design, participant recruitment, data collection, and data analysis. B. Mui wrote the original draft of the manuscript and all co-authors were involved in reviewing the draft.

3.3 Abstract

Purpose: The purpose of this study was to explore how teleaudiology is perceived by Australian-based hearing healthcare stakeholders (clients, clinicians, students, academics, and industry partners) to inform future teleaudiology implementation.

Method: Five cross-sectional online surveys were adopted, and a total of 366 stakeholders responded (173 clients, 110 clinicians, 58 students, 19 academics, and 6 industry partners).

Results: Results showed that 55% of clients and over 90% of clinicians, students, academics, and industry partners knew what teleaudiology was. Experience in teleaudiology appointments was shared by 85% of clinicians and 7% of clients. However, 98% of clients were not offered any teleaudiology appointments. Teleaudiology apps were used by 66% of clinicians and 26% of clients. Both clients and clinicians acknowledged the benefits of teleaudiology including convenience and accessibility and identified drawbacks, such as loss of personal interaction and communication difficulty. About 80% of students and academics reported inclusion of teleaudiology within their universities' curriculum but only to a limited extent. Low teleaudiology uptake rates in placement clinics, as well as insufficient funding and staffing, were suggested as barriers to learning and teaching teleaudiology. Industry partners were generally confident in training clinicians to use teleaudiology products and teaching students on teleaudiology, but only one industry partner had been invited by universities for teaching purposes.

Conclusions: Low teleaudiology use and reserved attitudes towards widespread teleaudiology implementation were observed among clients. Clinicians, students, academics, and industry partners generally displayed positive attitudes towards teleaudiology use. For teleaudiology uptake to be improved among those who are interested and willing to try and use it, increasing awareness of teleaudiology services and collaboration between stakeholders are crucial.

Keywords: Teleaudiology; Australia; hearing healthcare stakeholders; perspectives

3.4 Introduction

Teleaudiology refers to the remote delivery of hearing healthcare services via information and communications technology (ICT) when a clinician and client are in different locations (Audiology Australia, 2020). Current research evidence supports the safe and effective use of teleaudiology in the delivery of diverse services, ranging from hearing screening and diagnostic assessment to rehabilitation and support, such as hearing device fitting and tinnitus intervention (D'Onofrio &

Zeng, 2021; Muñoz et al., 2021). Teleaudiology services can be delivered using an asynchronous (store-and-forward), synchronous (real-time), or hybrid (a combination of both) model (Krumm & Syms, 2011). Teleaudiology also allows third parties, such as significant others and multidisciplinary health practitioners from another location, to easily and conveniently participate in the client's consultation and rehabilitation process (Eikelboom et al., 2021).

By allowing clients to receive services at their own home, teleaudiology reduces barriers such as travel time, physical inabilities to travel (Singh et al., 2014; Swanepoel, Clark, et al., 2010), and cost (Smith et al., 2003). Teleaudiology is the only means to access services for underserved populations in regions where in-person audiology services are severely inadequate (Swanepoel, Clark, et al., 2010).

During the COVID-19 pandemic, some audiology clinics switched their practices from in-person to online to ensure continuity of care (Coco, 2020). The pandemic prompted the audiology industry to reevaluate the potential benefits of teleaudiology, and the uptake of teleaudiology might have been motivated by a few factors. Australian audiology clinic owners reported increased use of teleaudiology services during the pandemic mostly due to government funding becoming applicable to teleaudiology services and the importance of keeping their staff and clients safe (Bennett, Kelsall-Foreman, et al., 2022b). Regarding professional support, a recent launch of teleaudiology guidelines in Australia is hoped to provide a framework for clinicians to safely and effectively provide teleaudiology services and for clients to safely use such services (Audiology Australia, 2022b). This large-scale shift in teleaudiology uptake has induced alterations for all stakeholders involved in hearing healthcare that can potentially be sustained beyond the pandemic.

Clients' and clinicians' perspectives towards teleaudiology are mixed. An international survey study conducted by Eikelboom and Swanepoel (2016) revealed that, although most of the clinicians were willing to use teleaudiology if training was provided, only 15.5% of respondents had used it. Studies in Malaysia and Canada suggested that a majority of clinicians believed that teleaudiology would minimally affect quality of care and positively affect service accessibility (Rashid et al., 2019; Singh et al., 2014). Clinicians nonetheless reported preferences in utilising teleaudiology to deliver certain services and for certain populations. For example, clinicians considered technologically savvy adult clients younger than 65 years to be the most suitable population to receive care via teleaudiology, whereas children aged 12 years or below and first-time clients were the least suitable (Rashid et al., 2019; Singh et al., 2014). Clinicians were most willing to utilise teleaudiology to provide information about hearing and hearing devices, and least willing to conduct CI mapping and fitting new HA users remotely (Rashid et al., 2019; Singh et al., 2014). Ratanjee-Vanmali et al. (2020b) reported positive experience and high satisfaction among 97% of clients in South Africa who received hybrid teleaudiology services, including online hearing screening, audiological rehabilitation, and counselling, following HA fitting. Another Australian study by Eikelboom and Atlas (2005) reported that 42% of clients were willing to use teleaudiology, though this study was conducted at a time when ICT was less advanced and widespread. The gap between clinicians' and clients' high willingness to use teleaudiology and its low uptake could be attributed to barriers such as insufficient infrastructure and technology (Elbeltagy et al., 2022; Ravi et al., 2018; Saunders & Roughley, 2021), lack of training (Ravi et al., 2018), reimbursement issues (Ravi et al., 2018), and preference for in-person services (Saunders & Roughley, 2021).

At the time of this study, over two and a half years had passed since the outbreak of the COVID-19 pandemic, and hearing healthcare stakeholders' perspectives towards teleaudiology might have changed since the pandemic began. There is a need for investigation into how they perceive teleaudiology uptake at present to explore the opportunities of using teleaudiology in the future. Apart from clients and clinicians, to the authors' knowledge, there is no research investigating how audiology students, academics, or industry partners think about teleaudiology. Since students, academics, and industry partners play crucial roles in the successful uptake and implementation of teleaudiology, it is important to take their opinions into consideration when devising and refining implementation strategies. This study therefore aimed to explore how teleaudiology is perceived by Australian-based hearing healthcare stakeholders, including clients, clinicians, students, academics, and industry partners, and use this information to guide future teleaudiology implementation.

3.5 Methods

3.5.1 Study design and ethics

A cross-sectional online survey research design was employed. Ethical approval was obtained from Flinders University Human Research Ethics Committee (Project ID: 2857).

3.5.2 Survey development and distribution

A customised survey was created for each stakeholder group (clients, clinicians, students, academics, and industry partners). Industry partners refer to the personnel working in the audiology industry who provide teleaudiology products and support to clinicians and may be involved in occasional teaching or training for audiology students. Survey questions encompassing themes including knowledge and experience of using/teaching/learning teleaudiology, support and satisfaction, and perception were developed. Depending on the stakeholder group, the surveys consisted of different closed-ended and open-ended questions and there were 21-61 questions in each survey. Complete versions of the surveys can be found in Appendices 2-6. Survey completion was estimated to take around 10-15 minutes. The following information was captured by the survey questions (varied between surveys based on the stakeholder group):

1. demographic information: age, gender, country of residence (all groups); institution (students and academics); hearing loss and tinnitus (clients); and work nature (clinicians and industry partners);
2. knowledge of teleaudiology (all groups);
3. experience and satisfaction in teleaudiology appointments and app usage (clients and clinicians);
4. experience in learning/teaching teleaudiology (students and academics);
5. experience in providing teleaudiology products and services (industry partners);
6. training and support (clinicians); and
7. perception of teleaudiology such as the importance of using and promoting teleaudiology and the respondents' interest and confidence in teleaudiology (all groups).

All surveys underwent a review process prior to data collection. Three individuals from each stakeholder group were invited to review the survey questions based on their relevance, appropriateness, and ease of understanding. They were asked to indicate the time needed to complete the surveys and suggest any missing or duplicated items. Modifications were made based on their feedback, which enhanced the logic and flow of the surveys. No expectation was set on the sample size before data collection.

The survey was distributed online using Qualtrics (https://www.qualtrics.com). The surveys were distributed to individuals aged 18 years or above. Survey distribution was conducted via newsletters and social media of professional bodies (e.g., Australian College of Audiology, Hearing Business Alliance), patient organisations (e.g., Deafness Forum Australia, Australian Tinnitus

Association), and Australian universities. The surveys were available in English only. Data collection period was from 17th May 2022 to 17th October 2022. Online written consent was sought from all respondents before commencing the survey.

3.5.3 Data analysis

Descriptive analysis was conducted using Microsoft Excel (Version 16.58). Two-sample *z*-tests and *t*-tests were conducted using Epitools (http://epitools.ausvet.com.au) to determine the significance of the comparisons between stakeholder groups. A *p*-value of .05 was adopted to determine statistical significance. Two-sample *z*-tests were conducted to compare the proportions between two stakeholder groups who selected a particular answer in binary questions, for example, comparing the proportion of clients to the proportion of clinicians who selected "yes" in "Have you ever attended/conducted any teleaudiology appointments?" Two-sample *t*-tests were conducted to compare the means between two stakeholder groups obtained from Likert scale questions, for example, "How likely will you continue using teleaudiology apps?" with a 5-point Likert scale from *very unlikely* to *very likely*. Responses from those Likert scale questions were transferred into scores of 1-5 for the calculation of a mean score in each stakeholder group, and the means were compared using *t*-tests. Qualitative data collected from open-ended questions were analysed by thematic analysis using the framework outlined by Graneheim and Lundman (2004). Open-ended responses were examined repeatedly and coded into meaning units, with similar meaning units categorised into subthemes and then themes. The first author (BM) performed initial data coding and created a codebook using Microsoft Excel, and the consistency of the results was cross-checked by the last author (GSS). Any inconsistencies, such as meaning units, subthemes, and themes overlooked by BM, were resolved through discussion with GSS. BM then repeated data coding based on GSS's suggestions. Only responses with a completion rate of 50% or above were included in data analysis.

3.6 Results

3.6.1 Demographic information

A total of 366 respondents completed the surveys, including 173 clients, 110 clinicians, 58 students, 19 academics, and 6 industry partners. The age and gender distribution of all stakeholder groups are shown in Table 3.1.

Table 3.1 Demographic information of respondents (*N* = 366).

Information	All respondents (*N* = 366)	Clients (*n* = 173)	Clinicians (*n* = 110)	Students (*n* = 58)	Academics (*n* = 19)	Industry partners (*n* = 6)
Age (mean ± *SD*; in years)	47 ± 17	60 ± 13	41 ± 11	26 ± 6	41 ± 12	36 ± 13
Gender: *n* (%)						
Female	248 (68)	103 (60)	80 (73)	47 (81)	15 (79)	3 (50)
Male	117 (32)	69 (40)	30 (27)	11 (19)	4 (21)	3 (50)
Other	1 (0.003)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
Job experience (mean ± *SD*; in years)	13 ± 10	/	13 ± 11	/	11 ± 9	7 ± 10
Job position: *n* (%)						
Audiologist	/	/	48 (44)	/	/	/
Audiometrist	/	/	58 (53)	/	/	/
Manager	/	/	/	/	/	1 (17)
Product specialist	/	/	/	/	/	2 (33)
Other	/	/	4 (4)	/	/	3 (50)
Client population: *n* (%)						
Adults only	/	/	84 (76)	/	/	/
Children only	/	/	4 (4)	/	/	/
Both adults and children	/	/	22 (20)	/	/	/
Clinical work setting: *n* (%)						
Large chain clinic (>20 clinics)	/	/	66 (60)	/	/	/
Small chain clinic (≤20 clinics)	/	/	6 (5)	/	/	/
Single independent clinic	/	/	28 (25)	/	/	/
Government hospital/clinic	/	/	6 (5)	/	/	/
Private hospital	/	/	1 (1)	/	/	/
University clinic	/	/	1 (1)	/	/	/
Other	/	/	2 (2)	/	/	/
Institution: *n* (%)						
The University of Queensland	/	/	/	5 (9)	3 (16)	/
The University of Western Australia	/	/	/	6 (10)	2 (11)	/
Flinders University	/	/	/	16 (28)	2 (11)	/
Macquarie University	/	/	/	16 (28)	1 (5)	/
The University of Melbourne	/	/	/	6 (10)	6 (32)	/
La Trobe University	/	/	/	7 (12)	3 (16)	/
Charles Darwin University	/	/	/	0 (0)	1 (5)	/
TAFE	/	/	/	1 (2)	0 (0)	/
Other	/	/	/	1 (2)	1 (5)	/

Note. Slashes indicate the information is not applicable to the corresponding group of respondents.

Among the clients, 72% had hearing loss and their average duration of hearing loss was 17 years (range: 0.5-68; *SD* = 17). Tinnitus was experienced by 90% of clients at an average of 15 years (range: 0.5-65; *SD* = 14), and most of them perceived their tinnitus in both ears and described it as constant and high-pitched. Sixty-six percent of clients reported both hearing loss and tinnitus.

Fifty-three percent of clinicians worked as audiometrists, whereas 44% worked as audiologists. Audiometrists are trained at diploma level and predominantly provide adult hearing assessment and rehabilitation services. Audiologists are trained at university level and provide a variety of audiology services to clients at all ages. A majority of audiometrists and audiologists had a client population consisting of adults only. Both groups of clinicians mostly worked in large chain clinics (>20 clinics) and single independent clinics.

About 70% of students were in the second year of university programs. The remaining students were in the first year of university programs with one being in the first year of a diploma program. Academics had a wide range of job experience from 0.5 to 33 years with an average of 11 years. At least one response was collected from students and academics in all seven Australian universities that offer a postgraduate audiology program (with the exception of students from Charles Darwin University, which commenced their program in 2022).

The industry partners were working in companies including HA manufacturers, an audiological equipment provider, and a CI manufacturer. Of the six industry partners, there were two managers, two product specialists, one teleaudiologist, and one customer support specialist and trainer. Four of them had been working in their positions for less than 2 years, while the other two had 8 and 23 years of job experience, respectively.

3.6.2 Knowledge of teleaudiology

Fifty-five percent of clients and over 90% of clinicians, students, academics, and industry partners understood what teleaudiology was and were able to provide some description. All stakeholder groups were asked to define teleaudiology in an open-ended question. Thematic analysis (Graneheim & Lundman, 2004) was conducted on the open-ended responses. Combined themes and subthemes of all stakeholder groups' description of teleaudiology are shown in Table 3.2. Across all stakeholder groups, results suggested that the greatest number of subthemes were found for the group of clinician respondents. All groups were able to describe teleaudiology as a remote means to deliver audiology services with the use of ICT. Examples of technology mentioned by clients, clinicians, students, and academics included smartphone and videoconferencing interfaces used to provide services, such as aural rehabilitation and counselling. Benefits of teleaudiology were noted by clinicians and students, particularly related to improved accessibility, whereas drawbacks of teleaudiology were noted by clients and clinicians, including limitations in technology and client's digital literacy. Among all stakeholder groups, only a small portion of clients (*n* = 12) expressed that they barely knew what teleaudiology was because they simply had not heard of it before.

Table 3.2 Combined themes and subthemes of all stakeholder groups' understanding of teleaudiology.

Themes	Subthemes	Clients	Clinicians	Students	Academics	Industry partners	Count of meaning units	Respondents' quotes
Means of delivery	Use of ICT	✓	✓	✓	✓	✓	199	"An opportunity to receive hearing health care via electronic means" (Female, 73 years, client)
	Remote delivery	✓	✓	✓	✓	✓	176	"A means to offer audiological services in a way that does not require the patient and audiologist to be in either the same room or at the same time as each other" (Male, 29 years, industry partner)
	Examples of technology	✓	✓	✓	✓		99	"Remotely accessing audiology services using electronic communication such as videoconferencing" (Male, 50 years, client) "Teleaudiology is the way which a client may reach audiological services via internet, phone, smartphone, etc." (Male, 38 years, student)
	Examples of service	✓	✓	✓	✓		36	"Providing services like rehabilitation, treatment, counselling, hearing aid adjustments online" (Male, 50 years, clinician)
	Synchronous/asynchronous mode		✓		✓		7	"Examples include synchronous appointments with clients (video or phone), remote programming of devices using cloud-based software, asynchronous assessments or data collection like online patient questionnaires" (Female, 33 years, academic)
Pros and cons	Benefits		✓	✓			10	"Being able to deliver services to clients outside of a face-to-face environment to improve timeliness, access to and quality of care" (Female, 37 years, clinician) "I believe it is making audiological services more accessible to patients who might live in rural or remote locations, or patients who may have a debilitating illness or have COVID or other contagious illnesses. This helps not only the patients to access healthcare, but for passionate clinicians to be able to provide this support to those who really need it and aren't being able to receive it due to certain factors." (Female, 21 years, student)

	Negative perceptions	✓	✓	4	"It has not been a great experience over the phone. Would rather (choose) face-to-face unless the latter (teleaudiology) was improved." (Male, 59 years, client) "Frustration - elderly clients that aren't digitally literate, poor internet services in regional areas. It has potential to work well, but in reality, not yet." (Female, 44 years, clinician)
	Client/family-centred care		✓	2	"The ability to deliver audiological services via telephone or video conferencing, where clinically appropriate to ensure best practice is deliver in a patient and family centred care model" (Female, 53 years, clinician)
	An adjunct to conventional service delivery		✓	1	"Teleaudiology does not substitute the need for face-to-face (services) but allows an alternative communication/ rehabilitation method for those clients whom may live with difficulties with attending an office for many reasons such as rural/remote areas, mobility disabilities or other commitments" (Male, 55 years, clinician)
Little understanding	No/limited knowledge	✓		12	"Haven't heard of it before" (Female, 61 years, client)

Note. Checks represent as suggested by that stakeholder group.

Students were able to list a wide range of services, which could be delivered via teleaudiology. The most mentioned services were HA finetuning and troubleshooting, counselling and education, and case history taking. Other examples included diagnostic assessments including otoscopy, audiometry, tympanometry and acoustic immittance, HA follow-up appointments, hearing needs and device discussion, hearing screening, HA fitting, tinnitus management, aural rehabilitation, auditory evoked potential testing, and CI mapping.

3.6.3 Teleaudiology appointments

Experience in conducting teleaudiology appointments was shared by 85% of clinicians, and 65% of these clinicians conducted such appointments since the COVID-19 outbreak. The top three most provided services via teleaudiology were HA review and finetuning (26%); counselling on everyday communication strategies or auditory training programs (20%); and discussion on HA, CI, or other hearing device options (16%). The appointments were delivered mainly by phone call (31%), Internet- or smartphone-based apps (21%), and videoconferencing (21%). Involvement of third parties in the appointments was noted, and 72% of them were significant others, 16% were facilitators, 7% were clinicians in another discipline, and 4% were other clients such as in a group hearing rehabilitation program. Two-thirds of clinicians found third parties, including the significant others, facilitators, other clinicians, and other clients, improved the appointment experience, for example, “able to communicate key information to multiple family members, helped to improve clinician understanding of family dynamics and preferences” (clinician, female, 37). However, two clinicians thought that the third parties, including a significant other and a facilitator, worsened the experience as they “took over.” Service quality was reported to be similar to in-person appointments by 41% of clinicians, while 29% thought it slightly improved, and 19% thought it slightly worsened. Similarly, a majority of clinicians (59%) reported no change in their relationships or interactions with clients when teleaudiology appointments were conducted, while 22% and 9% thought it slightly improved and slightly worsened, respectively. Approximately 44% and 23% of clinicians would very likely and somewhat likely, respectively, continue conducting teleaudiology appointments, whereas 11% and 4% thought it was very unlikely and somewhat unlikely, respectively.

In contrast, a significantly lower proportion of clients attended teleaudiology appointments, as only 7% of clients reported doing so (comparing to 85% of clinicians who had conducted those appointments; $z = 13.17$, $p < .01$). The appointments mostly focussed on tinnitus management, HA review and finetuning, and hearing assessment. Out of those who did not attend teleaudiology appointments, 98% were not offered any and 85% of them would accept it if offered. Service quality was reported to be similar to in-person appointments by 45% of those who attended teleaudiology appointments (n = 11), while 27% thought it significantly worsened and 18% thought it significantly improved. With regard to clients' relationships or interactions with clinicians, 55% of clients noticed no change when appointments were conducted via teleaudiology, whereas 18% of clients thought the appointments slightly worsened relative to in-person appointments, and 18% of clients thought the appointments significantly improved relative to in-person appointments. Out of those who attended teleaudiology appointments (n = 11), around half would very unlikely continue having such appointments, whereas 27% felt neutral about it and 18% would very likely do it again.

The clients and clinicians were asked to provide open-ended responses on what they liked and disliked about teleaudiology appointments, as well as what factors would constitute an ideal teleaudiology appointment, and thematic analysis was conducted on the responses (Graneheim & Lundman, 2004). When the clients and clinicians were asked what they liked about the teleaudiology appointments, they both acknowledged the reduced need for travelling and increase in service accessibility, convenience, and time efficiency. Clinicians suggested other advantages including ease in conducting teleaudiology appointments, flexibility in arranging appointments, being able to troubleshoot in real-life situations instead of clinical setting (e.g., by finetuning the HA settings in real time tailored to the client's home environment and hearing needs in such environment), and cost effectiveness. On the other hand, both groups found communication difficulty and loss in personal interaction during the teleaudiology appointments unfavourable. Additionally, clinicians were unsatisfied with poor Internet connection, inadequate technology and equipment, client's unfamiliarity with technology, and difficulty in inspecting ears and hearing devices. Both groups thought good Internet connection and reliable technology were essential for an ideal teleaudiology appointment. Clients appreciated supportive clinicians and want their health outcomes to be at least the same as in-person appointments. For clinicians, in order to have an ideal teleaudiology appointment, client's familiarity with technology, adequate planning and preparation beforehand, support from other parties (e.g., facilitators), visual aids and captions, and client acceptance are important as well. The aforementioned advantages and challenges of teleaudiology appointments and contributing factors to an ideal teleaudiology appointment are summarised in Figure 3.1.

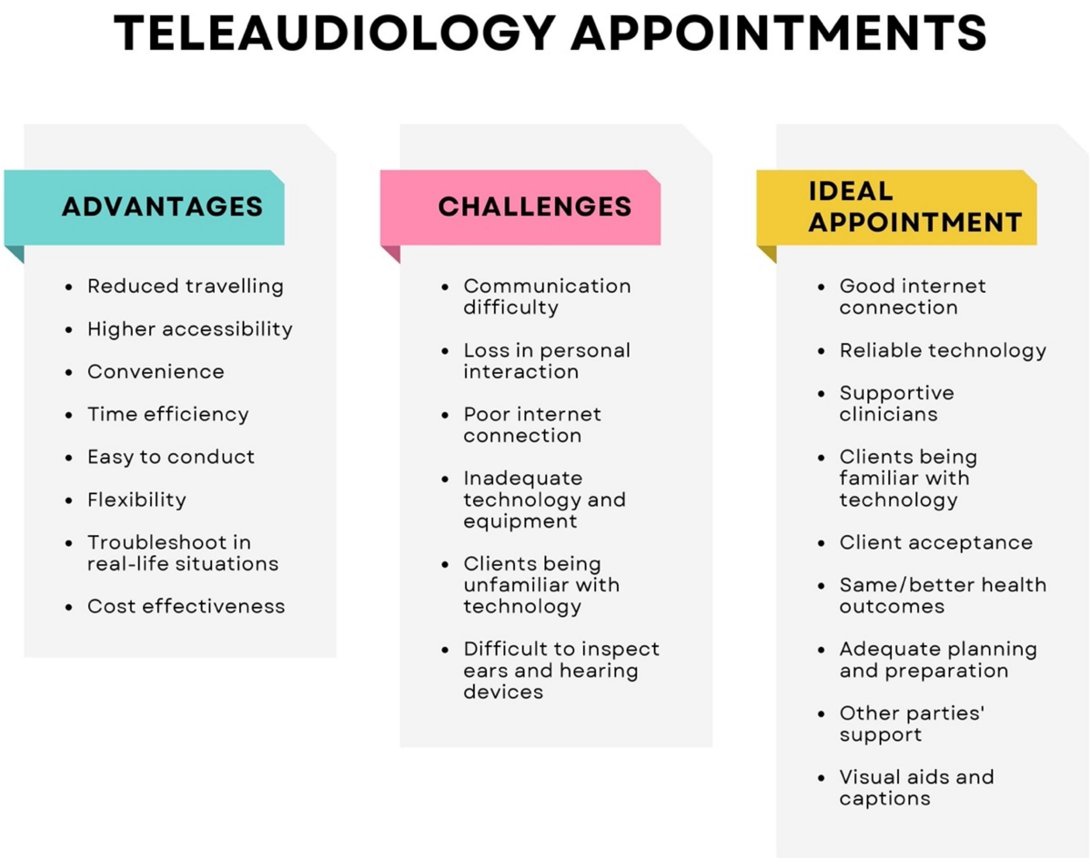


Figure 3.1 Advantages and challenges of teleaudiology appointments and factors constituting an ideal teleaudiology appointment as suggested by clients and clinicians.

Both clients and clinicians who had no experience in teleaudiology appointments were asked what factors hindered them from attending or providing such appointments. Table 3.3 summarised barriers to having teleaudiology appointments in which both groups thought that their personal preference for in-person appointments was the biggest barrier. Other major barriers to having teleaudiology appointments include client's unfamiliarity with technology, services they need or provide cannot be delivered online (e.g., taking ear impressions, paediatric hearing assessment), poor communication due to client's hearing impairment, and lack of suitable devices.

Table 3.3 Barriers to having teleaudiology appointments.

Barrier	Clients: *n* (%)	Clinicians: *n* (%)
Prefer in-person appointments	22 (39)	10 (19)
Client's unfamiliarity with technology	5 (9)	8 (15)
Client's hearing difficulty stops them from communicating well over the phone/online	5 (9)	/
Services I need/provide cannot be delivered online	5 (9)	8 (15)
Other	5 (9)	2 (4)
There is no need any more as lockdown has ended/social restrictions have been eased	4 (7)	5 (10)
Insufficient Internet connectivity	3 (5)	2 (4)
Lack of suitable devices (smartphone/tablet/computer)	2 (4)	6 (12)
Clinician's unfamiliarity with technology	2 (4)	3 (6)
Appointment not reimbursable	2 (4)	0 (0)
Unable to find service providers	1 (2)	/
Personal data security concern	1 (2)	3 (6)
No/limited training available	/	5 (10)

Note. Slashes indicate the barrier is not applicable to the corresponding group of respondents.

3.6.4 Teleaudiology apps

A great disparity was observed in the experience in using teleaudiology apps between clinicians and clients. Two-thirds of clinicians used apps developed for hearing assessment, HA finetuning, tinnitus management, noise monitor, and so forth as part of their service delivery, and 63% of clinicians used the apps only since the COVID-19 outbreak. The apps were mostly smartphone-based (49%) and computer-based (38%). The top three services those apps provided were HA finetuning (46%), tinnitus management (15%), and hearing screening (10%). Clinicians were generally positive about using teleaudiology apps in their service delivery in the future as 44% and 35% of them would very likely and somewhat likely, respectively, continue using the apps, while 50% and 28% of them would very likely and somewhat likely, respectively, continue recommending those apps to their clients.

Conversely, clients reported much less experience in using teleaudiology apps ($z = 6.69$, $p < .01$). Only 26% of clients used teleaudiology apps, and they mostly discovered those apps by searching on the Internet or app store (42%) and clinician’s suggestion (29%). A majority of apps the clients used were smartphone-based (65%) and computer-based (22%). Most of the clients accessed services including tinnitus management (32%), hearing screening (18%), hearing diagnostic test (18%), and HA finetuning (15%) through the apps. Clients were not as positive as clinicians regarding the use of teleaudiology apps in the future as shown in Table 3.4, $t(108) = 3.45$, $p < .01$, since 36% of clients were neutral about continuing using those apps, and 24% and 21% would somewhat likely and very likely, respectively, continue using them.

Table 3.4 Clients' and clinicians' attitudes towards continuing using teleaudiology apps in the future.

Response	Clients: *n* (%)	Clinicians: *n* (%)
Very unlikely (1 point)	5 (12)	3 (4)
Somewhat unlikely (2 points)	3 (7)	2 (3)
Neutral (3 points)	15 (36)	9 (13)
Somewhat likely (4 points)	10 (24)	24 (35)
Very likely (5 points)	9 (21)	30 (44)
Mean score	3.36	4.12

Open-ended responses were collected from the clients and clinicians on the most and the least desirable aspects of the teleaudiology apps they used, as well as what aspects would make an ideal teleaudiology app. The most mentioned desirable aspect of the apps by both clients and clinicians was their ease of use and user-friendliness. The two groups also reported the apps being able to achieve health outcomes, as a clinician said: "allows fitting/adjusting of aids remotely and whilst seeing the client" (clinician, male, 39). The convenience brought about by the apps, which allows flexibility around client's schedule, was suggested as "clients can use in their own time" (clinician, male, 41). Clients were satisfied since the apps could allow them to manage and adjust their hearing devices without much assistance from the clinicians, as a client explained: "They allow me to finetune hearing aids easily for my husband and myself" (client, female, 69). Other aspects such as smooth software operation, large range of app functionality, and messaging and videoconferencing functionality were also deemed favourable. It is nonetheless noteworthy that nine clients said they liked nothing about the apps. With regard to the unfavourable aspects of the apps, client's unfamiliarity with technology, poor Internet connection, and limited app functionality were clinicians' greatest concerns, as a clinician suggested: "found it limiting in comparison to what I could do in the centre" (clinician, female, 33). Clients were hesitant about the apps' low effectiveness and accuracy as well as limited functionality, as a client suggested: "the activity designed to minimise tinnitus did not work" (client, male, 53). Additional issues including some apps' complicated features rendering them difficult to use, poor compatibility with different smartphone models, and lack of personal touch were reported as well. For both clients and clinicians, an ideal teleaudiology app should have a good interface which makes it easy to navigate and an appropriate number of features, as a clinician explained: "not too many features as it confuses people" (clinician, female, 25). Good connectivity with hearing devices, ability to achieve health outcomes, clear instructions and data dashboard, and configurability are equally important, as a client explained: "with enough flexibility to finetune settings to the individual ear" (client, male, 36).

Table 3.5 outlined the factors hindering clients and clinicians from using teleaudiology apps. More than half of the clients were simply unaware of any teleaudiology apps and, therefore, did not access them. Some clients thought they did not have the need to use the apps, and they were unfamiliar with technology. From the clinicians' perspective, client's unfamiliarity with technology was the biggest barrier, and some of the clinicians were unaware of any teleaudiology apps, too. Poor Internet connectivity and their own unfamiliarity with technology also stopped the clinicians from including apps as part of their service delivery.

Table 3.5 Barriers to using teleaudiology apps.

Barrier	Clients: *n* (%)	Clinicians: *n* (%)
Unaware of any	92 (59)	8 (13)
Other	22 (14)	10 (16)
Client's unfamiliarity with technology	21 (14)	19 (31)
Insufficient research evidence to support their effectiveness	6 (4)	1 (2)
Lack of suitable devices (smartphone/tablet/computer)	5 (3)	6 (10)
Personal data security concern	5 (3)	3 (5)
Clinician's unfamiliarity with technology	3 (2)	7 (11)
Insufficient Internet connectivity	1 (1)	7 (11)

3.6.5 Learning and teaching teleaudiology

Students reported learning teleaudiology from lectures (26%), placements (24%), self-study (13%), clinical/practical sessions (9%), and tutorials (6%). It is notable that 12 students (21%) mentioned that they did not learn anything about teleaudiology. Learning teleaudiology has either positively influenced (78%) or did not change (22%) their perceptions of teleaudiology, as a student explained: "Initially I thought it would not work, but after seeing how efficiently we can make changes to lives, and in hearing aid software, I am more inclined to use teleaudiology if needed" (student, female, 23). As shown in Table 3.6, most of the students (60%) thought their universities only provided a limited amount of teaching/training on teleaudiology and 30% reported there was no such teaching/training at all. Over 60% of students agreed that it was important to learn teleaudiology during their study, whereas around 15% considered it unimportant. Seventy-four percent of students expressed interest in learning teleaudiology, and yet, 54% of them thought they were incompetent in teleaudiology.

Major barriers for allowing students to be more competent in teleaudiology included its omission from some curricula, low uptake rates among student placement clinics, reduced awareness of learning materials, and limited student placement opportunities. To motivate students to learn more about teleaudiology during their study, students agreed that it should be taught more often in class, and teleaudiology competency might need to become a requirement for program completion. Students also believed that through learning more about teleaudiology, it could increase future client satisfaction as well as students' competitiveness for employment.

Table 3.6 Amount of teaching/training about teleaudiology provided in the curriculum as reported by students and academics.

Response	Students: *n* (%)	Academics: *n* (%)
A lot	1 (2)	1 (6)
Quite a lot	0 (0)	2 (12)
Fair amount	5 (9)	1 (6)
Limited amount	34 (60)	13 (76)
None at all	17 (30)	0 (0)

Inclusion of teleaudiology as part of the curriculum was reported by 79% of academics. Teleaudiology was taught in lectures (34%), placements (29%), practical sessions (18%), and tutorials (16%). Aspects of teleaudiology taught in the above occasions varied, ranging from clinical skills, such as conducting teleaudiology appointments and using an interactive video platform, to theoretical knowledge, such as the strengths and weaknesses, facilitators and barriers, and infrastructure of teleaudiology. All academics exhibited interest in teaching teleaudiology as 53% of them were very interested, while 47% were slightly interested. Academics were generally confident in teaching teleaudiology, with 53% of them being slightly confident and 29% very confident. Forty-seven percent of academics reported that their teams invited industry partners to provide teleaudiology training for students. Six (32%) academics reported that industry partners trained the students on using their programs for remote HA programming and finetuning. Three (16%) academics reported that industry partners also provided the students an overview of the history and research evidence of teleaudiology and demonstrated how to use their company's diagnostic equipment in teleaudiology setting. Despite the inclusion of teleaudiology in the curriculum, 76% of academics thought it was only taught to a limited extent, as shown in Table 3.6.

For those academics whose curriculum did not include teleaudiology, they suggested the reasons behind the omission of teleaudiology from the curriculum were insufficient teaching materials available (33%), teleaudiology was less important in clinical settings (17%), all staff were busy with other work duties (17%), and there was a lack of national standards for practice (17%). Inclusion of teleaudiology in the curriculum was considered important by 82% and unimportant by 18% of academics. Academics answered open-ended questions on the things that could be done to better incorporate teleaudiology in the curriculum and to motivate students to learn about teleaudiology. In order to better incorporate teleaudiology in the curriculum and motivate students to learn about it, academics suggested that more learning opportunities should be provided via placements and practical sessions, as an academic suggested: "classes having hands-on experience with other students role-playing as a remote client" (academic, male, 27). Academics also thought it was pivotal to review current curriculum structure and secure more funding to increase staffing and resources. One academic would like to see teleaudiology education to be mandated by professional body, and five academics would welcome greater uptake of teleaudiology in clinical practice, as explained: "Greater adoption of teleaudiology in their clinical placements will allow exposure to the procedures and skills required" (academic, female, 33). In addition, assessment of teleaudiology competencies was suggested by academics since 80% of academics reported that such competencies were not assessed upon course completion.

3.6.6 Providing teleaudiology products and support

Industry partners reported that their companies provided various types of teleaudiology products, including equipment and apps for hearing screening, diagnostic assessments, and tinnitus management. Other teleaudiology products included HAs and assistive listening devices, which could be fitted and finetuned remotely, and their associated apps. Industry partners also provided apps for fitting and finetuning CIs, as well as for scheduling teleaudiology appointments. Three industry partners provided teleaudiology product support to clinicians sometimes. Two industry partners provided teleaudiology support to clinicians frequently, while one industry partner seldom did so. All industry partners were very confident in training clinicians to use teleaudiology products.

Industry partners responded to open-ended questions on clinicians' positive and negative feedback on the teleaudiology products provided by industry partners. All industry partners received predominantly positive feedback from clinicians on their companies' teleaudiology products. A manager from an audiological equipment provider mentioned that "feedback (was) very positive as (the equipment is) easy to use and extremely portable" (industry partner, male, 61), while another manager from an HA manufacturer reported that one of their HA models was "very easy to set up for both clinician and client, does not take up much time, do not need to be tech-savvy" (industry partner, female, 26). However, the same HA manufacturer manager reported that the aforementioned HA model also received negative feedback from clinicians, such as "not enough parameters that can be adjusted via a remote adjustment, cannot do a hearing test remotely, cannot perform a remote adjustment if the client's phone is not compatible with the appropriate app" (industry partner, female, 26).

All but one industry partner had never been invited to teach/train students on teleaudiology. Four of the industry partners were interested in teaching/training students if invited, and they expressed high confidence in doing so. When the industry partners were asked to give open-ended responses on the things that could be done to improve teleaudiology product promotion and clinical uptake, they suggested providing more training and demonstration, policy changes (e.g., making teleaudiology an approved means of providing services under Hearing Services Program (HSP), National Disability Insurance Scheme, Department of Veterans' Affairs, etc.), reimbursement guidelines, and organisational changes.

3.6.7 Perceptions of teleaudiology

Clinicians were predominantly confident in providing quality teleaudiology services, as approximately 60% expressed confidence, 25% lacked confidence, and 15% were neither confident nor unconfident. Clinicians' perceptions of client acceptance towards teleaudiology services were mixed, with 30% thinking their clients were slightly accepting and 19% slightly reluctant, 25% neutral, 14% very accepting, and 12% very reluctant. Regarding the training and support clinicians received from their clinics, 44% of clinicians reported that it was a limited amount, 33% reported a fair amount, 12% reported plenty, and 12% reported none at all. Similarly, 38% of clinicians said that they received a limited amount of support from the companies that provided teleaudiology products, 38% had a fair amount, 13% had plenty, and the remaining 12% had none.

Clients, clinicians, and industry partners were asked how much they agreed with the statement "I think teleaudiology services/apps should be promoted and used more often," and the findings are displayed in Table 3.7. Compared to clinicians, $t(270) = 2.77$, $p <. 01$, and industry partners, $t(173) = 2.8$, $p <. 01$, clients held more reserved attitudes towards widespread implementation of teleaudiology in the future. Forty-three percent of clients had neutral feeling about the statement, while 49% agreed and 9% disagreed. As for clinicians, only 21% were neutral about the statement, whereas 70% agreed and 9% disagreed. All industry partners agreed with the statement. Clients, clinicians, and industry partners were also asked to provide reasons of agreeing or disagreeing with the statement in an open-ended question. For the clients, clinicians, and industry partners who supported teleaudiology promotion and use, reduced travelling and increased service accessibility were the biggest reasons. Some clients suggested teleaudiology might potentially raise hearing health awareness, as a client explained: "I think we 'drift' into poor hearing health without noticing deterioration over time. Promotion of teleaudiology services/apps might prompt people like me into taking some action" (client, male, 62). Other supporting reasons included the provision of client-centred care, convenience, time efficiency, and believing that teleaudiology is the future of audiology. For the clients who were hesitant about teleaudiology promotion and use, they believed in-person services were superior to remote services and some clients found remote communication strenuous. Low client acceptance, lack of personal interaction, and inadequate technology and equipment were also mentioned as limitations by clients and clinicians who did not support teleaudiology implementation.

Table 3.7 Number of clients, clinicians, and industry partners agreeing with the statement "I think teleaudiology services/apps should be promoted and used more often."

Response	Clients: *n* (%)	Clinicians: *n* (%)	Industry partners: *n* (%)
Strongly agree	42 (25)	36 (35)	5 (83)
Slightly agree	40 (24)	36 (35)	1 (17)
Neutral	72 (43)	22 (21)	0 (0)
Slightly disagree	3 (2)	6 (6)	0 (0)
Strongly disagree	12 (7)	3 (3)	0 (0)

3.7 Discussion

The aim of this study was to investigate the perceptions of Australian-based hearing healthcare stakeholders including clients, clinicians, students, academics, and industry partners on teleaudiology and to inform future teleaudiology implementation taking their opinions into consideration. Overall, clients had less experience in teleaudiology than other stakeholder groups, as reflected by the small percentage of clients who attended teleaudiology appointments (7%) and used teleaudiology apps (26%). This is consistent with the findings from the 2020 National Teleaudiology Survey conducted by Audiology Australia (Bennett & Campbell, 2021). Their survey collected 746 responses from Australian-based clients, clinicians, clinic owners/managers, and administration staff in the midst of the COVID-19 pandemic (April to October 2020). Of the 246 clients, only 2% attended teleaudiology appointments, and 2% attended both teleaudiology and in-person appointments, despite nationwide lockdown restrictions. Bennett and Campbell (2021) also found that 74% of clients were not offered any teleaudiology appointments, whereas the current study revealed an even higher percentage (98%). It is nevertheless noteworthy that this finding requires caution when interpreting, since some clients in the current study experienced tinnitus only. They might not realise the need to consult an audiologist and might not be receiving any audiology service. Therefore, those clients might not have sought any in-person appointment, let alone teleaudiology appointments. Meanwhile, in the study by Bennett and Campbell (2021), all of the clients were receiving audiology services in community settings, and therefore, might have greater chances to be offered teleaudiology appointments when lockdown restrictions were in place.

Raising awareness of teleaudiology services may facilitate usage as clients will be able to recognise remote options of receiving hearing care whenever in-person services are inaccessible. All stakeholders share an equally important role in increasing awareness and uptake of teleaudiology services. For example, audiology clinics and clinicians are a frequent point of contact for clients who seek audiology services, and thus, they are in the best position to inform clients of available teleaudiology options. Industry partners may increase their market promotion to boost the usage of their teleaudiology products, as reflected by the fact that more than half of the clients in this study did not access teleaudiology apps simply because they were unaware of any. Additionally, continuous government funding is vital in supporting teleaudiology implementation and reimbursements. As suggested by Bennett, Kelsall-Foreman, et al. (2022b), increased use of teleaudiology in Australia during the COVID-19 pandemic could potentially be attributed to pandemic-related factors, such as increased government funding for teleaudiology services. It is nonetheless noteworthy that reimbursement may differ across countries and service models. For example, the Australian government only funds certain services, such as hearing device fitting, follow-up of fitting, client review, and aural rehabilitation, to be delivered via teleaudiology (Australian Government Department of Health and Aged Care, 2022a). On the other hand, services such as diagnostic hearing assessment and tinnitus assessment performed via teleaudiology are payable through Medicare in the USA (Jilla, 2021). Furthermore, only teleaudiology services delivered using a synchronous model are reimbursable through Medicare in the USA; that is, asynchronous teleaudiology services are not payable by Medicare (Jilla, 2021). To maintain the incentives for hearing healthcare providers to deliver teleaudiology services, as well as for clients to receive hearing care via teleaudiology, the government needs to explore the possibility of continuing and expanding funding for teleaudiology services beyond the pandemic.

Interestingly, our study revealed that 85% of the clients who had no experience with teleaudiology appointments would try them if offered, and yet half of those who had such appointments (7% of clients) would very unlikely continue having them. This finding highlights the need to address existing drawbacks of teleaudiology appointments, such as communication difficulty and loss in personal interaction as suggested by clients and clinicians. Communication issues during teleaudiology appointments may be mitigated by adopting videoconferencing with live captioning instead of phone call. Involvement of a third party on the client’s side (e.g., significant other, facilitator) may also be helpful in repeating the clinician’s instructions and troubleshooting, as a clinician explained: “(the significant other) provided assistance when patient was unsure and unable to explain difficulties.”

We found that 85% of clinicians conducted teleaudiology appointments, which is higher than the 62% teleaudiology use rate reported by Eikelboom et al. (2022) during the pandemic but lower than the 98% uptake rate reported by Saunders and Roughley (2021). However, Eikelboom et al. (2022) reported that 80% of audiologists expected using teleaudiology after the pandemic, while Saunders and Roughley (2021) reported that 86% of audiologists would continue using teleaudiology even when restrictions are lifted. Our finding from almost 3 years since the pandemic outbreak is in line with the audiologists’ expectations of teleaudiology use when restrictions are lifted, as reported by Eikelboom et al. (2022) and Saunders and Roughley (2021). Sixty-one percent of clinicians in our study were confident in providing quality teleaudiology services and would likely continue delivering teleaudiology services. This finding is in line with literature reporting 58% of the Australian-based clinicians being confident in their knowledge and understanding of teleaudiology service delivery and highly motivated to provide teleaudiology services (Bennett, Kelsall-Foreman, et al., 2022a). Clinicians who reported to be less confident in providing quality teleaudiology services might have less experience in this type of service delivery, or have had unsatisfactory experience in the past deterring them from offering such services further. This highlights the needs for more teleaudiology training and support if clinicians' confidence is to be improved. Although 85% of the clinicians in our study provided teleaudiology appointments, there exists a significant lack of teleaudiology uptake among clients. This may be due to the fact that some clients were unaware of teleaudiology as a service option, or clinicians did not offer teleaudiology services at all. For example, a client mentioned that "this survey is the first time I have heard of teleaudiology" (client, male, 61). In order to improve teleaudiology uptake among clients, awareness needs to be raised among both clients and clinicians to promote that teleaudiology is an available option to deliver hearing healthcare services as a complement to in-person services.

Clients' unfamiliarity with technology was suggested by both clinicians and clients as one of the biggest barriers to conducting teleaudiology appointments or using teleaudiology apps. The findings from Singh et al. (2014) showed that clinicians considered older populations (65 years old or above) as less suitable to have teleaudiology appointments. Those clinicians' rationale was often based on the perception and observation of older populations being less technologically savvy, and therefore, more time and effort may be required to ensure smooth consultation. This presents an age bias from the clinicians. Even though computer and Internet skills and usage were reported to be lower in older adults (i.e., above 65 years of age) compared to younger adults, older adults with hearing difficulty might use computers and the Internet more frequently than normal-hearing individuals at the same age (Henshaw et al., 2012; Thoren et al., 2013). In fact, 59% of older adults aged 65 years or above and 88% of adults aged 50 to 64 years were reported to use the Internet (Tennant et al., 2015). However, digital proficiency is not a predictor of accessing teleaudiology services (Ratanjee-Vanmali et al., 2020a). Positive change in patient perceptions towards telemedicine after brief usage has been reported (Cranen et al., 2011); therefore, the authors of the current study postulate the same may be true for teleaudiology. Clinicians should be mindful not to be selective in providing teleaudiology services only to younger clients without surveying older clients about their preferences. Client-centred services should be offered with the emphasis of whichever mode of service delivery suits clients the best, be it teleaudiology, in-person, or a combination of both. With a gradual shift of client population from predominantly baby boomers to Generation X over the coming decades, clients' overall digital proficiency should improve and unfamiliarity with technology should become less of a barrier to teleaudiology uptake.

Although most of the students and academics in the current study indicated that it was important to include teleaudiology in the curriculum, 52% of students and 21% of academics reported that teleaudiology was not a part of their universities' curriculum. This difference may be attributed to the different backgrounds of students and academics surveyed, as they were from different universities. A bigger representation of either group from certain universities might have skewed the results. It is also possible that the understanding of teleaudiology education differed between the two groups. For example, the incorporation of teleaudiology in any teaching activities (such as clinical practice or placements) might be considered as the inclusion of teleaudiology in the curriculum by academics but not by students. Students might only regard teaching in the more traditional way (such as lectures) as inclusion in the curriculum. Australian universities have been reviewing and revising their curriculum to better integrate teleaudiology. Executing curriculum change may prove challenging, especially with insufficient resources, staffing, and funding. In order to better equip students for utilising teleaudiology in future employment, universities should explore the feasibility of expanding fundings and ensure sufficient staffing to facilitate the incorporation of teleaudiology in the current curriculum. Universities also rely on Audiology Australia for guidelines on what to include in the curriculum. Audiology Australia oversees the accreditation of audiology programs in all Australian universities, and teleaudiology has not been listed as an accreditation requirement. The accreditation standards do not list specific competency skills or teleaudiology placement hours required for program completion. This creates uncertainty on whether teleaudiology would be included in the curriculum at all. Audiology Australia may therefore consider stating teleaudiology competency as one of the accreditation requirements to ensure curriculum uniformity among universities, and students can obtain as much teleaudiology experience and skills as possible during their study. On the other hand, it is noteworthy that the inclusion of teleaudiology in the curriculum may be implemented at the expense of removing other important curriculum components. This challenge requires careful review and planning to ensure the best balance of components in the curriculum which can most benefit students.

Academics suggested that more teleaudiology experience should be provided via university clinics and placement clinics. This suggestion calls for action from clinicians and clinic managers/owners to further improve teleaudiology implementation in their clinical practice. Another approach which may familiarise students with teleaudiology is receiving training from industry partners. Some universities have been adopting this approach by inviting industry partners from HA manufacturers to demonstrate how to navigate their companies' apps in the process of remote HA programming. In this study, half of the academics had invited industry partners for education purposes, but five out of six industry partners never received such invitation. This may reflect some of the academics' distrust of the industry, or existing conflict of interest or ethical concerns which need to be considered and addressed. It is apparent that there is room for more collaboration between academics and industry partners to enrich students' learning experience and knowledge on teleaudiology. Most importantly, this nexus of ideas generated by students and academics to potentially make universities a better source of knowledge of teleaudiology highlights the importance of mutual inputs from and collaboration of all hearing healthcare stakeholders.

3.8 Limitations and future directions

This study has a few limitations. Firstly, the surveys used in this study were non-standardised, although a review process was in place to ensure the accuracy and clarity of questions. The internal validity of surveys was not assessed. Secondly, sampling bias was likely to exist since all surveys were available online and in English only. Individuals who were unfamiliar with technology or English language might have been excluded from this study. Another potential source of sampling bias was from the respondents themselves as those who were more interested in teleaudiology and keen to share their opinions might more likely respond. Individuals who were less interested in teleaudiology or without previous experience in using it might have self-selected themselves to not participate. Furthermore, generalisation of results to beyond Australia may be difficult as factors such as university curriculum structure, national standards for practice, funding, reimbursement, and public health policies may vary widely across countries. Similarly, given the differences in healthcare systems across countries, findings from the current study might not be completely comparable and applicable to previous studies conducted in other countries.

The number of responses from industry partners collected in this study is particularly low and thus should not be representative of all Australian-based industry partners. The same may apply to students and academics despite their relatively higher response numbers. To the authors' best knowledge, this study is the first survey study exploring the perceptions of students, academics, and industry partners towards teleaudiology. Further research with a larger sample size is required to more comprehensively delineate how these stakeholders view teleaudiology, as well as to report any changes in university curriculum, which will potentially affect students' and academics' perceptions towards and competence in teleaudiology. A sample with greater diversity such as cultural background and ethnicity will also enhance representation and generalisation and reduce bias. This study revealed that 45% of clients were unfamiliar with the concept of teleaudiology and therefore were unaware of available teleaudiology services. More effort should be invested in research and campaigns to identify the best means of promoting awareness of teleaudiology services so that such evidence-supported services can become more accessible to individuals with hearing needs. Additionally, as a continuation of this study, focus groups and semi-structured interviews of consenting respondents will be organised to collect more in-depth opinions with regard to teleaudiology uptake and experience. We recommend a similar exercise globally, which will ensure embedding hearing healthcare stakeholders' voices in research co-design and facilitating the implementation and acceptance of teleaudiology services.

3.9 Conclusions

This study revealed that Australian-based hearing healthcare clients shared low teleaudiology use and reserved attitudes towards widespread teleaudiology implementation. Other stakeholder groups including clinicians, students, academics, and industry partners reported generally positive attitudes towards teleaudiology use. For teleaudiology uptake to be improved among those who are interested and willing to try and use it, increasing awareness of teleaudiology services and collaboration between stakeholders are crucial.

CHAPTER 4 – DIGITAL THERAPEUTICS IN TINNITUS CARE: A FEASIBILITY STUDY OF THE OTO SMARTPHONE APPLICATION (STUDY 2)

4.1 Contribution to overall PhD aim

Because of the paucity of well-designed tinnitus smartphone app validation studies, there remained a significant research gap in the evidence on the effectiveness of tinnitus smartphone apps. Study 2 examined the feasibility of using a multi-modal app-delivered tinnitus intervention, the Oto app, which was developed in 2020, to alleviate tinnitus symptoms and distress. This study aimed to investigate the trial acceptability, deliverability, and effectiveness of utilising Oto for tinnitus management. This chapter aims to answer **research question 2** – What is the effectiveness and usability of Oto, a smartphone application for tinnitus management, in reducing tinnitus distress?

4.2 Statement of co-authorship and author contributions

This chapter contains materials from the manuscript under review as indicated below. The signed co-authorship approval form can be found in Appendix 1.

Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Digital therapeutics in tinnitus care: A feasibility study of the Oto smartphone application. *Journal of the American Academy of Audiology*.

B. Mui, J. Muzaffar, and G. S. Shekhawat were involved in the study conceptualisation and design. B. Mui recruited participants and conducted data collection. B. Mui and J. Muzaffar were involved in data analysis. B. Mui wrote the original draft of the manuscript and all co-authors were involved in reviewing the draft.

4.3 Abstract

Background: Tinnitus is a prevalent condition affecting approximately 14.4% of the global adult population. With growing mobile phone ownership and usage globally, the utilisation of smartphone apps as tinnitus interventions has garnered research and clinical interest. Despite the abundant number of commercially available tinnitus smartphone apps, a majority of them lack validation of their effectiveness.

Purpose: To investigate the feasibility of utilising a smartphone app (Oto) in tinnitus management as determined by trial acceptability, deliverability, and effectiveness.

Research design: A two-arm controlled trial design was adopted.

Study sample: Sixty-two adults with chronic tinnitus were randomised to either Oto user group or non-user (control) group.

Intervention: The multimodal Oto smartphone app which combines patient education, cognitive behavioural therapy (CBT), relaxation, mindfulness, and sound therapy was used by the Oto user group for three months.

Data collection and analysis: Participants completed the Tinnitus Functional Index (TFI) at baseline, 1 month, and 3 months. Oto user group rated Oto's ease of use and their satisfaction on a 5-point Likert scale and answered open-ended questions on user experience at 3 months. One-way repeated measures ANOVA was performed with Bonferroni correction.

Results: Overall retention rate (defined as completion of trial at 3 months) was 87%. Among Oto users, four (16%) had a clinically meaningful reduction (≥13 points) in the TFI score from baseline to 1 and 3 months, whereas four (14%) and two (7%) non-users met the same criterion at 1 and 3 months, respectively. Oto user group showed no significant difference in TFI scores between baseline, 1 month, and 3 months, whereas the non-user group showed a significant increase in the overall TFI scores from baseline to 1 month and 3 months, $F(2, 56) = 7.78$, $p = .001$. Oto users found Oto easy to use and appreciated app features such as diversely themed therapy sessions and sound library. Suggestions including adjusting the duration of therapy sessions and more structured habituation program were also noted for improving Oto.

Conclusions: Utilisation of Oto in managing tinnitus was demonstrated to be deliverable and feasible with a high retention rate. A large-scale RCT is currently underway to further evaluate Oto's effectiveness and app usability.

Keywords: Tinnitus; smartphone applications (apps); therapy; mobile health; teleaudiology

4.4 Introduction

Tinnitus is the phantom perception of sounds usually generated by aberrant neural activity in the auditory system when there is an absence of external acoustic stimuli (Baguley et al., 2013; De

Ridder et al., 2021). Tinnitus can manifest as various types of sounds, such as ringing, hissing, or buzzing (Langguth et al., 2013). It affects approximately 14.4% of the global adult population, prominently older adults (aged 65 years or above) with an estimated prevalence of 23.6% (Jarach et al., 2022). Among people with tinnitus, 2.3% indicate that they are severely impacted by tinnitus (Jarach et al., 2022). Tinnitus can be differentiated into objective and subjective tinnitus based on the presence of an internal sound source. Objective tinnitus can be attributed to a corresponding internal sound source, e.g., from muscular or vascular origin, and is audible by other individuals upon examination (Langguth et al., 2013). Subjective tinnitus, in contrast, does not involve any internal sound generated by the body, and is only audible by the individuals with tinnitus (Langguth et al., 2013). The association of tinnitus with comorbidities, such as depression, anxiety, sleep difficulties, concentration problems, and hearing difficulties, has been reported (Langguth, 2011).

While the search for a definitive tinnitus cure continues, numerous treatments have been devised to alleviate symptoms. Zenner et al. (2017) identified about 60 different treatment modalities such as counselling, CBT, sound therapy, oral supplements and medications, tinnitus retraining therapy (TRT), hearing amplification devices, and electromagnetic stimulation. The heterogeneous nature of tinnitus means that the effectiveness of these treatments can vary from person to person. CBT stands out as one of the most evidence-supported and effective treatments for tinnitus (Soni & Dubey, 2020). CBT aims to identify and modify negative thoughts and emotions associated with tinnitus and as a result, individuals can habituate to their tinnitus with reduced impact on quality of life (Fuller et al., 2020). A systematic review of clinical guidelines for tinnitus treatment suggests a consensus in using CBT and HAs to improve psychological wellbeing and address hearing impairment, respectively (Fuller et al., 2017). Access to in-person CBT for tinnitus can be challenging due to cost, time, and location constraints, prompting researchers to explore digital tools for tinnitus management and care (Trochidis et al., 2021).

The possibilities of utilising digital tools to improve access to tinnitus management and care have garnered interest. In a systematic review, Demoen et al. (2023) identified 29 studies evaluating the effectiveness of telerehabilitation interventions for tinnitus. Such interventions were categorised into six forms, namely ICBT with guidance, ICBT without guidance, self-help manuals, self-help devices, smartphone apps, and other Internet-based interventions (Demoen et al., 2023). With a growth in mobile phone ownership and usage globally, there has been a surge in tinnitus-related smartphone apps (Deshpande & Shimunova, 2019). A search for tinnitus apps in three prominent mobile phone app stores (Apple iOS, Google Android, and Windows) revealed over 200 apps, which included free and paid versions (Deshpande & Shimunova, 2019). However, only a fraction of these apps has its effectiveness backed by empirical evidence. Specifically, only 12 validation studies were identified (Demoen et al., 2023; Mehdi, Dode, et al., 2020).

To address the discrepancy between the burgeoning market of smartphone apps and the lack of empirical validation of their use in tinnitus treatment, this study aims to investigate the feasibility of utilising a commercially available smartphone app (Oto) in tinnitus management using a two-arm controlled trial design. Oto is a novel multimodal app-delivered approach to tinnitus combining patient education, CBT, relaxation, mindfulness, and sound therapy. This app is available for the iOS and Android systems. Oto is registered with the Medicines and Healthcare products Regulatory Agency (MRHA) in the UK as a Class 1 medical device. This study considered three crucial outcomes relevant to translation: trial acceptability, deliverability, and effectiveness.

4.5 Methods

4.5.1 Ethics approval

This study was approved by the Flinders University Human Research Ethics Committee prior to data collection (Project ID: 5612). This study was registered in the Australian New Zealand Clinical Trials Registry (ANZCTR) retrospectively (Registration number: ACTRN12623001145695).

4.5.2 App features

All app features in Oto are dispersed across three screens, namely the *Home* screen, *Explore* screen, and *Sounds* screen as shown in Figure 4.1. On the *Home* screen, a tinnitus habituation program consisting of 52 recorded therapy sessions is displayed. Although progress through the therapy sessions is self-paced, a suggested timescale is provided in the app. The habituation program is set to last 27 days, with one to three therapy sessions allocated to each day. These sessions span multiple modalities, such as CBT, Acceptance and Commitment Therapy (ACT), visualisation, relaxation, and mindfulness. ACT helps the user to accept and gain control over negative emotions through exercises which illustrate that negative thoughts are less powerful and important than believed, whereas visualisation involves creation of a mental image of tinnitus to help control the reaction to it.

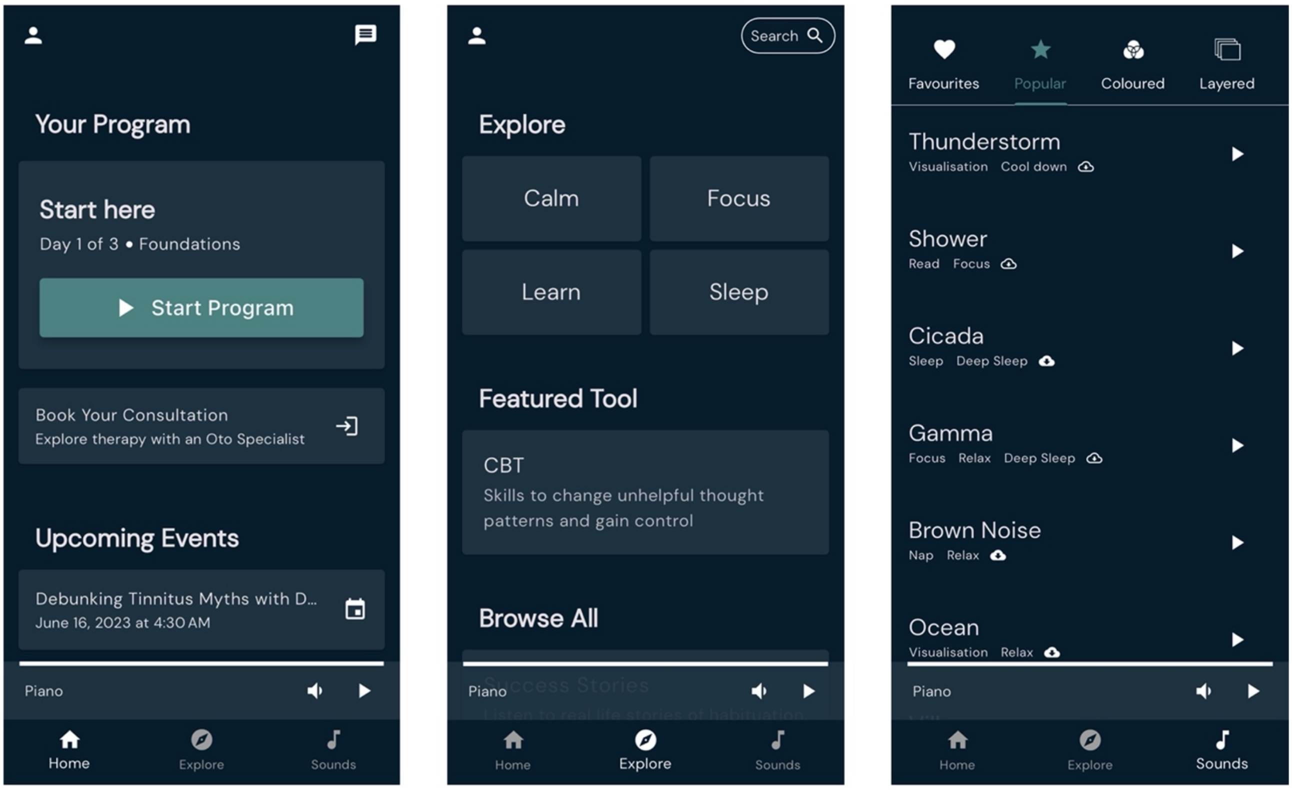


Figure 4.1 Screenshots of Oto.

The *Explore* screen showcases the entire collection of therapy sessions (100 sessions) in the app. All sessions are categorised by specific therapy goals, including “Calm”, “Focus”, “Learn”, and “Sleep”. For example, sessions about physical relaxation and breathing control are included in the “Calm” section. The “Focus” section guides app users through stress management and visualisation. The “Learn” section offers CBT sessions and success stories of how individuals with tinnitus habituate to their tinnitus, whereas the “Sleep” section includes sleep stories, stretching guide, and mindfulness practices.

A library of 98 sounds can be found on the sounds screen. The sounds are categorized into ten groups, such as coloured, urban, autonomous sensory meridian response (ASMR), and nature. All sounds can be played as a background sound while therapy sessions are played, or as a stand-alone sound for the purposes of diverting attention from tinnitus or facilitating sleep. In addition, a timer can be set to turn off the sounds automatically at a specific time if needed.

4.5.3 Participants

A total of 166 adults (≥18 years old) with self-reported chronic tinnitus (≥6 months) in South Australia were approached via email and social media. Only South Australian residents were included as participants were required to attend an appointment in person at baseline. An online participant information sheet and consent form was provided, detailing study details, eligibility criteria, withdrawal rights, confidentiality, data storage, ethics approval information, and consent statements. Sixty-three (38%) of the approached individuals completed the online consent form and were contacted to arrange the baseline appointment with our research team. One of the 63 consented individuals did not respond to our email for arranging the appointment and therefore, did not proceed to participate in this study. Individuals experiencing any type of tinnitus (objective or subjective) were included regardless of concomitant hearing impairment. Participants were required to have an iPhone or Android smartphone to install and use Oto if they were allocated to the Oto user group. Individuals were excluded from this study if they were undertaking another tinnitus intervention or awaiting surgical intervention for hearing or tinnitus. The non-user group was on a waiting list throughout the study period and received no tinnitus intervention.

4.5.4 Outcomes

The primary outcome in this study was the feasibility of utilising Oto in tinnitus management in terms of trial acceptability and deliverability. This was determined by recruitment success, retention, and dropouts.

The secondary outcomes were the change in tinnitus severity and distress from baseline to 1 month and 3 months, as well as app usability. Change in tinnitus severity and distress was measured using the Tinnitus Functional Index (TFI) (Meikle et al., 2012), a 25-item questionnaire which consists of eight subscales, namely intrusive, sense of control, cognitive, sleep, auditory, relaxation, quality of life, and emotional. A total score ranging from 0 to 100 can be calculated and a higher score indicates greater severity and distress. The developers of the TFI determined that a 13-point improvement could be considered clinically significant (Meikle et al., 2012). App usability was determined in terms of Oto’s ease of use, user satisfaction, and user experience. A 5-point Likert scale was used to rate Oto’s ease of use (1 is *very difficult*, 5 is *very easy*) and user satisfaction (1 is *very unsatisfied*, 5 is *very satisfied*), whereas open-ended questions (e.g., most useful app features, features to be improved) were employed to collect opinions on user experience.

4.5.5 Study design

A two-arm controlled trial design was employed. Participants were allocated into two groups, i.e., Oto user group and non-user (control) group, by a fixed sequence. Participants were alternatively allocated to the two groups based on their order of recruitment, that is, the first participant was allocated to the Oto user group, the second participant was allocated to the non-user group, and so on. Gender distribution, average age, hearing level, and tinnitus duration in both groups were checked after allocation to ensure similarity between groups. In the Oto user group, the participants were provided cost free access to Oto throughout the study period. In the non-user group, the participants were instructed not to install Oto or other smartphone apps for tinnitus and no free access to Oto was provided.

4.5.6 Procedures

The participant journey throughout the current study is visualised in Figure 4.2. Both groups of participants were seen by the research team at baseline for a hearing and tinnitus assessment. This assessment encompassed otoscopy, tympanometry, PTA, and tinnitus pitch and loudness matching. The Tinnitus Sample Case History Questionnaire (TSCHQ) (Langguth et al., 2007) was completed by participants to record their tinnitus characteristics. The TFI was completed by all participants at baseline as well to measure their initial tinnitus severity and negative impacts of tinnitus (see Appendix 7). Oto users were instructed to install Oto on their smartphones and granted cost free access to Oto for the entire study period. The research team provided these participants a brief explanation of app features. Oto users were reminded that the nature of Oto was self-guided and they could navigate the app at their own pace. At 1 month and 3 months, all participants were asked to complete the TFI again to measure any change in their tinnitus severity. At 3 months, Oto user group participants were also asked to rate Oto's ease of use ("Do you find Oto easy to use?") and their satisfaction ("Overall, how satisfied are you with Oto?") on a 5-point Likert scale. They also answered open-ended questions on user experience including "Which parts of Oto do you find most helpful?" and "Which parts of Oto need to be improved?".

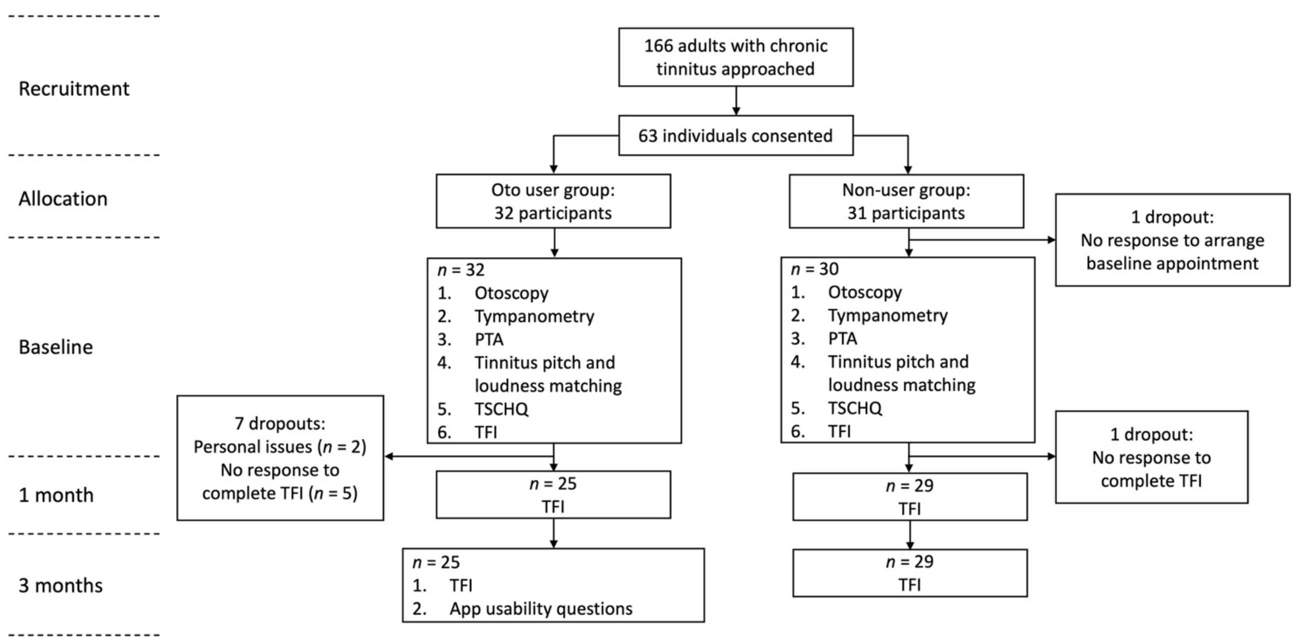


Figure 4.2 Flowchart of the participant journey. PTA = pure tone audiometry; TFI = Tinnitus Functional Index; TSCHQ = Tinnitus Sample Case History Questionnaire.

4.5.7 Data analysis

Eight out of 62 participants who opted out from this study before 1 month and therefore, did not complete the 1 month and 3 months TFI, were only included in data analysis partially (i.e., in participant characteristics and retention). IBM SPSS Statistics (Version 28) was employed for statistical analysis. Descriptive analysis, including mean and standard deviation, was conducted. Two-sample *t*-tests were performed to compare the means of participant characteristics (e.g., age, tinnitus duration) between the two groups. Normality of the data was checked by Shapiro-Wilk tests and Q-Q plots. Sphericity was examined using Mauchly's test and adjusted using Greenhouse-Geisser correction when sphericity had been violated. One-way repeated measures ANOVA was performed to determine any statistically significant differences in the TFI scores within each group from baseline to 1 month and 3 months. Due to multiple analyses using one-way repeated measures ANOVA, the *p*-value was adjusted to .003 to be considered as statistically significant via Bonferroni correction. *Post-hoc* Tukey's test was used to perform pairwise comparisons of TFI scores between baseline, 1 month, and 3 months. Relationships between app usage and continuous variables, such as age and change in TFI scores, were examined by visual inspection of scatterplots. For the app usage data which were not normally distributed, the differences in app usage between genders were compared using Mann-Whitney U test.

4.6 Results

4.6.1 Participant characteristics

A total of 62 Australian individuals with chronic tinnitus participated in this study, in which 32 were allocated to the Oto user group and 30 were allocated to the non-user group. One consented individual was allocated to the non-user group before the baseline appointment but did not proceed to finalise the date for the appointment and therefore, did not participate in this study. Table 4.1 outlines the participant characteristics, including age, gender, hearing level, and tinnitus characteristics. The age of all participants ranged from 27 to 79 years with an average of 61 years (SD = 11). The numbers of female and male participants were approximately the same (32 females vs 30 males). The participants' air-conduction pure tone average ranged from -2 to 55 dB HL with a mean of 15 dB HL (SD = 11) in the left ear and ranged from -2 to 50 dB HL with a mean of 15 dB HL (SD = 11) in the right ear. The average pure tone audiograms of both groups are presented in Figure 4.3. Regarding their tinnitus characteristics, 65% of participants experienced non-pulsatile tinnitus whereas 36% experienced pulsatile tinnitus, in which 23% reported a tinnitus pulsating in synchronisation with heartbeat and 13% reported a tinnitus pulsating differently from heartbeat. Most of the participants (61%) perceived tinnitus in both ears, 24% perceived it in only one ear, and the remaining 15% reported that it was from inside the head. On average, the participants had been experiencing tinnitus for 18 years (SD = 13) with a range from one to 45 years. Two (6%) and three (10%) participants from the Oto user group and non-user group were hearing aid users, respectively. The Oto user group and non-user group were matched in terms of gender, $z = 0.20$, $p = .81$, age, $t(60) = -1.34$, $p = .19$, hearing level, left ear: $t(59) = -0.68$, $p = .50$, right ear: $t(59) = -0.94$, $p = .35$, and tinnitus duration, $t(52) = 0.41$, $p = .68$.

Table 4.1 Participant characteristics.

Characteristics	All participants (*N* = 62)	Oto user group (*n* = 32)	Non-user group (*n* = 30)
Age (mean ± *SD*; in years)	61 ± 11	60 ± 11	63 ± 10
Gender: *n* (%)			
Female	32 (52)	16 (50)	16 (53)
Male	30 (48)	16 (50)	14 (47)
AC pure tone average (mean ± *SD*; in dB HL)			
Left ear	15 ± 11	14 ± 11	16 ± 12
Right ear	15 ± 11	14 ± 9	17 ± 13
Pulsating nature of tinnitus: *n* (%)			
Pulsatile, with heartbeat	14 (23)	7 (22)	7 (23)
Pulsatile, different from heartbeat	8 (13)	4 (13)	4 (13)
Non-pulsatile	40 (65)	21 (66)	19 (63)
Location of tinnitus: *n* (%)			
One ear only	15 (24)	7 (22)	8 (27)
Both ears	38 (61)	21 (66)	17 (57)
Inside the head	9 (15)	4 (13)	5 (17)
Tinnitus duration (mean ± *SD*; in years)	18 ± 13	19 ± 14	18 ± 13
Hearing aid users: *n* (%)	5 (8)	2 (6)	3 (10)

Note: AC = Air conduction.

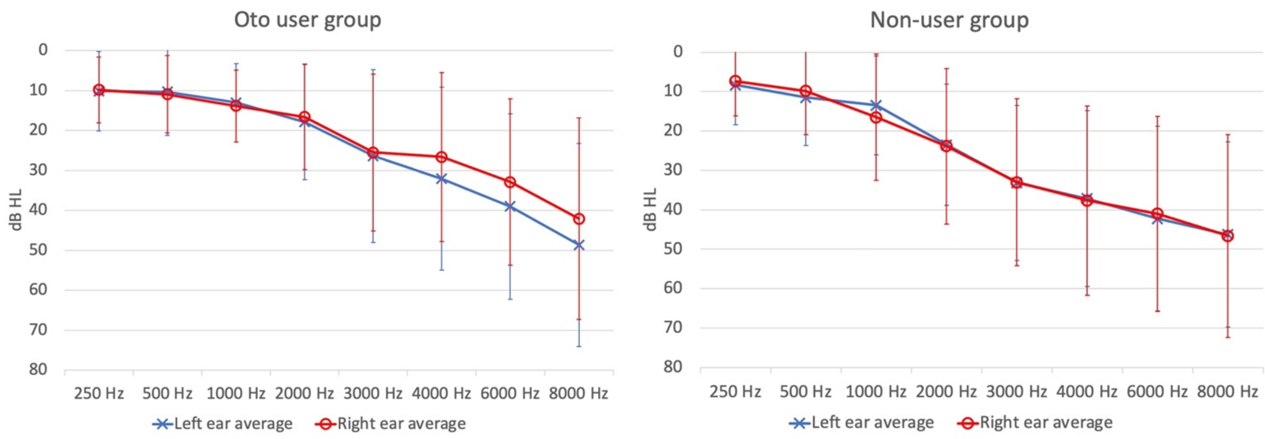


Figure 4.3 Average pure tone audiograms of the Oto user group (*n* = 32) and non-user group (*n* = 30). Error bar represents 1 *SD*.

4.6.2 Retention and dropouts

Overall retention is defined as completion of trial at 3 months, i.e., completion of the 3 months surveys. Out of the 62 participants recruited, eight (seven from Oto user group and one from non-user group) opted out from this study before the 1-month timepoint due to personal issues (Oto user group: *n* = 2) and non-response to questionnaire completion (Oto user group: *n* = 5; non-user group: *n* = 1). The overall dropout rate from baseline to 1 month was 13% (22% for Oto user group and 3% for non-user group), resulting in an overall retention rate of 87%. There was no further dropout from 1 month to 3 months.

4.6.3 Changes in tinnitus severity

Table 4.2 summarises the mean TFI overall and subscale scores and the repeated measures ANOVA results for both groups at baseline, 1 month, and 3 months. Progression of the TFI overall and subscale scores in both groups from baseline to 3 months is also displayed in Figure 4.4. On a group level, the Oto user group's mean overall TFI score increased marginally from 43 to 44 from baseline to 1 month and decreased to 42 at 3 months. For the intrusive and sense of control subscales, a gradual reduction of six and nine points, respectively, in the TFI scores from baseline to 3 months was observed, although the reduction was less than 13 points, which was defined as a clinically meaningful reduction by Meikle et al. (2012). A slight increase of four points was observed in the cognitive subscale from baseline to 3 months. As for the other five subscales (sleep, auditory, relaxation, quality of life, and emotional), the mean scores either increased or decreased from baseline to 1 month, then changed in the opposite direction (i.e., decreased or increased, respectively) from 1 month to 3 months. There was a slight decrease of four and one points in the sleep and auditory subscales, respectively; and a slight increase of one, three, and two points in the relaxation, quality of life, and emotional subscales, respectively, from baseline to 3 months. *Post-hoc* analyses after performing repeated measures ANOVA performed on the Oto user group's overall TFI and subscale scores revealed no significant difference between baseline, 1 month, and 3 months. On an individual level, a reduction in the overall TFI score from baseline to 1 month and 3 months was observed in 13 (52%) participants. Four out of those 13 (16% of Oto users) participants met the criterion for a clinically meaningful reduction, i.e., at least 13 points of reduction.

Table 4.2 Mean overall TFI and subscale scores of the Oto user group and non-user group and the corresponding repeated measures ANOVA results from baseline to 3 months.

TFI score (mean ± *SD*)	Oto user group			ANOVA	Non-user group			ANOVA
	Baseline	1 month	3 months		Baseline	1 month	3 months	
Overall TFI	43 ± 19	44 ± 22	42 ± 23	$F(2, 48) = 0.30$, $p = .74$	34 ± 17	42 ± 21	43 ± 24	$F(2, 56) = 7.78$, $p = .001$*
Subscales								
Intrusive	60 ± 22	58 ± 22	54 ± 25	$F(2, 48) = 1.29$, $p = .29$	49 ± 20	57 ± 23	55 ± 26	$F(2, 56) = 4.79$, $p = .01$
Sense of control	58 ± 24	52 ± 27	49 ± 26	$F(1.35, 32.39) = 2.68$, $p = .10$	49 ± 20	57 ± 21	52 ± 25	$F(2, 56) = 1.57$, $p = .22$
Cognitive	36 ± 21	37 ± 23	40 ± 27	$F(2, 48) = 0.57$, $p = .57$	28 ± 25	39 ± 27	36 ± 25	$F(2, 56) = 3.02$, $p = .06$
Sleep	40 ± 23	42 ± 25	36 ± 24	$F(1.60, 38.48) = 1.76$, $p = .19$	27 ± 23	28 ± 24	34 ± 29	$F(2, 56) = 3.17$, $p = .05$
Auditory	47 ± 29	37 ± 23	46 ± 30	$F(1.52, 36.46) = 2.11$, $p = .15$	33 ± 27	48 ± 31	53 ± 30	$F(2, 56) = 13.73$, $p < .001$*
Relaxation	49 ± 22	51 ± 26	50 ± 27	$F(2, 48) = 0.24$, $p = .79$	43 ± 24	49 ± 31	48 ± 31	$F(2, 56) = 1.52$, $p = .23$
Quality of life	29 ± 26	33 ± 27	32 ± 25	$F(2, 48) = 1.04$, $p = .36$	20 ± 20	30 ± 24	38 ± 26	$F(2, 56) = 17.23$, $p < .001$*
Emotional	31 ± 26	35 ± 28	33 ± 26	$F(1.51, 36.16) = 0.67$, $p = .48$	24 ± 20	30 ± 25	32 ± 26	$F(2, 56) = 2.83$, $p = .07$

Note. Asterisk denotes statistically significant result.

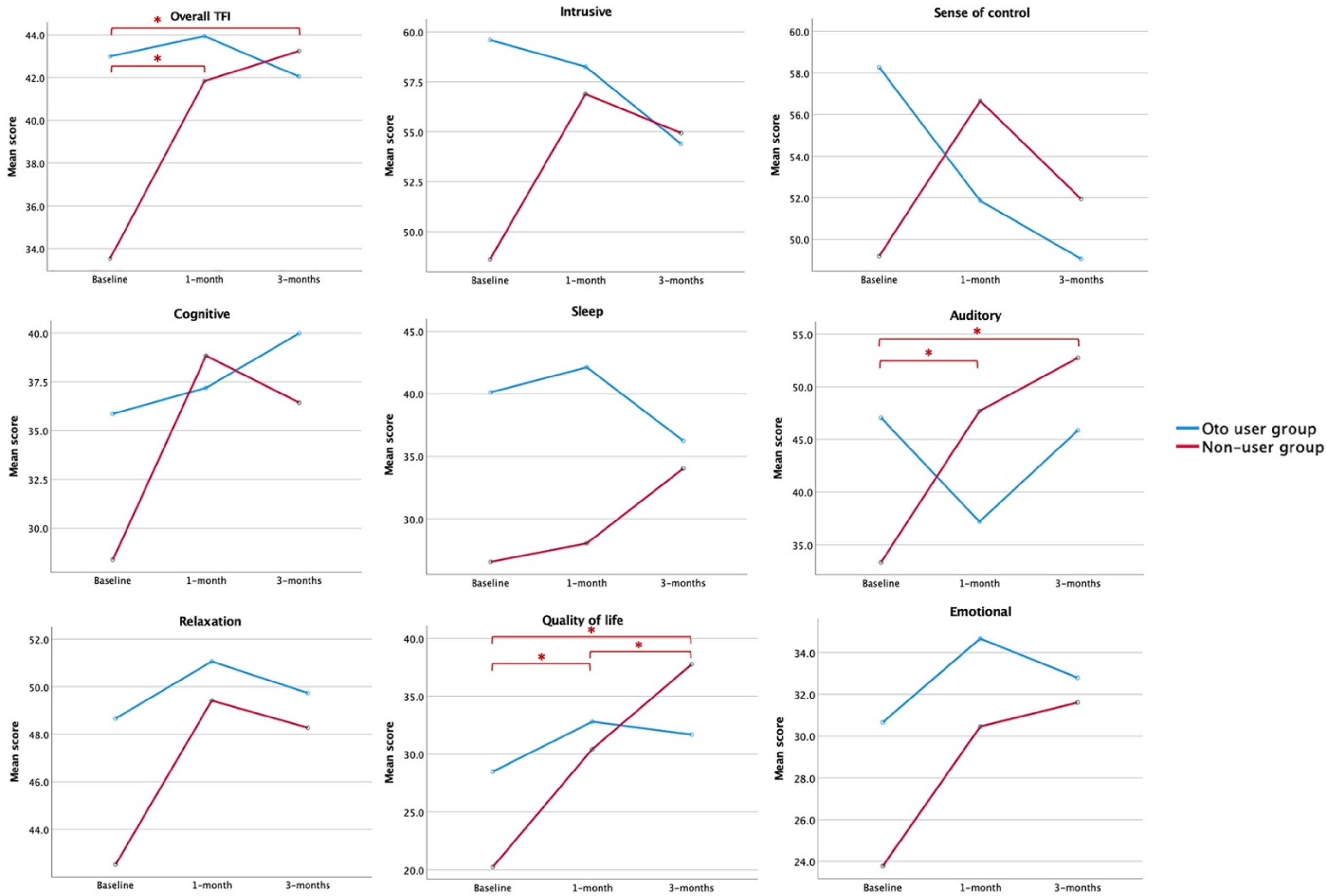


Figure 4.4 Progression of the overall TFI and subscale scores in the Oto user group and non-user group from baseline to 3 months. Asterisk denotes a statistically significant difference in the scores between the two timepoints in the non-user group.

Conversely, as a group collectively, the non-user group exhibited a steady increase in the overall TFI score from 34 to 43 from baseline to 3 months. An overall increase ranging from three to 20 points was also observed across all TFI subscales when comparing the 3 months scores to the baseline scores. For the sleep, auditory, quality of life, and emotional subscales, the TFI scores increased continuously during the study period, whereas the scores for the intrusive, sense of control, cognitive, and relaxation subscales first increased from baseline to 1 month, then decreased slightly at 3 months. Results from the *post-hoc* analyses after the repeated measures ANOVA indicated that there was a significant increase in the overall TFI, $F(2, 56) = 7.78$, $p = .001$, and auditory subscale scores, $F(2, 56) = 13.73$, $p < .001$, from baseline to 1 month and from baseline to 3 months, but the increase from 1 month to 3 months was insignificant. It was also revealed that the increase in the quality of life subscale scores from baseline to 1 month, 1 month to 3 months, and baseline to 3 months was significant, $F(2, 56) = 17.23$, $p < .001$. On an individual level, six (21%) of the 29 participants from the non-user group reported a reduction in their overall TFI scores from baseline to 1 month and 3 months. Of those six participants, four (14% of non-users) achieved a clinically meaningful reduction of at least 13 points from baseline to 1 month, and only two (7% of non-users) still met the same criterion at 3 months.

4.6.4 App usage

Data on app usage were extracted from the back end of Oto. All Oto users previously consented to the collection of app usage data on Oto's server. App usage was gauged by five parameters: 1) number of therapy sessions listened, 2) length of therapy sessions listened, 3) percentage of habituation program completed, 4) length of sounds played, and 5) total time spent in the app. App usage data from two Oto users were irretrievable and therefore, excluded from the analysis. App usage data from the remaining 23 Oto users are reported in Table 4.3. A great variation was observed in each of the five parameters among the Oto users, with some users barely having used certain app features at all, while others utilised the app to a substantial extent. On average, 45 therapy sessions (*SD* = 42; range: 2-133) and 151 minutes of therapy sessions (*SD* = 153; range: 0-619) were listened. Four Oto users listened to more than 100 therapy sessions (number of the entire collection of therapy sessions), implying that at least four users listened to some of the sessions repeatedly. Regarding the progress of completing the tinnitus habituation program which consists of 52 therapy sessions, Oto users completed an average of 46% of the program (*SD* = 35%; range: 0%-100%), in which three users completed the entire program. Another feature of Oto, the sound library, was accessed by the users with an average duration of 14 minutes (*SD* = 23; range: 0-83). Combining the usage of all features in Oto, the users spent 48 hours on average in the app (*SD* = 95; range: 0.06-408).

Table 4.3 App usage data from the Oto User Group (*n* = 23).

App usage	Mean	SD	Range
Number of therapy sessions listened (*n*)	45	42	2-133
Length of therapy sessions listened (minutes)	151	153	0-619
Percentage of habituation program completed (%)	46	35	0-100
Length of sounds played (minutes)	14	23	0-83
Total time spent in app (hours)	48	95	0.06-408

Relationships between the five app usage parameters and other variables, including age, gender, initial overall TFI score, and change in overall TFI score from baseline to 1 month and 3 months were examined. For continuous variables (age, initial overall TFI score, and change in overall TFI score), their relationships with each of the app usage parameters were investigated by visual inspection of scatterplots, and no clear relationship was found between any of the continuous variables and app usage parameters. To determine the differences in app usage between genders, Mann-Whitney U tests were performed on the app usage parameters which were not normally distributed (number of therapy sessions listened, length of therapy sessions listened, length of sounds played, and total time spent in the app), and two-sample *t*-test was performed on the app usage parameter which was normally distributed (percentage of habituation program completed). Mann-Whitney U tests revealed no significant difference in the number of therapy sessions listened, $U = 35.5$, $p = .06$, length of therapy sessions listened, $U = 35$, $p = .06$, length of sounds played, $U = 63$, $p = .85$, and total time spent in the app, $U = 54$, $p = .46$, between genders. However, female users (62% completion) were found to complete a significantly higher percentage of habituation program than male users (30% completion), $t(21) = 2.40$, $p = .03$.

4.6.5 App usability: ease of use, satisfaction, and user experience

In addition to measuring how participants' tinnitus severity changed and how much they used Oto in this study, users' feedback on app usability, including ease of use, satisfaction, and user experience, was also of interest. Oto users were asked "Do you find Oto easy to use?" and rated their responses on a 5-point Likert scale (1 is *very difficult*, 5 is *very easy*). Oto was deemed easy to use by 56% ($n = 14/25$) and difficult to use by 20% ($n = 5/25$) of Oto users. The remaining 24% ($n = 6/25$) of Oto users were neutral about the app's ease of use, resulting in a mean score of 3.7. Those users who reported Oto as easy to use had a significantly lower mean age (57 years) than those who reported it as difficult or neither easy nor difficult (66 years), $t(23) = 2.35$, $p = .03$. In addition, more female users rated Oto easy to use ($n = 9/14$; 64%) than difficult or neither easy nor difficult to use ($n = 4/11$; 36%).

Similarly, Oto users rated their satisfaction with Oto on a 5-point Likert scale (1 is *very unsatisfied*, 5 is *very satisfied*). An average score of 2.8 was reported, with 28% ($n = 7/25$), 44% ($n = 11/25$), and 28% ($n = 7/25$) of Oto users expressing satisfaction, neutral feeling, and dissatisfaction, respectively. Unlike the ease-of-use question, the mean age of those users who were satisfied with Oto (57 years) did not differ significantly from that of the users who felt dissatisfied or neutral (62 years), $t(23) = 1.16$, $p = .26$. Gender distribution was similar among satisfied users (female: $n = 4/7$; 57%) and dissatisfied/neutral users (female: $n = 9/18$; 50%) as well.

When being asked which parts of Oto the users found most helpful, the most mentioned app features ($n = 7$) were therapy sessions focusing on physical relaxation such as breathing and jaw exercises, and mindfulness sessions (e.g., calming and distraction techniques). Other helpful features included the sound library ($n = 3$), CBT-themed therapy sessions ($n = 2$), sessions providing explanation of tinnitus ($n = 2$), sleep stories ($n = 1$), and the ease of use ($n = 1$). On the other hand, Oto users made suggestions (yet two were contradictory) on how Oto could be improved, including adjusting the duration of therapy sessions (two users thought the sessions were too long, whereas one thought they were too short) ($n = 3$), more structured habituation program ($n = 1$), providing clear advice on how to revisit the exercises and form helpful behaviours ($n = 1$), changing the therapy sessions' emphasis on tinnitus (one user thought there was too much emphasis on tinnitus and their awareness to it was increased, whereas another user preferred the sessions to be more specific to tinnitus) ($n = 2$), cross-referencing other meditation programs ($n = 1$), and translation into another language ($n = 1$).

4.7 Discussion

This study aimed at investigating the feasibility of utilising Oto, a smartphone app, in tinnitus management in terms of therapy retention, effectiveness, and user experience of using Oto in reducing tinnitus symptoms and distress. Oto has only become commercially available since 2021 and this study is a feasibility study that was designed to underpin a larger-scale RCT that is currently underway. This study also complements the limited yet growing body of literature on the use of smartphone apps for tinnitus management.

This study showed that 16% of Oto users recorded a clinically meaningful reduction (≥13 points) on the TFI from baseline to 3 months, whereas 7% of non-users achieved the same improvement. More interestingly, no significant change was observed in the Oto user group's overall TFI and subscale scores from baseline to 3 months, whereas the non-user group reported a significant increase in the overall TFI and auditory and quality of life subscale scores from baseline to 3 months. There might be various factors contributing to such discrepancy between the participant groups. For example, participants' aroused attention to their tinnitus during the study might be one of those factors. All participants were prompted to complete the TFI at baseline, 1 month, and 3 months to monitor any changes in their tinnitus severity. While responding to the questionnaires, more attention and focus might be directed towards tinnitus perception and symptoms, as well as the impacts tinnitus made on the participants' everyday life. It is known that attentional focus can be crucial in modulating tinnitus experience. For instance, individuals with tinnitus could perceive worsened tinnitus by simply putting their mind on it, discussing it, or undergoing an experimental trial about tinnitus (Colagrosso et al., 2019). It is reasonable to speculate that over the course of the current study, the non-users might have been discussing this study or their tinnitus experiences more often with their families and friends, anticipating the questionnaires and paying more attention to the variations in tinnitus perception and symptoms as well as the associated emotional changes, or repeatedly thinking about participating in this study without receiving an intervention. All these actions could prompt the participants to notice the more subtle nuances and changes in their tinnitus and more easily provoke negative thoughts about tinnitus, and resurface the participants' tinnitus symptoms which were once kept under control by coping strategies such as diverting attention from tinnitus. This could in return be reflected by the increase in TFI scores in the non-user group. On the contrary, Oto users might have shared similar experiences of heightened attention towards tinnitus, but the use of Oto could have potentially provided some mitigation, resulting in relatively stabler TFI scores in the Oto user group than the non-user group over the course of three months.

Previous studies examining the effectiveness of smartphone apps as a means of tinnitus intervention, albeit with great variations in study design and outcome measures, demonstrated promising results. Chatterjee et al. (2021) conducted a controlled trial with one participant group undertaking TRT and another group undertaking mindfulness-based tinnitus stress reduction. Sound therapy delivered via the ReSound Tinnitus Relief app was administered as part of the TRT. Chatterjee et al. (2021) reported a significant reduction in the post-treatment Tinnitus Handicap Inventory (THI) and Tinnitus Cognitions Questionnaire (TCQ) scores in both participant groups. Another controlled trial by Abouzari et al. (2021) demonstrated a significantly greater improvement in THI scores in the treatment group which received sound therapy and CBT via a smartphone app than the control group which was placed on a waiting list. As for trials without a control group, Henry et al. (2017) reported that progressive tinnitus management (PTM) offered by the Tinnitus Coach app resulted in a clinically meaningful reduction (≥13 points) on TFI in 32% of participants. Effectiveness of the ReSound Tinnitus Relief app was further validated by Kutyba, Gos, et al. (2022) as tinnitus patients' THI and TFI scores dropped significantly from baseline to 3 months and 6 months, and Tyler et al. (2018) reported that three out of ten cochlear implant users found the app-delivered sound therapy at least 70% effective. Moreover, participants who underwent app-delivered tailor-made notched music therapy and Ginkgo biloba combined treatment for three months reported significantly improved THI scores (Kim et al., 2017). In another study examining a combined treatment of an acupressure device which applied soft pressure at different points around the ear, and a self-help app which taught participants coping strategies and tips for tinnitus management, participants' tinnitus loudness and stress significantly decreased after six weeks (Schlee et al., 2021). Results from the above studies may be difficult to compare or perhaps incomparable due to the differences in their study design and outcome measures. For example, it is difficult to determine whether studies without a control group (for example, Henry et al., 2017; Kutyba, Gos, et al., 2022; Tyler et al., 2018) truly demonstrated effectiveness of the tinnitus apps. The improvement of tinnitus severity and distress reported could have been spontaneous without comparison of people with equivalent clinical characteristics. A range of outcome measures was also employed in different studies, rendering comparisons of results across studies difficult. The same applies to the results from this study, although no significant improvement in the overall TFI score was reported in the Oto user group.

The current study attempted to address some of the limitations of previous studies on smartphone apps for tinnitus intervention. First of all, only three of the existing paucity of validation studies were controlled trials (Abouzari et al., 2021; Barozzi et al., 2016; Chatterjee et al., 2021). Different types of control groups were utilised, including a waiting list (Abouzari et al., 2021), sound therapy by streaming broadband noise from HAs (Barozzi et al., 2016), and mindfulness-based tinnitus stress reduction (Chatterjee et al., 2021). The current study included a control group which was on a waiting list and received no tinnitus intervention during the study period. Inclusion of a control group is deemed important as tinnitus symptoms may change spontaneously and without a comparison with a control group, it may appear equivocal to attribute the improvement in tinnitus severity observed in the intervention group solely to the intervention. Secondly, the dropout rate was often unreported in studies of similar kind. In the three tinnitus smartphone app studies which reported the dropout rate, it varied greatly and was reported to be 8% (Henry et al., 2017), 23% (Tyler et al., 2018), and 46% (Kutyba, Gos, et al., 2022). The dropout rates in other smartphone app trials were unreported, rendering it impossible to determine whether any dropout truly occurred. The overall dropout rate of the current study was 13%, with a 22% dropout in the Oto user group and 3% dropout in the non-user group. The dropout rates in this study were within expectation and coherent with the literature. Multiple factors could have contributed to the dropouts, for example, participants might be occupied by other commitments and unable to spend time on the app, they might have lost interest in the app, or the app might be unable to achieve expected effectiveness. Although it might be hard to pinpoint the reasons behind dropouts, qualitative user experience responses collected could potentially provide insights on this matter. For example, one participant suggested that a more structured habituation program could be offered and three participants suggested that the duration of some therapy sessions could be adjusted. By taking the app users' feedback into consideration and reviewing and modifying the app contents, user experience, satisfaction, and retention rate can potentially be improved.

A gender disparity was revealed regarding the percentage of tinnitus habituation program completed in this study, with female Oto users exhibiting a significantly higher percentage of program completion than male users (62% completion in females vs 30% completion in males). This finding aligns with the literature as females have been previously reported as more likely to search for health information online and utilise telehealth services (Escoffery, 2018; Kontos et al., 2014; Lindsay et al., 2022). It was suggested that this gender difference might be attributed to the greater use of social media in females and their role of health-care liaison for their families (Kontos et al., 2014).

4.7.1 Limitations

Limitations in the current study which should be noted are firstly, the two groups varied on the TFI scores at baseline. Measures of ensuring equivalent demographic features such as age and gender between groups were taken but it was more challenging to apply to the TFI scores due to participant recruitment constraints. This might have led to less comparable results between groups at the subsequent timepoints. This limitation was nonetheless rectified in Study 5 (Chapter 7) through stratification. Moreover, a majority of participants were from an older population and only one-third of participants were aged below 60 years. Despite the absence of relationship observed between app usage and age, it may not be appropriate to generalise such finding to the broader population of individuals with tinnitus as the participant sample presented in the current study may not be representative of younger individuals (e.g., below 40 years). Younger individuals may exhibit higher comfortability, confidence, and knowledge of using smartphone apps and therefore, respond to the app-delivered tinnitus therapy in a different fashion. Individuals with any type of tinnitus were included in this study due to challenges in participant recruitment. Given the heterogeneity of tinnitus, narrowing down the eligibility criteria to exclude certain types of tinnitus (e.g., unilateral, pulsatile) would have resulted in more homogeneous intervention and control groups, which could have better elucidated Oto's effectiveness. In a large-scale RCT which is underway in Australia, the eligibility criteria have been modified as suggested above to improve sample homogeneity. Research rigour may also be enhanced with a placebo control (e.g., provision of written information about tinnitus) rather than a waiting list control. By using such a control, the effectiveness of Oto can be more accurately determined with lower placebo effect. Furthermore, the follow-up period in the current study was relatively short, i.e., only three months. Any long-standing effects of Oto remained unknown and it would be of interest to investigate whether using Oto, especially the therapy sessions which introduce coping strategies, could provide long-term benefits to the users. The administration of the outcome measure (i.e., TFI) at only two timepoints since the baseline could also present as a potential limitation, as it only captured the participants' tinnitus severity on the day of questionnaire completion, or a maximum of one week prior as instructed by the TFI to recall their tinnitus symptoms in the previous week. Tinnitus perception can be affected by factors such as stress and anxiety, so hypothetically, if a participant had an extremely stressful time due to substantial life events before completing the TFI, the change in TFI score might not accurately reflect the actual effectiveness of Oto. In addition, the nature of this app-delivered tinnitus therapy was predominantly self-guided, which meant that it was not mandatory for participants to dedicate a minimum amount of time to Oto each day and we had no control over the participant's frequency and extent of app usage. This was also mirrored by the immense differences observed in app usage between participants. The inconsistency in app usage among participants was, however, revealed to have insignificant effect on how effective they found Oto, as no clear relationship was observed between app usage and change in overall TFI score.

4.7.2 Future directions

A large-scale nationwide RCT is underway in Australia. Changes in participants' tinnitus symptoms and Oto's effectiveness will be evaluated over a longer study time frame, i.e., nine months. To collect more in-depth and quality data on app usability, the mHealth App Usability Questionnaire (MAUQ) (Zhou et al., 2019), which is a validated questionnaire, will be employed to explore multiple aspects of app usability, including ease of use and satisfaction, system information arrangement, and usefulness. As a complement to the data collected using the MAUQ, a focus group will be organised to survey Oto users' experiences with using Oto and their suggestions on improving Oto. New app features (e.g., webinars) have been added to Oto since the current study and the upcoming RCT will also attempt to evaluate the usefulness and benefits of such features.

4.8 Conclusions

Utilisation of Oto in managing tinnitus was demonstrated to be deliverable and feasible with high retention rate. To explore the observed difference in treatment response between groups (i.e., non-users experienced worsened tinnitus while Oto users did not) and to contribute to the existing paucity of tinnitus smartphone app validation studies, a large-scale RCT is underway to evaluate Oto's effectiveness and usability.

4.9 Disclosure of interest statement

This study was funded by Flinders University and Oto Health Ltd. Boaz Mui (first author) is a current PhD candidate at Flinders University and his PhD is jointly funded by Flinders University and Oto Health Ltd. Jameel Muzaffar (second author) is the Chief Scientific Officer at Oto Health Ltd and he had no access to the participants or data.

CHAPTER 5 – AUSTRALIAN HEARING HEALTHCARE STAKEHOLDERS' EXPERIENCES OF AND ATTITUDES TOWARDS TELEAUDIOLOGY UPTAKE: A QUALITATIVE STUDY (STUDY 3)

5.1 Contribution to overall PhD aim

To provide further evidence on informing post-pandemic teleaudiology uptake, this study aimed at exploring the hearing healthcare stakeholders' perceptions towards teleaudiology from additional perspectives using a different research method, i.e., semi-structured interview. Therefore, this chapter also aims to answer **research question 1** – How is teleaudiology perceived by hearing healthcare stakeholders including the clients, clinicians, students, academics, and industry partners in Australia?

5.2 Statement of co-authorship and author contributions

This chapter contains materials from the publication indicated below. The signed co-authorship approval form can be found in Appendix 1.

Mui, B., Lawless, M., Timmer, B. H. B., Gopinath, B., Tang, D., Venning, A., May, D., Muzaffar, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Australian hearing healthcare stakeholders' experiences of and attitudes towards teleaudiology uptake: A qualitative study. *Speech, Language and Hearing*, 1-10. https://doi.org/10.1080/2050571X.2024.2372171

B. Mui and G. S. Shekhawat were involved in the study conceptualisation and design. B. Mui recruited participants and conducted all interviews. The initial interview guides were drafted by B. Mui and revised with feedback from all co-authors. B. Mui performed initial data coding and M. Lawless and D. Tang checked its accuracy. B. Mui performed the remaining data coding and wrote the original draft of the manuscript, and all co-authors were involved in reviewing the draft.

5.3 Abstract

Purpose: This study aimed to explore the experiences of Australian-based hearing healthcare stakeholders with using teleaudiology and their views on future teleaudiology uptake.

Method: Qualitative semi-structured interviews were conducted with 23 stakeholders (six clients, 10 clinicians, three students, two academics, and two industry partners).

Results: Six themes were generated: 1) Barriers to and facilitators of teleaudiology uptake, 2) Advantages and challenges of using teleaudiology, 3) Additional considerations when using teleaudiology, 4) Teleaudiology education at university, 5) Recent development in improving teleaudiology uptake, and 6) Attitudinal changes in post-pandemic teleaudiology uptake. Poor digital literacy and positive support received from other stakeholders were found to be the biggest barrier and facilitator, respectively. Additional considerations including the type of service offered and clear communication strategies were highlighted. Students and academics noted inadequate teleaudiology education at university, mainly due to a lack of infrastructure and equipment. Recent encouragement from management and improvement in university infrastructure were reported. Most participants were optimistic about post-pandemic teleaudiology uptake and expressed increased willingness to use teleaudiology over time.

Conclusions: Generally positive attitudes towards future teleaudiology uptake were observed. Gradually increasing collaborative effort was seen in improving teleaudiology uptake, yet certain challenges and barriers need to be addressed to further promote teleaudiology uptake in post-pandemic times.

Keywords: Teleaudiology; Australia; hearing healthcare stakeholders; experiences; attitudes

5.4 Introduction

Teleaudiology is a branch of telehealth or telemedicine in which hearing healthcare services are delivered remotely by means of digital communication and information technology when the client and clinician are in different geographic locations (Audiology Australia, 2020). Hearing healthcare services can be delivered via teleaudiology in a synchronous mode in which communication and exchange of medical information occur in real time, in an asynchronous mode in which patient data are saved and sent to clinicians for review at another time, or in a hybrid mode consisting of both synchronous and asynchronous service delivery (American Speech-Language-Hearing Association, n.d.-d). Delivery of various types of hearing healthcare services to children and adults via teleaudiology, including hearing screening, diagnostic audiometric testing, and audiological rehabilitation, has been shown to be feasible, reliable, and effective (Kim et al., 2021; Saunders, 2020a, 2020b). The nature of service delivery via teleaudiology enables easier and more immediate access to hearing healthcare in remote and rural populations which are often underserved (Mealings, Harkus, Flesher, et al., 2020; Swanepoel, Clark, et al., 2010). Teleaudiology is also thought to be able to reduce losses to follow-up, service wait times, travel time, and costs while maintaining quality of care (D'Onofrio & Zeng, 2021; Gajarawala & Pelkowski, 2021).

Despite recognising the potential benefits of teleaudiology, its uptake was slow prior to the COVID-19 pandemic. An international survey revealed that only 16% of audiologists had teleaudiology experience (Eikelboom & Swanepoel, 2016). Yet, hearing healthcare clinicians generally viewed teleaudiology positively and were open to its use if adequate training was provided (Eikelboom & Swanepoel, 2016; Ravi et al., 2018). The low adoption rates were attributable to lack of suitable technology and infrastructure (Ravi et al., 2018), limited availability of trained clinicians (Ramkumar et al., 2023), patient data confidentiality and privacy concerns (Bennett, Kelsall-Foreman, et al., 2022a; Ravi et al., 2018), licensure and reimbursement issues (Ramkumar et al., 2023; Ravi et al., 2018), and uncertainties about the reliability of remote audiometric testing (Bennett, Kelsall-Foreman, et al., 2022a). Moreover, some clinicians perceived teleaudiology as less suitable in certain contexts, for example, conducting diagnostic assessments or fitting hearing aids for first-time clients and children (Singh et al., 2014).

Since the onset of COVID-19 pandemic and the accompanying restrictions, there was a temporary surge in teleaudiology usage aimed at ensuring care continuity and sustaining businesses (Coco, 2020). An international survey of audiologists has shown an increase in teleaudiology uptake from 41% pre-pandemic to 62% during the pandemic, with expectation of further increase to 80% post-pandemic (Eikelboom et al., 2022). Similar trends were observed in country-specific surveys in the UK and Australia (Chong-White et al., 2023; Saunders & Roughley, 2021). The surge in teleaudiology uptake during the pandemic might be largely attributable to exogenous pandemic-related factors, such as the prioritisation of client and staff safety, availability of funding for teleaudiology services, and lockdowns prompting audiology clinics to explore alternative service delivery models to sustain their income, and as such it was suggested the surge might revert once the pandemic was over (Bennett, Kelsall-Foreman, et al., 2022b).

As the pandemic is over, understanding the perspectives, motivation, and challenges of teleaudiology users becomes crucial for its uptake in the post-pandemic landscape. Previous studies predominantly explored perceptions of hearing healthcare clients and clinicians towards teleaudiology uptake with minimal emphasis on other stakeholder groups. This study aimed to holistically explore teleaudiology's post-pandemic landscape by gathering insights from five groups of hearing healthcare stakeholders in Australia: clients, clinicians, students, academics, and industry partners. This study also sought to explore both barriers to and facilitators of teleaudiology uptake.

5.5 Materials and methods

The current study is an extension of a nationwide survey conducted in Australia from May to October 2022 (Mui et al., 2023). Consenting survey respondents who were hearing healthcare stakeholders (e.g., clients, clinicians, students, academics, and industry partners) were invited to participate in a semi-structured interview. Due to the qualitative nature of the current study, the Consolidated criteria for reporting qualitative studies (COREQ) (Tong et al., 2007) was employed to guide the reporting of various aspects of study design and data analysis (see Appendix 8 for completed COREQ checklist).

5.5.1 Ethics

Ethical approval was obtained from the Flinders University Human Research Ethics Committee before the commencement of data collection (Project ID: 2875).

5.5.2 Research team characteristics and relationship with participants

The first author (BM) conducted all of the 23 semi-structured interviews. BM had no prior experience in conducting semi-structured interviews but did undergo training provided by the second author (ML), who had extensive experience in conducting qualitative research, prior to commencement of this study. Relationships were established between BM and some participants prior to study commencement, e.g., clinicians whom BM knew through personal connections and students and academics from the same university where BM was undertaking his study. No prior relationship was otherwise established between BM and other participants. Prior to the interviews, participants were encouraged to express their opinions freely and their responses would be kept confidential. Participants with established relationships with BM shared both positive and negative opinions regarding teleaudiology use and therefore, we believed social desirability bias was insignificant. Information about the purposes and design of this study was provided to the participants in an online participant information sheet and consent form.

5.5.3 Study design

5.5.3.1 Theoretical framework

Grounded theory was utilised in this study to derive theories from systematic analysis of the data in an inductive approach (Chun Tie et al., 2019). Reflexive thematic analysis is a widely used analytic method in qualitative research which is useful in investigating the perspectives of different individuals on the topics of research interest as well as in identifying, describing, analysing, and reporting themes generated from a dataset (Braun & Clarke, 2019, 2021). For the purposes of gathering in-depth insights from multiple groups of hearing healthcare stakeholders in Australia on teleaudiology uptake without predetermined hypotheses, grounded theory and reflexive thematic analysis were selected to be the methodological orientation to underpin this study.

5.5.3.2 Interview guide development

Five interview guides were developed, with one for each stakeholder group (see Appendices 9-13 for the interview guides). The questions in the guides were crafted to explore stakeholders' experiences with using teleaudiology, their views on its future uptake, and facilitators of and barriers to its uptake. The interview guides were reviewed by all authors to check for appropriate wording, coherence, and comprehensive coverage of the study objectives.

5.5.3.3 Participant selection

Participants were recruited from an existing study conducted from May to October 2022 (Mui et al., 2023). This study involved completion of a survey to understand the perspectives of hearing healthcare stakeholders in Australia, including clients, clinicians, students, academics, and industry partners, on teleaudiology uptake. In this context, industry partners are defined as those offering audiology products, training, and after-sales services to hearing healthcare providers. The industry partner participants in this study were responsible for the provision of teleaudiology products, training, and after-sales services to clinicians and clinics. Both users and non-users (e.g., clients with tinnitus who were eligible for but never used teleaudiology services) of teleaudiology were recruited in the above study. Survey respondents were recruited via social media and the professional networks of the first author (BM) and last author (GSS). All survey respondents answered a question at the end of the survey about their interest in participating in the current study. An email invitation with a link to the online participant information sheet and consent form were sent to the 154 consenting survey respondents. Out of the 154 individuals contacted, 23 (six clients, 10 clinicians, three students, two academics, and two industry partners) completed the consent form and interview. The invited individuals who did not complete the consent form did not provide reasons for their non-participation.

5.5.3.4 Setting

As the participants were geographically scattered across different states of Australia, all interviews were conducted online using Microsoft Teams. Each participant was provided a unique link to the online meeting room which was only available to the participant and interviewer (BM). No one else was present in the interviews.

5.5.3.5 Data collection

Interview guides were provided to the participants at least one week before the interview so they could familiarise themselves with the questions to be discussed. All interviews were video-recorded and automatically transcribed on Microsoft Teams, and interview recordings were deleted at the end of this study. Field notes were also made by the interviewer during the interviews. Each interview took 12-36 minutes to complete (mean: 22 minutes). Interview transcripts were returned to participants for comment and correction, e.g., spelling corrections and removal of participant's company name. All interviews were conducted by the first author (BM), who was a PhD candidate with an Audiology background.

5.5.4 Data analysis and reporting

Verbatim interview transcripts were imported into the NVivo R1 software for data analysis. BM performed the initial coding following an inductive thematic analytic approach (Braun & Clarke, 2006). Interview transcripts were examined repeatedly to identify individual codes and similar codes were grouped into themes. A codebook consisting of codes, description of codes, example quotes, and frequency of codes in all transcripts was established. The codebook was reviewed by co-authors (ML and DT) to check interpretations and ensure appropriate categorisation of codes into themes and to evaluate their relevance regarding study objectives. The codebook was modified by BM according to the feedback from ML and DT, which resulted in the removal of redundant codes and facilitated the identification of distinct themes. Participant quotes and ID numbers were included to elucidate the themes identified in this study.

5.6 Results

A total of 23 hearing healthcare stakeholders (six clients, 10 clinicians, three students, two academics, and two industry partners) were interviewed. Among the clinicians (n = 10), four had 1-5 years of work experience as a clinician, three had 6-10 years, two had 11-15 years, and one had more than 15 years. Six of the clinicians worked in large chain clinics (>20 clinics), three worked in independent clinics, and one worked in government hospital/clinic. The three students were from two universities and all of them were in their second year of study. The two academics were from two universities and they each had 1-5 years and 6-10 years of work experience as an academic. As for the two industry partners, they respectively had 1-5 years and 6-10 years of work experience as an industry partner.

Overall, six themes were generated from the participant responses (see Figure 5.1 and Tables 5.1-5.6).

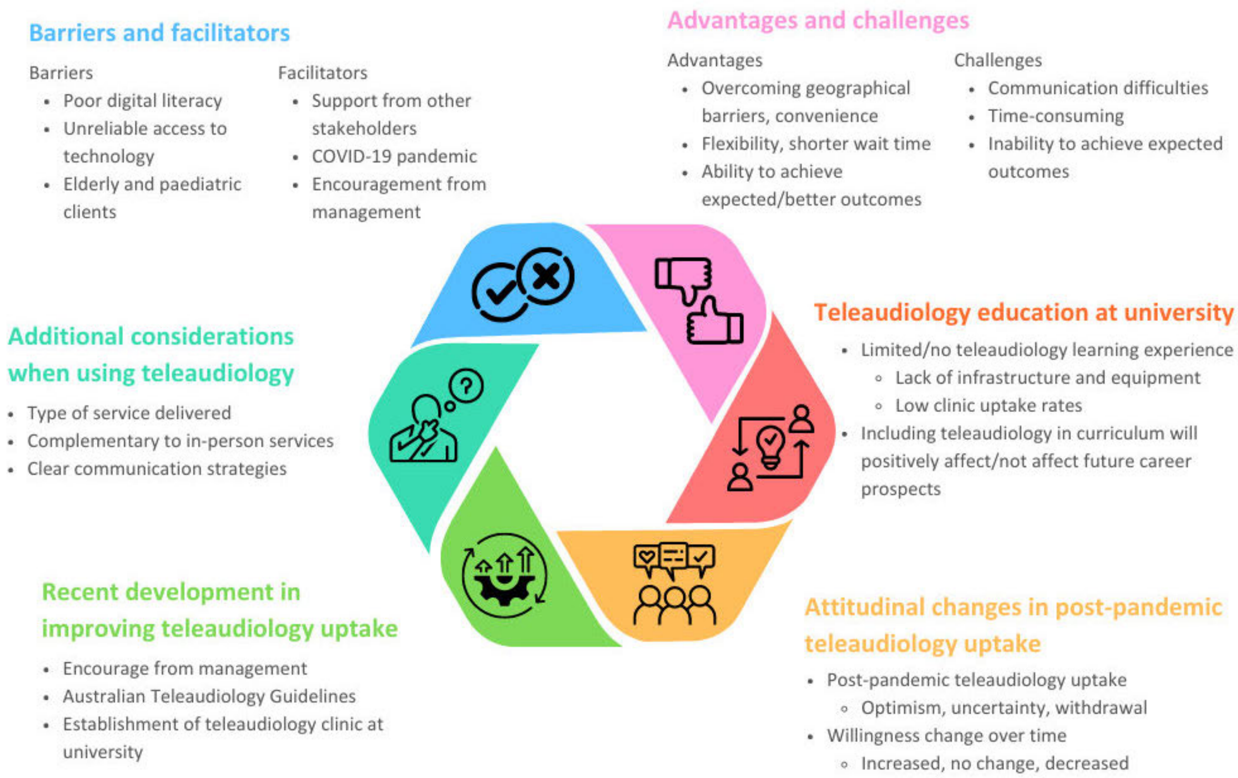


Figure 5.1 Six themes generated from participant responses regarding their experiences with using teleaudiology and their views on future teleaudiology uptake.

5.6.1 Barriers to and facilitators of teleaudiology uptake

The five groups of hearing healthcare stakeholders (clients, clinicians, students, academics, and industry partners) suggested various barriers to and facilitators of teleaudiology uptake which could be categorised at individual, organisational, and technological levels. Table 5.1 presents the barriers and facilitators suggested with example quotes from the participants. Barriers at individual level can be associated with clients, clinicians, other stakeholders, or a combination of the above. For example, the most mentioned barrier was poor digital literacy and confidence among clients and clinicians, as an industry partner suggested, “with people who are not familiar with teleaudiology, there’s lots of scepticism and fear from clinics who are not involved in teleaudiology” (Participant 10, female, industry partner). The other two most mentioned individual-level barriers were client age (elderly and paediatric), e.g., a clinician questioned the availability of research evidence on using teleaudiology in paediatric diagnostic testing, and poor personal connection as a client "would prefer in person, because people actually have a very healing quality in them" (Participant 2, female, client). Little or lack of support from other stakeholders was also noted as a barrier, as a clinician explained:

> Whenever I'm doing it with an assistant, sometimes it's perfect, but sometimes it can be a bit of like miscommunication between the audiologists and that front staff, and they might like to think that they can run the whole appointment (Participant 20, female, clinician).

Other individual-level barriers included client's and clinician's preference for in-person services, client's unawareness of available teleaudiology services, clinicians assuming clients would not prefer teleaudiology options, clients with complex hearing loss and needs, low demand for teleaudiology, and clients with poor dexterity.

Table 5.1 Barriers to and facilitators of teleaudiology uptake.

Codes		Level		
Barriers to teleaudiology uptake	Example quotes	Individual	Organisational	Technological
Poor digital literacy and confidence among clients and clinicians	I guess the main thing is whether or not the client is accepting of the technology and you know, obviously you need the client to be you know, okay with the technology. (Participant 19, female, clinician) With people who are not familiar with teleaudiology, there's lots of scepticism and fear from clinics who are not involved in teleaudiology. That's completely natural, you know, and not familiar of course, they're gonna be scared. (Participant 10, female, industry partner)	✓		
Unreliable access to phone, Internet connection, and technology	I think one of the other facts is as well, the reception that the client has in the area that they live in, because some regional areas don't get good phone network, so you can't really do a teleaudiology appointment there neither. (Participant 12, female, clinician)			✓
Elderly and paediatric clients	I think probably a big one at the moment is probably just the types of clients that you're seeing in terms of the age brackets. I don't think that right now a lot of our clients would, it would be something that they would be easily able to do. (Participant 19, female, clinician) I know there's a lot of evidence with adults and rehab, that's been successfully delivered via telehealth, but I feel like this is a very different ball game, very different realm here. We're talking infants, we're talking diagnostics. (Participant 14, female, clinician)	✓		

Poor personal connection	I think everything I would prefer in person, because people actually have a very healing quality in them. And I think with people with hearing issues where we're stressed or in distress, I was very distressed and I needed to be with somebody who could talk me through it. (Participant 2, female, client)	✓		
Poor/no support from other hearing healthcare stakeholders	I had to go through my own learning, which really in the end was self-taught...I don't have assistants and anybody else at the other end. (Participant 15, female, clinician) Whenever I'm doing it with an assistant, sometimes it's perfect, but sometimes it can be a bit of like miscommunication between the audiologists and that front staff, and they might like to think that they can run the whole appointment. (Participant 20, female, clinician)	✓		
Complex teleaudiology apps	The apps can be a little unwieldy. Maybe they just need to be more user friendly. (Participant 15, female, clinician)			✓
Client's and clinician's personal preference for in-person services	(Clients) are more willing to come in and have a face to face (appointment) and we have actually clients who hold on to coming (in). So they actually rejected the telecare and then they want to come in and they had to wait for it. (Participant 5, male, clinician) It's not my favourite thing to do just because of my personality, I prefer face to face and I hate talking on the phone. Obviously I provide it, but I think it really depends on the personality of the audiologist as well. (Participant 20, female, clinician)	✓		
High cost and insufficient funding	I can't remember quite how the pricing was set up with those telehealth (appointments). The few that I've had, I've only had two, I think two or three. But I do know my audiologist with tinnitus counselling. It's around in the high three hundreds. Very expensive,		✓	

	very expensive and I don't get any rebates on that. (Participant 2, female, client)		
Client's unawareness of available teleaudiology services or apps	I'd use them if they're available, but I'm not aware of any that are available. (Participant 3, male, client) I don't even know what apps exist to help. (Participant 1, female, client)	✓	
Clinician's assumption of client preferences towards teleaudiology	I think clinics can be a bit like, “my clients aren't interested in that. My patients aren't interested in that.” They've already made that assessment decision for them. (Participant 22, male, industry partner)	✓	
Reimbursement issues	I don't get any insurance, any claims. I can't make claims yet. I'm paying top cover. Umm, because, you know, hearing health is somehow not part of the national health conversation. (Participant 2, female, client)		✓
Clients with complex hearing loss and needs	The other factor as far as clinicians were concerned was being appropriate for complex client, which is a fair point. (Participant 10, female, industry partner)	✓	
Rigid business model of large hearing service providers	Remote care is probably something that (bigger chains) would shy away from, from my perspective, because of the implementation of it and it being a bit more rigid in that type of sausage factory of retail, fitting of hearing devices and things like this...It will be yeah, those types of market forces will mean that teleaudiology and remote care will be much more accepted in the independent space. (Participant 22, male, industry partner)		✓
Hesitation from management	Because of my boss’ standpoint, her viewpoint in terms of how she's thinking how we should go into this area, it might be something that she's still pretty conservative about. (Participant 4, female, clinician)		✓

No urge or need for teleaudiology	Right now the demand, like the work that you would need to put in to maybe set up your protocols and get your app set up and all that stuff, the work that would be involved in doing that versus how many clients you would actually get, that would actually want it, I think it’s not really you know that really line up. (Participant 19, female, clinician)	✓		
Poor dexterity	Their dexterity. (Participant 7, female, client)	✓		

Facilitators of teleaudiology uptake	Example quotes	Individual	Organisational	Technological
Support and training received from other hearing healthcare stakeholders	Our clinical coach has actually come in to have a training session about the new teleaudiology platform. It's very positive from what I can see. (Participant 11, female, clinician) When you're doing an actual teleaudiology appointment, you would have like an allied health assistant to help you put the equipment on. (Participant 23, female, student) We had a number of our students dial into appointments from home to observe them and have a conversation with the patients, but certainly no adjusting or conducting a hearing assessment online or anything like that. (Participant 18, female, academic) It's just that they build in their clinic flow, front of house staff are as well trained on how to handle those types of appointments and much needed for it. (Participant 22, male, industry partner)	✓		
Risk of COVID-19 pandemic and health concerns	Obviously it was more during the lockdown. It is more for rural (clients). But as we go forward, I prefer to actually see my clients who can come in, so it has decreased over time from the lockdown. (Participant 20, female, clinician)	✓		

Encouragement from management	I think the company is investing in like a complete new department. I think it's been there for a while now, but they're recruiting more clinicians to join them 100% work from home as teleaudiologists. (Participant 11, female, clinician)		✓	
Client reaching later stage of hearing care journey	You might have had a lot of testing done, set up with your devices, and just be going through some familiarisation appointments. So that's where (teleaudiology) could be really handy. After you've done the initial testing and just sort of getting on that support journey. (Participant 7, female, client)	✓		
Technology advancement	When we first had it, it was great to see the people, but I only had some adjustments of the hearing aids. I couldn't do everything but now I can basically do as much on the hearing aids as if they were sitting here right in front of me. So now that the technology has caught up, I actually am a big fan of the telehealth appointments. (Participant 15, female, clinician)			✓
Word of mouth	One of those (clients) now sings from the same hymn sheet and is quite happy and tells all her friends it's not as scary as she first thought it was. (Participant 17, female, clinician)	✓		
Increased client awareness of hearing care	I think with the awareness of audiology, people get to know it better and they see a need for hearing care. It's definitely going to be something everyone has to learn and do. I think as an audiologist, you are expected to provide telehealth. (Participant 23, female, student)	✓		
High digital literacy among students	I think with the new generation of students that we have and they're younger and younger every year, there's a lot of, you know, the digital sort of awareness and digital literacy. (Participant 18, female, academic)	✓		

Note. Checks indicate that the barrier is at the corresponding level.

At an organisational level, a perceived high cost of accessing teleaudiology services and difficulties in providing reimbursements could deter clients from using teleaudiology. An industry partner suggested that large hearing service providers appeared to be less accepting of teleaudiology uptake due to their more rigid business model, as:

> Remote care is probably something that (bigger chains) would shy away from…because of the implementation of it and it being a bit more rigid in that type of sausage factory of retail, fitting of hearing devices and things like this…teleaudiology and remote care will be much more accepted in the independent space" (Participant 22, male, industry partner).

Hesitant attitudes from the management level might also hinder teleaudiology uptake, as a clinician said, "because of my boss' standpoint…it might be something that she's still pretty conservative about" (Participant 4, female, clinician). In relation to technology, unreliable access to phone, Internet connection, and technology, and complex teleaudiology apps were identified as barriers to teleaudiology uptake.

Similar to the barriers, facilitators of teleaudiology uptake can be categorised at individual, organisational, and technological levels. The most common facilitator was reported to be the support and training provided by other hearing healthcare stakeholders. For instance, clinical coaches, allied health assistants, and front of house staff played important roles in implementing and facilitating teleaudiology service delivery. The COVID-19 pandemic also prompted teleaudiology uptake for the purposes of minimising in-person contact and health risks. Clients who had reached a later stage in their hearing care journey might find teleaudiology more useful, as a client explained: "(teleaudiology) could be really handy after you've done the initial testing and just sort of getting on that support journey" (Participant 7, female, client). In addition, word of mouth, increased client awareness of hearing care, and high digital literacy among students were suggested as other individual-level facilitators.

At an organisational level, positive attitudes from the management level could promote teleaudiology uptake, e.g., a clinician mentioned that their organisation was investing in a new department which would recruit clinicians to work completely remotely as teleaudiologists. Meanwhile, technology advancement were facilitators at the technological level, as previously clinicians "couldn't do everything (via teleaudiology) but now they can basically do as much on the hearing aids as if the clients were sitting here right in front of them" (Participant 15, female, clinician).

5.6.2 Advantages and challenges of using teleaudiology

Table 5.2 displays the advantages and challenges of using teleaudiology suggested by the participants. Among the advantages identified, the ability to overcome geographical barriers, reduce travel needs and time, and increase convenience were the most mentioned. Overcoming the geographical limitations may work in both ways as clients residing in remote areas can more readily access hearing healthcare and clinicians who are located remotely "can actually provide services from their laptop at their home" (Participant 20, female, clinician). Participants also found teleaudiology beneficial in terms of flexibility, reduced wait time, and immediate access to care, as explained by a clinician: "who doesn't love the fact that you can do all your medical consults and things from home when you want to squeeze it in while you're at work or whatever" (Participant 8, male, clinician). Clinicians appreciated that expected health outcomes were able to be achieved or surpassed via teleaudiology. For example, a clinician was able to adjust a client's HAs in real time based on the client's home environment with the client at home. Other suggested advantages of using teleaudiology included unaffected rapport and trust when comparing to in-person services, comprehensive teleaudiology app functionality, use as an effective triage tool, increased revenue, easy provision of information for clients, and timely referral to other health professionals.

Table 5.2 Advantages and challenges of using teleaudiology.

Codes **Advantages of using teleaudiology**	Example quotes
Overcoming geographical barriers, less travel needs and time, and convenience	I certainly would save time often to get to appointments and it might save time for the professional as well. Also, if people are living in more regional areas, it's definitely a plus for them and I think that would be really good. And that aspect, because it opens a lot of doors for them to get care. (Participant 7, female, client) I was thinking like eventually teleaudiology is not only convenient for clients who are remote. It can be convenient for an audiologist who is remote, so they can actually provide services from their laptop at their home. (Participant 20, female, clinician)
Flexibility, shorter wait time, and immediate access of care	Everybody's looking to make things easier right now, especially as people get busier and you know, who doesn't love the fact that you can do all your medical consults and things from home when you want to squeeze it in while you're at work or whatever. (Participant 8, male, clinician)
Ability to achieve expected/better outcomes	It was good because we, you know, he needed an adjustment and he was in Melbourne and I was here, so it was good for the fact that we could still do that for him. (Participant 19, female, clinician) People might be at home saying like, "I can't stand the sound of my neighbour's birds". Well, I can fix that or I can try to fix it (when) we're in clinic and then they're just gonna go home and experiment. But actually, if I can change the sound while they're in their home and they're listening to the birds and they're - so I've actually found that there's some really, really good benefits. (Participant 15, female, clinician)
Unaffected rapport and trust	Absolutely fine, because I would just need the information. I would need to get my problems solved regardless of who they are. (Participant 16, female, client) I would feel OK so long as that person was a willing participant. So that was some of that person wanted to be in that appointment and had the ability to communicate with me. (Participant 12, female, clinician)

Comprehensive app functionality	The app is so useful, even with hearing test, technically it's like in-situ hearing tests that we do where the patient wears the hearing aid and you do the hearing test, some of the companies do provide this system. And tinnitus management, again, I think because hearing aid companies are very integrative, they take into account all these things. (Participant 4, female, clinician)
Effective triage tool	The bit that I think is actually very important and most people don't quite appreciate is how teleaudiology is relevant to triaging client need audiologically or otherwise. But it's actually understood as a very effective triage tool. (Participant 10, female, industry partner)
Increased revenue	I think that's probably the one characteristic among the staff who have been better and have benefited from it because those staff created more time for more sales. (Participant 10, female, industry partner)
Easy provision of information	By email, I can send them user manuals, I can screenshot a lot of things, I can even take pictures of what they should do with instructions or explanation of the pictures, and even articles. (Participant 5, male, clincian)
Timely referral to other health professionals	And that audiologist via the telehealth may say, in Coober Pedy there's a very good audiologist near you, and you can go to them and see them. (Participant 2, female, clinician)
Challenges of using teleaudiology	Example quotes
Communication difficulties	It was hard to understand. I misheard information and I found that there was a lag in the communication stream that tended to overlap questions and answers, and just generally did not feel comfortable. (Participant 16, female, client)
Time-consuming nature	It's just clunky to get into and get started, so it was what should be nice quick teleaudiology appointment, I was having to add on an extra 10-15 minutes, just to make sure we could all log in and everything was OK. (Participant 15, female, clinician)
Inability to achieve expected outcomes	I've used the tinnitus apps which haven't worked. (Participant 3, male, client) I know we've got like hearing test software that's recently starting to come out where you know the

	person can conduct their own hearing test. I don't think they're very accurate. (Participant 12, female, clinician)
Difficulties building rapport and trust with clients	I think you're able to maybe build a bit more rapport when it's face to face, it makes the client trust you that you know, your actual physical clinic that it's a big clinic and they trust you. I've got remarks like that from clients, "wow, your clinic is so big and clean", you know. And that just adds extra points to you know, the rapport and the trust factor. (Participant 11, female, clinician)
Inability to check audiological testing equipment or hearing device placement	I think with aspects regarding hearing aids, just especially obviously fittings because you wanna physically see sort of how it fits in their ear. I would prefer obviously to do some real ear measures and also just in terms of going through management with them. (Participant 19, female, clinician)
Technological limitations pre-COVID-19	So teleaudiology really started in about 2017. There were earlier facets to it prior to that, but they were quite convoluted and needed a lot of preparation and weren't as reliable. But we've adopted it since 2017. (Participant 8, male, clinician)
Less client recognition	So that just clients will have less recognition to our work maybe. (Participant 21, female, student)
Uncertainty about clinician's full attention	You don't feel the same benefit like somebody's really listening to you or are they doing something else in the background that's like multitasking? So you just don't feel their full attention, that's all. (Participant 16, , female, client)

On the contrary, the use of teleaudiology was reported to create challenges which were otherwise not encountered in in-person service delivery. Oral communication via video calls could be difficult, as a client elaborated: “I misheard information and I found that there was a lag in the communication stream that tended to overlap questions and answers, and just generally did not feel comfortable” (Participant 16, female, client). Teleaudiology appointments might also require more time for preparation and troubleshooting, e.g., a clinician had to “add on an extra 10-15 minutes, just to make sure we could all log in and everything was OK” (Participant 15, female, clinician). The ability of certain teleaudiology products to achieve expected health outcomes was questioned. For instance, a client “used the tinnitus apps which haven't worked” (Participant 3, male, client) and a clinician doubted the accuracy of self-administered hearing assessment software by saying “I know we've got like hearing test software that's recently starting to come out where you know the person can conduct their own hearing test. I don't think they're very accurate” (Participant 12, female, clinician). Moreover, clinicians being unable to meet clients in person might hinder rapport and trust building. Interestingly, a clinician mentioned that their client who visited their physical clinic complimented on how big and clean the clinic was, and the clinician believed the visit facilitated trust building. Furthermore, the inability to check the placement of audiological testing equipment or hearing device, technological limitations before the COVID-19 pandemic, less client recognition of clinician’s work, and client’s uncertainty about clinician’s full attention during teleaudiology appointment were identified as other challenges of using teleaudiology.

5.6.3 Additional considerations when using teleaudiology

Prior to and during the use of teleaudiology, the participants noted several points as shown in Table 5.3 which required attention and consideration for best service delivery. Firstly, clinicians might have preferences for the type of service delivered via teleaudiology, as a clinician suggested: “For audiology services (like) diagnostic test, it’s gonna be very hard to conduct online. But I think primarily, services that require counselling or even hearing aid tuning and aural rehabilitation, it’s very helpful to have it online” (Participant 4, female, clinician). Secondly, teleaudiology should act as a complement to in-person services rather than a replacement and clients should be offered options of receiving services via either means or a combination of both. In order to tackle the communication difficulties in a videoconferencing appointment, clear communication strategies need to be in place, e.g., a clinician suggested “having clear instructions and something that is visual so that clients can follow through, like step-by-step guide” (Participant 5, male, clinician).

Moreover, emotional support and empathy should be shown as per standard in-person service delivery. One of the challenges of using teleaudiology as suggested by participants is rapport building, and a clinician suggested rapport building strategies such as reminding the client of the clinician's experience and the purpose of the appointment, as well as the capability of conducting procedures with the support of an assistant on the client's side.

Table 5.3 Additional considerations when using teleaudiology.

Codes	Example quotes
Type of service to be delivered	For audiology services (like) diagnostic test, it's gonna be very hard to conduct online. But I think primarily, services that require counselling or even hearing aid tuning and aural rehabilitation, it's very helpful to have it online. (Participant 4, female, clinician)
Used to complement in-person services	I think the biggest part to it is that it's not something that replaces face to face appointments, but it's a really strong addition to the services and care you can provide. (Participant 8, male, clinician)
Clear communication strategies	So having clear instructions and something that is visual so that they can follow through, like step-by-step guide, might be helpful for these people. (Participant 5, male, clinician)
Emotional support and empathy	So that (clients) feel like they're being handheld. They don't feel they're isolated and they're much more accepting of what we do as a profession. (Participant 17, female, clinician)
Rapport building strategies	I personally normally say to them that they're seeing an experienced audiologist, or experienced audiometrist, depending which member of the team they're saying. And we explained to them that as a company, we've identified an area in remote and regional areas in Australia, where they're not getting those services and that we would want to offer those services. And that although the service may feel uncomfortable because it's not done in the same room where we can't reach across and hold each other's hand, there is nothing that I can't do here without the support of a technician. (Participant 17, female, clinician)
Mode of service delivery	If I'm doing a check-up on a hearing aid, I'm going to do a video call because I really need to see what's the environment, I need to see how are they doing things, and I have to show them as well. (Participant 20, female, clinician)
Privacy and confidentiality	Security of that technology, again, you know that patient confidentiality is very important. (Participant 14, female, clinician)

Person-centred care	With people who are not familiar with teleaudiology, you know there's lots of scepticism and fear from clinics who are not involved in teleaudiology...But the reality is that, and by having a model that focuses around the consumer instead of the clinic, what you end up realising is that the consumers' relationship with their hearing aid and the help they get is much more positive. (Participant 10, female, industry partner)
Qualified and professional clinicians	I guess initially my audiologist, if she wasn't available, someone who was trained. Someone similar. I wouldn't like to be consulting someone who didn't know what they were talking about in relation to my care or my history. (Participant 7, female, client)
HSP compliant	We did develop an in-house flow chart for dealing with (tele)audiology and again, it was just to make sure that we were HSP compliant and doing the best by our patients and not just bringing up and going, "yeah, yeah, OK". So yeah, well, that still stands today. (Participant 15, female, clinician)
Required time	How much time has been allocated for me to make the teleaudiology appointment, like video will take a lot longer, so you know, I should get longer time to make that appointment; versus a phone call, which should be done in like 15 minutes tops, right? (Participant 5, male, clinician)
Maintaining service outcomes and quality	If you're booked in for like an hour, and if most of the time we're spending, you know, figuring out why we can't hear them and why the client can't hear us, that doesn't leave us enough time to actually get to the appointment and do what we're meant to be doing during the appointment. (Participant 12, female, clinician)
Noise level on client's side	I think it's really the connection and the environment, because you can't control the environment around you, right? Like where the patient is. Because usually for hearing tests specifically, we have a certain requirement - you want it to be at certain sound level. (Participant 4, female, clinician)

Similar to having preferences for the type of service delivered via teleaudiology, clinicians also reported preferences for the mode of service delivery based on the type of service provided. For example, a clinician would opt for a video call for HA check-ups as they would need to see the client's home environment, how they manage the HAs, and to give visual instructions to the client. Furthermore, the importance of client privacy, confidentiality, and provision of person-centred care should never be overlooked when using teleaudiology. Both clients and clinicians noted that the clinicians conducting teleaudiology appointments should be equally qualified and professional as if the appointments were conducted in person. Some clinicians highlighted the significance of delivering teleaudiology services compliant with the government-funded HSP in order to maintain best practice and fulfil reimbursement requirements. Additionally, clinicians should be mindful of the time needed for conducting teleaudiology appointments, as in some circumstances extra time might be necessary to achieve planned outcomes with the same service quality. The ambient noise level on the client's side is another consideration, especially when conducting remote hearing assessment.

5.6.4 Teleaudiology education at university

When being prompted to consider teaching and learning teleaudiology at university, students and academics expressed their opinions in multiple facets, as displayed in Table 5.4. Initially, both students and academics thought teleaudiology education was inadequate or entirely lacking. Only a small number of lectures or subjects were allocated to introducing teleaudiology, according to a student and an academic. The two stakeholder groups attributed the lack of teleaudiology education to six factors: lack of infrastructure and equipment, low clinic uptake rates, importance of teleaudiology is not recognised, limited capacity of curriculum, difficulty in designing teleaudiology teaching, and accreditation standards.

Table 5.4 Teleaudiology education at university.

Codes	Example quotes
Limited or no teleaudiology learning experience	Just this semester. We only had one subject. It was like an overall professional conduct kind of course. (Participant 23, female, student) We do have a small amount of lecture content that's dedicated to teleaudiology...Because just the way that it's currently taught, I don't feel it's sufficient. (Participant 13, female, academic) From my memory, I don't think I have learned anything about teleaudiology in university, in the lectures now. We never touch on teleaudiology, no. (Participant 21, female, student)
Lack of infrastructure and equipment	Because we don't have a clinic, we don't get an opportunity to test out or try out new clinical skills for our students in a true clinical setting. (Participant 13, female, academic) I don't feel that there's lots of financial resources at our university to acquire equipment that may be required to teach teleaudiology. (Participant 13, female, academic)
Low clinic uptake rates	My experience with our students is that they're not exposed to teleaudiology in their clinical placements. They're not, their supervisors aren't using it that often. It's very sporadically used in the clinic. (Participant 13, female, academic)
Importance of teleaudiology not recognised	Maybe just how the university designs the curriculum, how they design our study. I don't know. Maybe at the time we are designing the curriculum or like building the content of the lectures, teleaudiology is not that essential at that point. (Participant 21, female, student)
Limited capacity of curriculum	My perception is that education of audiology generally has not been really quick (to) take up teleaudiology because there's not a great deal of space in the time that we teach them. (Participant 13, female, academic)
Difficulty in designing teleaudiology teaching	I think the barriers that clinics have been finding adopting teleaudiology is also reflected on how easily it's taught. Because it's not something really nice and self-contained and you can just do it either. I think it does take quite a bit of that creativity to design useful workshops and practical assessment pieces. (Participant 13, female, academic)

Accreditation standards	I know Audiology Australia has just redone the accreditation process for audiology teaching, but because it's not specific skills, they don't kind of go into really specific skills, it just gives university so much scope to do kind of what they think is best...So it's maybe difficult to start out...That just maybe mean sort of be slower to get to a really polished part of the curriculum and really polished package for the students. (Participant 13, female, academic)
Positively affected or unaffected future career prospects by the inclusion of teleaudiology in curriculum	I don't think it would negatively affect their future job prospects. It can only positively affect them. The more the students are aware and the way in which we provide service to, you know, the hearing-impaired population can only improve their skills and therefore improve their job prospects. (Participant 18, female, academic) I don't think it would affect it. I think it would probably not mean that there's less chance of having future job prospects or there's more chance. I think probably in the middle where it - yeah, I hope that it wouldn't affect it too much. (Participant 6, female, student)
Strategies and suggestions to facilitate inclusion of teleaudiology in the curriculum	I'm just imagining we may have like a guest lecture teaching us about how to run like phone call, video call appointment with client. I wish we will have that. And also just ask any like very experienced clinicians who often use teleaudiology and phone call. Give us a lecture about how to do that, what we need to be aware of, like when we're talking to the client, how we build the connection. (Participant 21, female, student) Our school has set up a massive teleaudiology clinic that is going to be used for the purpose of teaching and also seeing patients. (Participant 18, female, academic)
Assessment of teleaudiology competencies	The exam was over teleaudiology...the exam was pretty much you would have a client who was like roleplayed by the clinical educators from the school…you would instruct them how to put the headphones on, how to do tympanometry. Everything is instructed to the client so they do everything themselves...at the end of the testing you would explain the result and you would do a feedback and management plan. (Participant 23, female, student)
Clear indication of teleaudiology learning at the start of program	I think from day one in audiology, we already taught that you know, we are expected to work with the regional communities after we graduate. And I think in everyone's mind, we already know that teleaudiology is definitely going to be part of your work. (Participant 23, female, student)

Universities as a key driver of teleaudiology uptake	It's not often that, well I haven't seen it happened often that from the education side, you can really drive change. And it's maybe mostly been from you know, equipment or devices or government regulation or funding that has driven change in our industry. But maybe universities could make a contribution in that space to shift the skills and the mindset and the willingness for clinicians to take on teleaudiology, to see the opportunities that it presents. (Participant 13, female, academic)

As indicated by the students and an academic, some universities might not have a dedicated clinic with appropriate equipment where students could observe teleaudiology appointments and practice teleaudiology-related clinical skills. Low teleaudiology uptake rates among placement clinics further reduced students' exposure to and perhaps confidence of teleaudiology use. A student conjectured that, maybe at the time when the curriculum was designed, teleaudiology was not as essential and therefore, did not receive much attention to be incorporated in the curriculum. An academic pointed out that the capacity of curriculum seemed merely sufficient to cover the basic topics, let alone additional topics such as teleaudiology. Besides, inclusion of teleaudiology in the curriculum might appear complicated under some circumstances, for example, an academic believed that "it does take quite a bit of creativity to design useful workshops and practical assessment pieces" (Participant 13, female, academic). The accreditation standards set by Audiology Australia, the professional body in charge of postgraduate audiology program accreditation in Australia, might have added complexity to defining and refining specific teleaudiology skills to be taught, as an academic explained:

> It just gives university so much scope to do kind of what they think is best…so it's maybe difficult to start out…and slower to get to a really polished part of the curriculum and really polished package for the students (Participant 13, female, academic).

Despite the inadequate amount of teleaudiology education at the university, both students and academics thought students' future career prospects would either be positively affected or unaffected by learning teleaudiology, as an academic explained: "the more the students are aware and the way in which we provide service to the hearing-impaired population can only improve their skills and therefore improve their job prospects" (Participant 18, female, academic). A few strategies and suggestions to facilitate teleaudiology teaching arose from the interviews, including inviting experienced guest lecturers to teach students how to conduct teleaudiology appointments by phone and video calls and particular tips to be mindful of and establishing a teaching clinic built specifically for teleaudiology education. Some universities began integrating teleaudiology more in the curriculum by putting students' teleaudiology competencies to test, as a student reported undertaking a clinical exam, from instructing the client to conducting audiological assessments and explaining the results and management plan, over a video call. Meanwhile, some universities might emphasise from the start of the program that students were expected to work with regional communities and thus, teleaudiology would be essential under students' clinical belt. All of the university programs were based in metropolitan locations at the time of this study and many had in-house clinics, therefore there might be less incentive to provide exposure to teleaudiology as the client need was low. However, some universities might be more insightful of the client need in rural or remote locations and start to prepare students for teleaudiology at an earlier stage. In addition, an academic was hopeful that universities could act as a key driver of teleaudiology uptake by preparing students to become clinicians with skills, confidence, and willingness to use teleaudiology, instead of passively waiting for changes to occur from the industry or government.

5.6.5 Recent development in improving teleaudiology uptake

Throughout the interviews, participants from each stakeholder group noted recent development in improving teleaudiology uptake in different areas of the audiology profession since the COVID-19 pandemic, as detailed in Table 5.5. A monumental development occurred in Australia in 2022 when the Australian Teleaudiology Guidelines were introduced by Audiology Australia for the purpose of informing safe and effective teleaudiology service delivery (Audiology Australia, 2022b). All of the 10 clinicians interviewed were aware of these guidelines, but only half of them had read the guidelines. For the clinicians who had read the guidelines, they expressed mixed feedback. Examples of negative feedback included the guidelines being not concise, practical, and elaborate enough, for example, a clinician would like to know "what is expected of me and where the boundaries lie? What do I have to do to be HSP compliant?" (Participant 15, female, clinician). Another clinician thought the guidelines did not add much value to their clinical practice because they were just outlining the teleaudiology work they had been doing. Meanwhile, two clinicians found the guidelines helpful in providing instructions on what to ask, do, and expect in a teleaudiology appointment, as well as acting as a reasonable framework for clinics to start using teleaudiology. For the clinicians who had not read the guidelines, they thought teleaudiology did not constitute a significant part of their work and so there was no need to read the guidelines, or they were simply too busy.

Table 5.5 Recent development in improving teleaudiology uptake.

Codes	Example quotes
Encouragement from management	I think the company is investing in like a complete new department. I think it's been there for a while now, but they're recruiting more clinicians to join them 100% work from home as teleaudiologists. (Participant 11, female, clinician)
Australian Teleaudiology Guidelines - clinicians are aware but have not read them	I haven't read about it in detail, but I have heard of it. (Participant 5, male, clinician)
Teleaudiology is not a significant part of job	I'm not using teleaudiology like all the time, so I didn't find that I needed to read it. (Participant 12, female, clinician)
Too busy	It's just been you know, very busy service, lots of things going on and I'm keen to do it. We have a project on the table looking at teleaudiology and I will be reading them as part of that project, but I have not had the time so. (Participant 14, female, clinician)
Australian Teleaudiology Guidelines - clinicians are aware and have read them	We've reviewed it and we received it when it came out initially and all our clinicians are aware of it. (Participant 8, male, clinician)
Negative perceptions	I think some of them were, they're very, I guess they're trying to fit all shoes, I think in all different situations. I don't think they were as concise as they could have been, or there's quite a lot that's a bit meaningless in there...Maybe we need to just lock down a little bit more of the actual framework that the industry works in and how to utilize teleaudiology. (Participant 8, male, clinician) I found it a bit wordy like I was after a real practical, really looking from my point of view, what is expected of me and where the boundaries lie? What do I have to do to be HSP compliant? (Participant 15, female, clinician) They're probably about what I was already doing anyway, so a lot of what they brought in, we had already embraced. I don't think we added anything additional to what they had. (Participant 17, female, clinician)

Positive perceptions	It is helpful because, uh, if you're ordering your remote appointments for instance, annual review, it's going to basically tell you what you ask and what to do and what to expect, so I find it helpful, yeah. (Participant 20, female, clinician) It's a lovely framework to begin how a clinic would start to address telehealth appointments. (Participant 8, male, clinician)
Strategies and suggestions to facilitate inclusion of teleaudiology in the curriculum	Our school has set up a massive teleaudiology clinic that is going to be used for the purpose of teaching and also seeing patients. (Participant 18, female, academic)
Assessment of teleaudiology competencies	The exam was over teleaudiology...the exam was pretty much you would have a client who was like roleplayed by the clinical educators from the school…you would instruct them how to put the headphones on, how to do tympanometry. Everything is instructed to the client so they do everything themselves...at the end of the testing you would explain the result and you would do a feedback and management plan. (Participant 23, female, student)

Apart from the introduction of the Australian Teleaudiology Guidelines, other development was observed recently across clinics and universities in the hope of facilitating teleaudiology uptake. Examples including hearing healthcare providers establishing departments dedicated solely to teleaudiology service delivery, universities setting up teleaudiology teaching clinics, and assessing students' teleaudiology competencies as a requirement for program completion have been mentioned earlier in *Barriers to and facilitators of teleaudiology uptake* and *Teleaudiology education at university* (Chapter 5.3.1).

5.6.6 Attitudinal changes in post-pandemic teleaudiology uptake

As described in Table 5.6, participants showed diverse responses when being asked about their feelings towards teleaudiology uptake over time and after the COVID-19 pandemic. In regard to post-pandemic teleaudiology uptake, all participants shared an optimistic attitude that people would potentially be more accepting of teleaudiology. A student believed that with gradually increasing awareness of hearing healthcare, potential clients would more likely recognise the need for audiology services and especially those who live in regional areas would most directly benefit from teleaudiology. Moreover, an academic observed an ongoing shift towards telehealth not only in the audiology profession but also in other medical and allied health professions, and the fact that some hearing healthcare stakeholders started exploring the feasibility of teleaudiology use during the pandemic would further encourage its continued use. Improvement in client digital literacy and confidence might be another reason behind the optimism about post-pandemic teleaudiology uptake, as an industry partner suggested: "As generations get older and they're more comfortable with communicating through text and all that type of stuff, I think those types of services will just be rapidly continue to grow for sure" (Participant 22, male, industry partner).

Table 5.6 Attitudinal changes in post-pandemic teleaudiology uptake.

Codes	Example quote
Teleaudiology uptake post-COVID-19	/
Optimism	Absolutely yes...I think it's just gonna need a little bit more work and time for people to accept it. (Participant 16, female, client) I think there's a few ways that people will start to use it may not be best practice, but in the main, I think it's definitely something that's gonna stay. (Participant 8, male, clinician) Absolutely. Queensland (is) so big and most of the regional communities are so far away and it's definitely a movement. And I think with the awareness of audiology, people get to know it better and they see a need for hearing care. It's definitely going to be something everyone has to learn and do. (Participant 23, female, student) I think that this is, you know, the medical profession, the allied health profession, we're all moving in this direction. And it's really, really great to see that you know, a lot of people in audiology have explored this during COVID. (Participant 18, female, academic) As generations get older and they're more comfortable with communicating through text and all that type of stuff, I think those types of services will just be yeah, rapidly continue to grow for sure. (Participant 22, male, industry partner)
Uncertainty	But how far that goes, I don't know. I don't know if it'll be all of our country appointments or some of them or what. (Participant 14, female, clinician)
Withdrawal	I think it's such a shame that, or from what I've seen, that the rates of adoption of teleaudiology went backwards after COVID. I think that speaks to a little bit about the haphazardness or the lack of formal structure and implementation that clinics who did adopt teleaudiology, they just used it as a stopgap measure rather than trying to create a really solid business and the plan and procedure to long term adoption of teleaudiology, I mean that's what I saw in my clinical experience. (Participant 13, female, academic)
Willingness to use/learn/teach teleaudiology over time	/

Increased willingness	Certainly has. I think, particularly over the last two or three years when we've had to use a lot of Zoom, a lot of Teams, a lot of umm, you know, teleaudiology type of appointment, even with other medical professionals. Because we haven't been able to go personally, I think that's improved a lot of people’s skills and willingness to actually do it, because I think it's sort of proved that it's viable. (Participant 7, female, client) I think it's certainly over time, you know, and my willingness to do it will increase because I think the technology will get better, which means it will be less hassle. Clients will be more accepting of it, which means they'll seek it out and we'll be happy to obviously engage in it as well. (Participant 12, female, clinician) I think it's become a much bigger thing since COVID and definitely much more of a willingness and much more motivated to learn about it since COVID. And with a lot of things going online as well. So I'd say in the last few years for sure, like just telehealth in general, (I have) become a lot more motivated to learn. (Participant 6, female, student) I definitely think that students are more interested in exploring various digital ways in which they can interact with their patients. (Participant 18, female, academic) I see quite a lot of clinics ranging in all sizes and shapes and sizes across NSW (New South Wales) and ACT (Australian Capital Territory). And I'd say over the last 12 months, I've seen in an increased interest in providing remote care teleaudiology services. (Participant 22, male, industry partner)
No change in willingness	No (change), I guess. (Participant 2, female, client) I've always been very willing. (Participant 8, male, clinician) I'm a very big supporter of utilising technologies to improve the way that we work. So, you know, the experience of COVID was way welcomed in the sense that it pushed a lot of people to do things that they otherwise were very reluctant in doing. So I don't think I need to push. I think I'm already there, but it certainly helps push other people and COVID has helped with that a lot. (Participant 18, female, academic) It probably hasn't changed over time, to be honest. You know, I've always been willing. (Participant 22, male, industry partner)
Decreased willingness	It was after that experience, I was kind of like, well, I won't be doing that unless I absolutely have to. (Participant 19, female, clinician) Obviously it was more during the lockdown. It is more for rural (clients). But as we go forward, I prefer to

		actually see my clients who can come in, so it has decreased over time from the lockdown. (Participant 20, female, clinician)

Note. Slashes indicate there is no example quote for the corresponding code.

Nonetheless, a clinician simultaneously expressed uncertainty due to their client population and work nature (paediatric diagnostic assessment), thinking that teleaudiology might have a place in their work, but they were unsure to what extent it could be used. In addition, it is noteworthy that an academic observed withdrawal from teleaudiology use after the pandemic, as some clinics which adopted teleaudiology during the pandemic "just used it as a stopgap measure rather than trying to create a really solid business and the plan and procedure to long term adoption of teleaudiology" (Participant 13, female, academic).

When participants were asked how their willingness to use/learn/teach teleaudiology changed over time, increased willingness was the most common response (n = 14), followed by unchanged willingness (n = 6), then decreased willingness (n = 3). In general, advancement in technology, the occurrence of the COVID-19 pandemic, and the popularisation of Internet communications underpinned participants' increased willingness. For instance, as a client elaborated:

> I think, particularly over the last two or three years when we've had to use a lot of Zoom, a lot of Teams, a lot of teleaudiology type of appointment, even with other medical professionals. Because we haven't been able to go personally, I think that's improved a lot of people's skills and willingness to actually do it, because I think it's sort of proved that it's viable (Participant 7, female, client).

As for the participants with unchanged willingness, a majority of them explained that they were already willing to use teleaudiology and it had not changed over time. For example, an academic had been a big supporter of teleaudiology and did not need additional motivation to accept teleaudiology use, but they thought that the pandemic gave such motivation to other people who would not try teleaudiology otherwise. Lastly, for the participants who reported decreased willingness, they either encountered technological difficulties which dampened their confidence in future teleaudiology uptake, or felt that teleaudiology was no longer necessary with the ease of social restrictions post-pandemic.

5.7 Discussion

The current study into teleaudiology use in Australian hearing healthcare stakeholders post-pandemic identified digital literacy, technological issues, and a preference for face-to-face services as key barriers to future uptake; echoing concerns in existing literature (Bennett & Campbell, 2021; Eikelboom & Swanepoel, 2016; Mui et al., 2023). Similarly, clinicians have reported teleaudiology as unsuitable for specific client populations and types of services, e.g., elderly clients and paediatric diagnostic assessment (Rashid et al., 2019; Singh et al., 2014). This shows that age and unconscious bias is present among some clinicians.

Receiving little to no support from other stakeholders, such as clinicians or allied health assistants, was noted to be a barrier to teleaudiology uptake. In contrast, participants also shared positive experiences of receiving support from their fellow colleagues, which enabled the successful use of teleaudiology. Apart from the provider's perspective, clients who need help with utilising technology may also benefit from the assistance of a third party, such as their family members, parents, or caregivers, before and during a teleaudiology appointment. Having a facilitator on the client's side during a teleaudiology appointment is not a rare practice, as indicated by a scoping review (Coco et al., 2020). There lies a caveat, nevertheless, that miscommunication between the clinician and assistant can potentially result in less favoured outcomes. For example, a clinician in this study described how their front of house staff took over the teleaudiology appointment and overstepped their duties. In order to maximise the benefits of a facilitator's involvement, training should be provided to the facilitator beforehand on their duties and responsibilities, and the purposes and expectations of the appointment should be communicated clearly between the clinician and the facilitator. Reflective debriefing sessions may also be organised to discuss strengths to be upheld and weaknesses to be improved.

As an extension of a nationwide survey conducted in Australia in 2022 (Mui et al., 2023), participants in the current study reported some recent development in improving teleaudiology uptake which was not observed in the previous study, e.g., increased support from management in clinical and university settings. It is encouraging to know that the leadership team of certain hearing healthcare providers advocates teleaudiology use by investing in positions and departments dedicated to teleaudiology service delivery. This can be an indicator of the leadership team recognising and acknowledging the feasibility and benefits of teleaudiology use, and a display of the hearing healthcare providers' commitment to ensuring continuity of care and servicing to remote communities.

Commitment to teleaudiology in the university setting has also been observed. One university had established a teleaudiology clinic to be used for clinical and teaching purposes. This is an important investment as a lack of infrastructure has been noted in multiple studies as a barrier to teleaudiology uptake (Eikelboom & Swanepoel, 2016; Saunders & Roughley, 2021; Zaitoun et al., 2022). Although the above studies explored barriers from clinicians' point of view, it is rational to postulate that the same barrier applies to universities. Without suitable space, equipment, and personnel, teleaudiology education can be rendered restrictive, possibly merely at the level of theoretical knowledge transfer with no hands-on clinical experience. Acquisition of knowledge and experience through clinical practice is essential for students, not only to solidify their learning by interacting with real-life clients, but also to improve students' confidence levels (Santella et al., 2020). Universities are the nurturing grounds for future clinicians. Increased opportunities for students to learn teleaudiology will likely improve their acceptance and willingness of using teleaudiology when they practice as clinicians. Same as any other topics in the curriculum, addition of teleaudiology to the curriculum requires meticulous planning and preparation. To name a few, staffing, funding, infrastructure, and teaching materials are some of the imperative considerations. Bringing changes to the university curriculum may not be a simple and quick process, yet in an era where teleaudiology has been proven to be viable and advantageous, it may be worthwhile for universities to reevaluate the importance of teleaudiology education and take the initiative in the joint effort of the accreditation organisation (Audiology Australia) to be a key driver of teleaudiology uptake. There is room for the accreditation standards and process to be strengthened and continually reviewed.

This study revealed generally positive attitudes towards teleaudiology uptake among hearing healthcare stakeholders in Australia. Towards the end of the COVID-19 pandemic, most participants indicated that their willingness to use teleaudiology over time increased, and they were optimistic about post-pandemic teleaudiology uptake. These findings echo those from previous studies reporting increased perceived importance of teleaudiology during the pandemic and increased motivation to use teleaudiology during and after the pandemic (Bennett, Kelsall-Foreman, et al., 2022a; Eikelboom et al., 2022; Saunders & Roughley, 2021). It is nonetheless notable that uncertainties around the accuracy and effectiveness of some types of teleaudiology services (e.g., diagnostic assessment) still exist and need to be addressed before teleaudiology is more widely accepted and used. As some of the participants in this study emphasised, teleaudiology is best considered as a complement rather than a replacement of in-person services. As with in-person service delivery, teleaudiology may not be a one-size-fits-all solution, but its capability and benefits certainly need more recognition for this option to be made available to a larger population. Teleaudiology will be here to stay beyond the pandemic, only if hearing healthcare stakeholders are willing to try to utilise it and the government provides continuous support (e.g., funding for reimbursement).

5.7.1 Limitations

The sample size of each stakeholder group was small (*N* = 23; six clients, 10 clinicians, three students, two academics, and two industry partners) despite all effort in participant recruitment. It is highly likely that underrepresentation of each stakeholder group exists, especially for students, academics, and industry partners. Moreover, as the lockdown measures during the COVID-19 pandemic, status of teleaudiology implementation, motivation for teleaudiology adoption (e.g., government funding), hearing healthcare system structure, and the diversity of stakeholders (such as cultural background, ethnicity, and spoken language) may vary greatly between Australia and other countries, it may not be appropriate to generalise the findings from this study to other countries. Additionally, the small number of responses collected from each stakeholder group rendered the determination of data saturation impossible. Lastly, self-selection bias might exist in this study, as individuals who were more vocal about teleaudiology might be more inclined to accept the invitation to participate in this study.

5.7.2 Future directions

For the aforementioned limitations to be addressed, qualitative studies with larger sample size per stakeholder group are needed to further explore the views of different hearing healthcare stakeholders on teleaudiology uptake. Changes in the extent of teleaudiology uptake may also be continuously observed in the post-pandemic environment. Future studies at an international scale will be useful in delineating the differences in the landscape of teleaudiology uptake across countries, from which novel insights may be obtained to improve teleaudiology use. For example, strategies for improving teleaudiology uptake (e.g., strategic measures and policies implemented by hearing healthcare providers and governments) may be shared and referred to within and among countries. In addition, further investigation on the roles and effects of facilitators on the quality, satisfaction, and outcomes of teleaudiology consultations, as well as the significance and effectiveness of training provided to facilitators may be of interest.

Follow-up studies on teleaudiology education at universities may prove beneficial, especially with the recent developments in university infrastructure and curriculum modification at some universities. It will be interesting to discover whether universities that do not currently include teleaudiology in the curriculum will follow the steps of the universities that have, and the motivation and challenges behind such decisions. Furthermore, it may be worthwhile to investigate how much the curriculum makes a difference to clinical practice. For example, the kind of influence the curriculum can create on clinical practice that may or may not support teleaudiology education. Besides, students' willingness and confidence in using teleaudiology may be of particular interest, as these future clinicians may become strong advocates for teleaudiology use if they gain adequate relevant experiences during their study.

CHAPTER 6 – VALIDATING SMARTPHONE-BASED AND WEB-BASED APPLICATIONS FOR REMOTE HEARING ASSESSMENT (STUDY 4)

6.1 Contribution to overall PhD aim

For the purpose of expanding the research evidence of utilising apps for hearing assessment, this study examined various aspects of two smartphone-based hearing assessment applications alongside one web-based application in comparison with conventional in-person hearing assessment. This addition to the current literature will hopefully facilitate discussion and reflection upon adopting teleaudiology tools in conducting hearing assessment in Australia where such practice is uncommon. This chapter aims to answer **research question 3** – What is the performance, ecological validity, and usability of two smartphone-based hearing assessment applications – Hearing Test (Android version) and Mimi Hearing Test (iOS version) – alongside a web-based application, MDHearing Aid in screening for mild and moderate hearing loss?

6.2 Statement of co-authorship and author contributions

This chapter contains materials from the accepted manuscript as indicated below. The signed co-authorship approval form can be found in Appendix 1.

Mui, B., Swanepoel, D. W., Manchaiah, V., Muzaffar, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Validating smartphone-based and web-based applications for remote hearing assessment. *Journal of the American Academy of Audiology*.

B. Mui, D. W. Swanepoel, V. Manchaiah, and G. S. Shekhawat were involved in the study conceptualisation and design. B. Mui recruited participants and conducted data collection. B. Mui, D. W. Swanepoel, and V. Manchaiah were involved in data analysis. B. Mui wrote the original draft of the manuscript and all co-authors were involved in reviewing the draft.

6.3 Abstract

Background: High prevalence of hearing loss and its physical, mental, and social impacts when unaddressed underscore a need for early identification. However, in-person hearing assessment may be inaccessible in certain countries and areas. As such, numerous smartphone-based and web-based apps have been developed to perform remote hearing assessment and yet, many of them remain unvalidated.

Purpose: To evaluate the performance, ecological validity, and usability of two freely available smartphone-based hearing assessment apps – Hearing Test (Android) and Mimi Hearing Test (iOS) – alongside a web-based app, MDHearing Aid in screening for mild and moderate hearing loss.

Research design: A cross-sectional validation study.

Study sample: Sixty adults with hearing thresholds no greater than 20 dB HL or any degree of sensorineural hearing loss.

Data collection and analysis: Participants completed standard audiometric testing followed by assessments using three apps in a controlled laboratory setting. The assessments were repeated by participants at home the subsequent day. The MAUQ was administered to evaluate the apps' usability. Performance metrics included sensitivity, specificity, accuracy, and test-retest reliability. Intraclass correlation coefficient (ICC) estimates were calculated to measure the apps' accuracy, test-retest reliability, and ecological validity.

Results: All apps had moderate to good sensitivity (0.67-1.00) and specificity (0.72-0.99). Hearing Test app showed poor accuracy at lower frequencies (ICC: 0.24-0.53) and moderate to good accuracy above 1000 Hz (ICC: 0.74-0.83). Mimi Hearing Test showed poor accuracy at lower frequencies (ICC: 0.27-0.50) and moderate to good accuracy above 2000 Hz (ICC: 0.68-0.85). Web-based MDHearing Aid test showed moderate to good accuracy across frequencies (ICC: 0.64-0.85). All apps had moderate to excellent test-retest reliability (ICC: 0.66-0.99), and showed poor ecological validity below 500 Hz (ICC: 0.20-0.51) and moderate to excellent ecological validity above 1000 Hz (ICC: 0.54-0.95). Usability was rated highly across all apps, with MAUQ scores ranging from 5.4 to 5.9 out of 7.

Conclusions: The examined apps exhibit varied accuracy levels and generally reasonable sensitivity, specificity, test-retest reliability, ecological validity, and usability. With additional validation, the Hearing Test app may be useful for hearing screening and monitoring in adults. There is a necessity for further research to unlock the examined apps' full clinical potential.

Keywords: Teleaudiology; smartphone; website; applications (apps); hearing assessment

6.4 Introduction

Hearing loss is a highly prevalent condition affecting at least 1.5 billion people globally, with about one-third experiencing moderate to profound hearing loss (World Health Organization, 2021). Ranked as the third most common disability, hearing loss has profound physical, mental, and social ramifications (Haile et al., 2021). Unaddressed hearing loss is linked to various adverse outcomes, including impaired speech development in children (Kennedy et al., 2006; Khairi Md Daud et al., 2010), communication difficulties (Davisa & Hoffman, 2019), diminished mental wellbeing and quality of life (Nordvik et al., 2018; Tambs, 2004), increased risk of cognitive decline and dementia (Thomson et al., 2017), lower educational achievements (Emmett & Francis, 2015), and higher unemployment rates (Emmett & Francis, 2015; Winn, 2007). Prescription of hearing aids (HAs) is a common intervention for hearing loss. Despite the above impacts, only 17% of those who could benefit from wearing a HA actually use one (World Health Organization, 2021).

Early detection and subsequent hearing assessment is key to understanding an individual's hearing performance and determining the type of intervention or support. Pure tone audiometry (PTA) is fundamental in diagnosing and managing hearing loss by characterising hearing sensitivity across the frequency spectrum (typically 250 to 8000 Hz) and classifying the degree of hearing loss (no hearing loss, mild, moderate, severe, or profound hearing loss) (World Health Organization, 2021). However, access to in-person hearing assessment is not universally available, especially in low- and middle-income countries as well as rural areas in high-income countries where hearing care providers are scarce and hearing loss is prevalent (World Health Organization, 2021).

Teleaudiology, leveraging telecommunication to deliver hearing care remotely, has emerged as a potential solution, encompassing a range of services from screening to rehabilitation (American Speech-Language-Hearing Association, n.d.-d; D'Onofrio & Zeng, 2021; Eikelboom et al., 2021; Frisby et al., 2021; Jacobs & Saunders, 2014). Apart from real-time or store-and-forward consultations, teleaudiology can enable clients to manage their hearing health independently using smartphone-based and web-based apps without the involvement of a clinician (Eikelboom et al., 2021; Jacobs & Saunders, 2014). Examples of self-led management include the use of apps to measure and monitor hearing thresholds, perform auditory training, manage hearing devices, learn to manage tinnitus distress, and obtain knowledge and skills to manage hearing loss (Eikelboom et al., 2021; Jacobs & Saunders, 2014).

The high prevalence of smartphone ownership has made self-administered hearing assessment via smartphone apps and web-based apps more accessible, predominantly in higher income countries where smartphones are more readily accessible (Almufarrij et al., 2022; Bright & Pallawela, 2016; Degenhard, 2023; Irace et al., 2021). Two types of audiometric testing – tone-based and speech-based tests – are usually employed by these apps (Swanepoel et al., 2019). Tone-based hearing assessment apps typically utilise PTA to assess hearing sensitivity, whereas speech-based apps (e.g., the official hearWHO app released by WHO (De Sousa et al., 2022)) often utilise speech-in-noise tests to gauge users' speech recognition ability in noise (Swanepoel et al., 2019). Reviews of hearing assessment apps revealed a growing number of validation studies on their accuracy but comparing to the number of hearing assessment apps, the number of these studies is still lacking. In 2015, only six out of 30 hearing assessment apps were evaluated in peer-reviewed studies (Bright & Pallawela, 2016). Most of the validation studies were prone to high risk of bias and the accuracy of apps varied greatly across studies (Bright & Pallawela, 2016). In 2020, Irace et al. conducted another review and identified 44 smartphone apps and seven of those had been validated (Irace et al., 2021). Almufarrij et al. expanded the list of hearing assessment apps in the same year with the inclusion of web-based apps and 187 apps were identified (Almufarrij et al., 2022). Twenty-two apps were evaluated in peer-reviewed studies and 14 were determined to have acceptable functionality (Almufarrij et al., 2022). All reviews concluded that validation studies of hearing assessment apps were largely lacking and the accuracy of most apps remained unknown (Almufarrij et al., 2022; Bright & Pallawela, 2016; Irace et al., 2021).

Given the potential of PTA hearing assessment apps in the marketplace to reach wider populations, there is a pressing need for more rigorous independent evaluations into their overall quality and effectiveness. This study aims to address this gap by evaluating the performance (sensitivity, specificity, accuracy, test-retest reliability), ecological validity, and usability of two smartphone apps and one web-based app against standard PTA testing.

6.5 Materials and methods

Ethical approval was obtained from Flinders University Human Research Ethics Committee prior to the start of data collection (Project ID: 6268).

6.5.1 Participants

Sixty adult participants (*N* = 60) from South Australia were recruited through the research team's participant database and Facebook advertisements. The inclusion criteria were: 1) aged 18 years or older, 2) having either hearing thresholds no greater than 20 dB HL (the reference range) or any degree of sensorineural hearing loss (confirmed by a baseline in-person hearing assessment), 3) having access to a smartphone device capable of running either of the two smartphone apps and the web-based app, and 4) having earphones for all hearing assessments. Individuals with conductive or mixed hearing losses were excluded due to the presence of an air-bone gap in their hearing thresholds which was unlikely to be detected by a smartphone app with a set of standard earphones. All participants completed an online consent form prior to their participation.

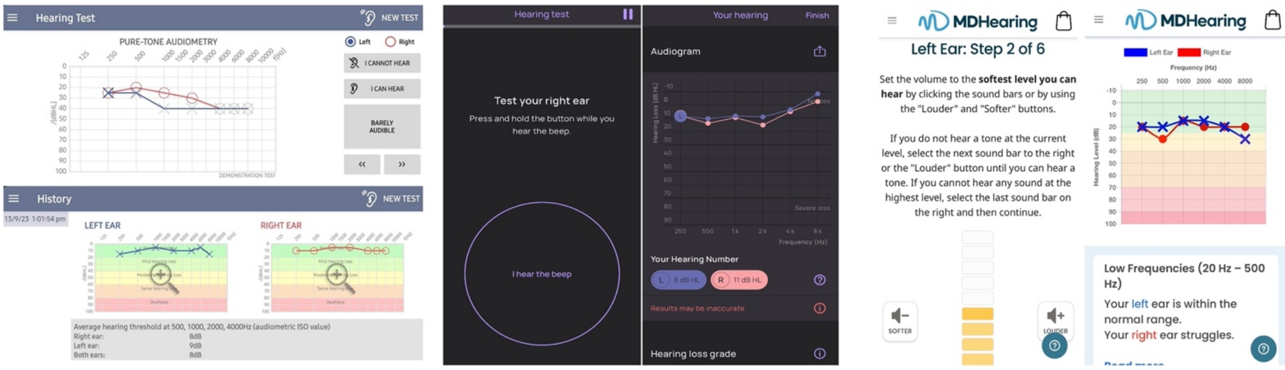
6.5.2 Selected apps

Two smartphone apps, Hearing Test (Android version; e-audiologia.pl, Radwanice, Poland) and Mimi Hearing Test (iOS version; Mimi Hearing Technologies, Berlin, Germany), and one web-based app, MDHearing Aid (https://www.mdhearingaid.com/hearing-test/) (MDHearing, Chicago, USA), were selected for this study. The criteria for app selection included being available for free, the provision of PTA-based testing that outputs numerical hearing thresholds, and high ratings on the Mobile App Rating Scale (MARS), according to findings from previous studies (Almufarrij et al., 2022; Irace et al., 2021).

The Hearing Test app and the MDHearing Aid web-based test determine users' hearing thresholds by presenting tones at individual frequencies. Users are instructed to adjust the volume until the tone is barely audible. While the Hearing Test app displays an audiogram of recorded thresholds in real time, the MDHearing Aid test reveals the complete audiogram only after the test concludes. In contrast, the Mimi Hearing Test employs Békésy audiometry (Erlandsson et al., 1979), featuring a tone that sweeps continuously across frequencies. Users press and hold a button to indicate the tone's audibility and release it when the tone is no longer heard. For the MDHearing Aid test and Mimi Hearing Test, users must set their earphone volume to 100% and 50%, respectively, before starting. Additionally, the Mimi Hearing Test includes a noise monitoring function that pauses the test if ambient noise levels become too high. A comparative analysis of the apps' features is available in Table 6.1, with screenshots provided in Figure 6.1.

Table 6.1 Comparison of app features between Hearing Test (Android) app, Mimi Hearing Test (iOS) app, and MDHearing Aid (Web) test.

App feature	Hearing Test (Android) app	Mimi Hearing Test (iOS) app	MDHearing Aid (Web) test
Testing method	Conventional PTA: user adjusts volume until tone reaches lowest audible level	Békésy audiometry: user listens to a tone continuously sweeping across frequencies and presses and holds a button when tone is heard, then releases button when tone is no longer audible	Conventional PTA: user adjusts volume until tone reaches lowest audible level
Test frequencies (Hz)	250, 500, 1000, 2000, 4000, 6000, 8000	250, 500, 1000, 2000, 4000, 8000	250, 500, 1000, 2000, 4000, 8000
Volume setting	None	Set to 50%	Set to 100%
Audiogram	Displayed during test; Hearing thresholds recorded from -10 to 75 dB HL in 5-dB intervals	Not displayed during test; Hearing thresholds recorded from -10 to 75 dB HL in 1-dB intervals	Not displayed during test; Hearing thresholds recorded from -10 to 80 dB HL in 5-dB intervals
Noise monitoring	None	Active during test, test will be paused if ambient noise levels become too high	None



(a) (b) (c)

Figure 6.1 Screenshots of (a) Hearing Test (Android) app, (b) Mimi Hearing Test (iOS) app, and (c) MDHearing Aid (Web) test.

6.5.3 Procedures

6.5.3.1 Baseline hearing assessment (Day 1)

The testing procedure is summarised in Figure 6.2. All participants attended an in-person hearing assessment performed by the research team at baseline (Day 1). The hearing assessment took place in a double-walled, sound-proof room at Flinders University. The baseline assessment included otoscopy, tympanometry, and PTA ranging from 250 to 8000 Hz. Tympanometry was conducted using Grason-Stadler GSI-38 V.4 Auto Tympanometer. Both air-conduction and bone-conduction PTA were performed using MedRx AVANT A2D+ Audiometer and NOAH 4 software. Air-conduction thresholds were bilaterally measured at 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz using circumaural DD450 earphones. Bone-conduction thresholds were monaurally measured using a bone conductor at 500, 1000, 2000, and 4000 Hz. Modified Hughson-Westlake procedure was utilized for PTA (Carhart & Jerger, 1959). Masking was applied to obtain air-conduction and bone-conduction thresholds when necessary.

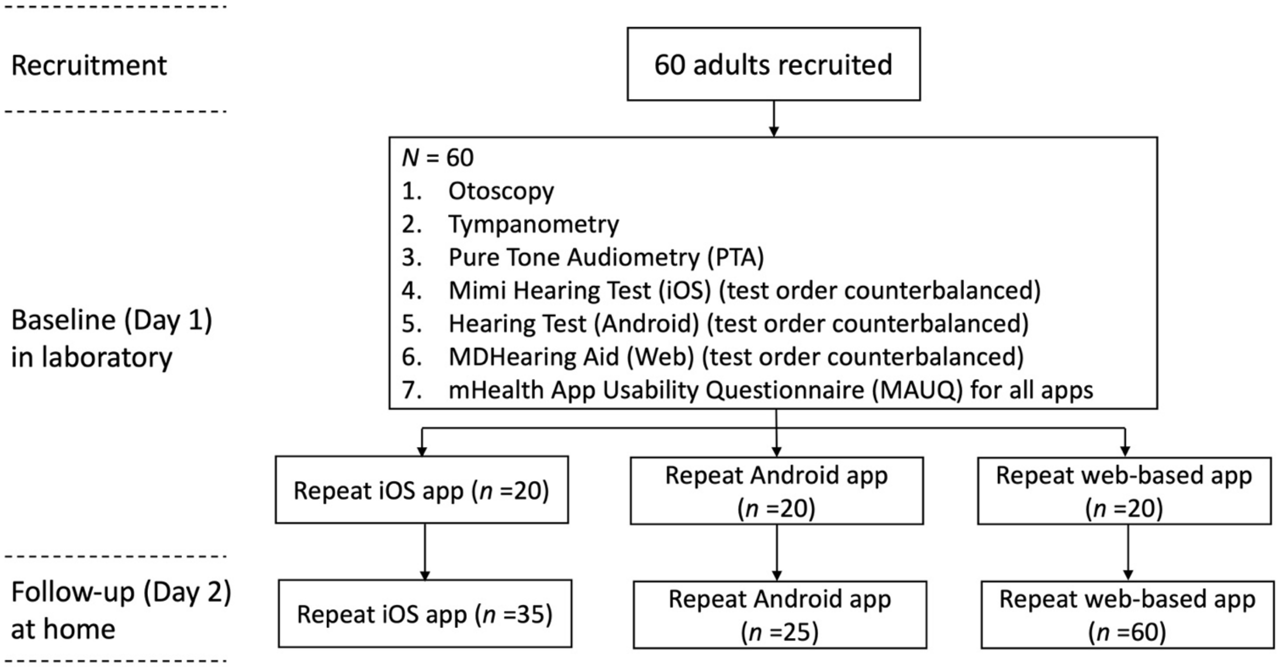


Figure 6.2 Flowchart of testing procedure.

After the researcher-administered hearing assessment, participants completed assessments using each of the three selected apps. All app-based hearing assessments on Day 1 were done using iPhone 11 with AirPods Pro and Samsung Galaxy A13 with Galaxy Buds2 provided by the research team. Web-based hearing assessments were completed using iPhone 11 with AirPods Pro. The testing order was randomised using a list randomiser (https://www.random.org/lists/) according to the order of participant recruitment to reduce order-effect bias, e.g., first participant tested in the order of iOS-Android-Web apps, second participant in Android-iOS-Web order, third participant in Web-iOS-Android order, and so forth. To collect data on app usability, participants completed the MAUQ immediately after using each app (Zhou et al., 2019). The MAUQ is an 18-item validated questionnaire using a 7-point Likert scale to rate various aspects of app usability from strongly disagree (1 point) to strongly agree (7 points) (see Appendix 14). A mean MAUQ score was calculated for each app by dividing the total MAUQ score by 18. The lowest and highest possible mean MAUQ scores were 1.0 and 7.0, respectively. A higher score indicated higher app usability.

Towards the end of the session, participants were asked to redo an assessment using one of the three apps to determine test-retest reliability. They were randomly assigned to three groups based on the order of participant recruitment, each repeating the test on a different app. All hearing assessments using the three apps were performed in the same sound-proof room with the door opened so that soft ambient sounds could enter to imitate a quiet testing environment. The researcher stayed with the participant in the same room throughout the appointment to administer the MAUQ, answer participants' questions, and troubleshoot when necessary.

6.5.3.2 Follow-up hearing assessment (Day 2)

On the following day (Day 2), participants completed hearing assessments using the web-based app (*n* = 60) and one of the smartphone apps based on the smartphone model they owned (iOS: *n* = 35; Android: *n* = 25). Participants were instructed to undertake the assessments preferably in the morning with their own smartphones and earphones in a quiet location at their home. They then took screenshots of the audiograms generated from the apps and sent them to the research team.

6.5.4 Data analysis

IBM SPSS Statistics (Version 29) was used for data analysis. Descriptive analysis (e.g., mean, standard deviation) was performed. App sensitivity and specificity were determined in comparison with standard audiometric testing in terms of hearing loss identification. Sensitivity was calculated by: True positives/(True positives + False negatives), and specificity was calculated by: True negatives/(True negatives + False positives), and both were averaged across ears. Hearing loss is defined by a pure tone average (calculated from 500, 1000, 2000, and 4000 Hz) greater than 20 dB HL (Olusanya et al., 2019). Accuracy of apps was determined by the percentage of tested ears which yielded hearing thresholds within 5 and 10 dB between app measurement and standard audiometric testing, root mean square deviation (RMSD), and ICC estimates on Day 1. RMSD values of 10 dB or lower (i.e., quadratic mean of the differences between hearing thresholds obtained from the apps and standard audiometric testing ≤ 10 dB) were considered as within minimum acceptable accuracy (Wasmann et al., 2022). Test-retest reliability was determined by the ICC estimates of the hearing thresholds obtained from the first and repeated tests using each app on Day 1. Ecological validity was determined by the ICC estimates of the hearing thresholds obtained from the first tests on Day 1 (laboratory environment) and repeated tests on Day 2 (home environment) using the same app. App usability was calculated from mean MAUQ scores. ICC estimates and their 95% confidence intervals were calculated based on an absolute-agreement, two-way mixed-effects model. ICC values of less than 0.5 indicated poor reliability, 0.5 to 0.75 indicated moderate reliability, 0.75 to 0.9 indicated good reliability, and greater than 0.9 indicated excellent reliability (Koo & Li, 2016). Out-of-range hearing thresholds which were unable to be determined by standard audiometric testing and the apps at certain frequencies were excluded from analysis.

6.6 Results

6.6.1 Participant characteristics

Of 60 participants, 31 (52%) were female (mean age: 50 years; *SD* = 17; range: 24-74), 28 (47%) were male (mean age: 49 years; *SD* = 18; range: 24-80), and one (0.02%) identified as other gender. The participants had an overall mean age of 50 years (*SD*: 17; range: 23-80). Of 120 ears tested, 93 (78%) had hearing thresholds in the reference range and 27 (23%) had some degree of sensorineural hearing loss. No ear tested had conductive or mixed hearing loss.

6.6.2 Sensitivity, specificity, and accuracy

In terms of sensitivity and specificity in identifying a hearing loss, Hearing Test app had the best performance in general, with a sensitivity of 0.96 and a specificity of 0.99. Mimi Hearing Test had a sensitivity of 1.00 and a specificity of 0.72, whereas MDHearing Aid test had a sensitivity of 0.67 and a specificity of 0.94.

Mean hearing thresholds obtained from standard audiometric testing and the three apps (participants *N* = 60; ears *N* = 120) are shown in Tables 6.2-6.4 and the corresponding audiograms are visualised in Figure 6.3. Hearing Test app had poor accuracy at lower frequencies of 250 and 500 Hz (ICC: 0.24-0.53), and 13-32% and 38-69% of tested ears had hearing threshold differences within 5 and 10 dB between app testing and standard audiometric testing, respectively. Its accuracy was moderate to good from 1000 to 8000 Hz (ICC: 0.74-0.83), and 43-63% and 71-88% of tested ears had hearing threshold differences within 5 and 10 dB between app testing and standard audiometric testing, respectively. Hearing Test app generally overestimated hearing thresholds (i.e., reduced hearing) below 2000 Hz and underestimated hearing thresholds (i.e., better hearing) from 4000 to 8000 Hz. This app showed RMSD values ranging from 8.2 to 17.1 dB across frequencies, with those at 1000 and 2000 Hz (8.2 and 9.0, respectively) being within minimum acceptable level. Mean hearing thresholds obtained from Hearing Test app and standard audiometric testing differed by 2 to 15 dB across all frequencies.

Table 6.2 Hearing thresholds obtained from standard audiometric testing and Hearing Test (Android) app (participants *N* = 60; ears *N* = 120).

	Hearing threshold (dB HL) (mean ± SD)						
Frequency	Standard audiometric testing	Hearing Test (Android)	Absolute Mean difference (dB HL ± SD)	Hearing threshold difference within 5 dB (% of total number of ears)	Hearing threshold difference within 10 dB (% of total number of ears)	RMSD (dB)	ICC (95% CI)
250 Hz	5.2 ± 8.5	20.5 ± 8.9	15.3 ± 7.8	13%	38%	17.1	0.24 (0-0.56)
500 Hz	6.9 ± 11.8	16.8 ± 9.8	9.9 ± 7.8	32%	69%	12.5	0.53 (0-0.79)
1000 Hz	9.2 ± 13.1	13.4 ± 8.3	4.2 ± 7.1	63%	88%	8.2	0.74 (0.50-0.85)
2000 Hz	12.8 ± 17.3	14.3 ± 10.6	1.6 ± 8.9	53%	85%	9.0	0.80 (0.73-0.86)
4000 Hz	21.0 ± 22.8	18.6 ± 14.7	2.4 ± 11.6	44%	71%	11.8	0.81 (0.74-0.87)
6000 Hz	23.4 ± 22.3	19.7 ± 14.7	3.7 ± 10.5	43%	74%	11.1	0.83 (0.75-0.89)
8000 Hz	28.1 ± 25.9	23.1 ± 16.6	5.0 ± 12.4	49%	71%	13.3	0.82 (0.71-0.88)

Note. RMSD = Root mean square deviation; ICC = Intraclass correlation coefficient; CI = Confidence interval.

Table 6.3 Hearing thresholds obtained from standard audiometric testing and Mimi Hearing Test (iOS) app (participants *N* = 60; ears *N* = 120).

	Hearing threshold (dB HL) (mean ± SD)						
Frequency	Standard audiometric testing	Mimi Hearing Test (iOS)	Absolute Mean difference (dB HL ± SD)	Hearing threshold difference within 5 dB (% of total number of ears)	Hearing threshold difference within 10 dB (% of total number of ears)	RMSD (dB)	ICC (95% CI)
250 Hz	5.2 ± 8.5	21.2 ± 8.9	16.0 ± 6.6	4%	15%	17.3	0.27 (0-0.62)
500 Hz	6.4 ± 10.6	18.5 ± 10.0	12.0 ± 6.8	14%	40%	13.8	0.47 (0-0.78)
1000 Hz	8.7 ± 11.9	22.4 ± 11.4	13.8 ± 6.5	9%	26%	15.2	0.50 (0-0.81)
2000 Hz	12.2 ± 16.4	24.9 ± 15.0	12.8 ± 7.0	14%	38%	14.6	0.68 (0-0.90)
4000 Hz	18.2 ± 19.7	25.5 ± 16.9	7.3 ± 7.7	36%	69%	10.6	0.85 (0.39-0.94)
8000 Hz	15.9 ± 14.5	14.0 ± 12.9	1.9 ± 8.2	38%	60%	8.4	0.81 (0.73-0.88)

Note. RMSD = Root mean square deviation; ICC = Intraclass correlation coefficient; CI = Confidence interval.

Table 6.4 Hearing thresholds obtained from standard audiometric testing and MDHearing Aid (Web) test (participants *N* = 60; ears *N* = 120).

	Hearing threshold (dB HL) (mean ± SD)						
Frequency	Standard audiometric testing	MDHearing Aid (Web)	Absolute Mean difference (dB HL ± SD)	Hearing threshold difference within 5 dB (% of total number of ears)	Hearing threshold difference within 10 dB (% of total number of ears)	RMSD (dB)	ICC (95% CI)
250 Hz	6.1 ± 10.8	3.7 ± 13.3	2.4 ± 10.1	67%	84%	10.4	0.64 (0.52-0.74)
500 Hz	6.9 ± 11.8	3.7 ± 12.9	3.3 ± 9.6	53%	83%	10.1	0.68 (0.55-0.77)
1000 Hz	9.2 ± 13.1	5.7 ± 14.2	3.5 ± 9.7	60%	78%	10.3	0.73 (0.60-0.81)
2000 Hz	12.8 ± 17.3	8.7 ± 16.5	4.1 ± 10.4	54%	75%	11.1	0.79 (0.68-0.86)
4000 Hz	21.0 ± 22.8	16.5 ± 20.5	4.5 ± 11.0	48%	74%	11.9	0.85 (0.76-0.91)
8000 Hz	29.6 ± 27.3	18.4 ± 25.5	11.3 ± 11.1	24%	48%	15.8	0.84 (0.31-0.94)

Note. RMSD = Root mean square deviation; ICC = Intraclass correlation coefficient; CI = Confidence interval.

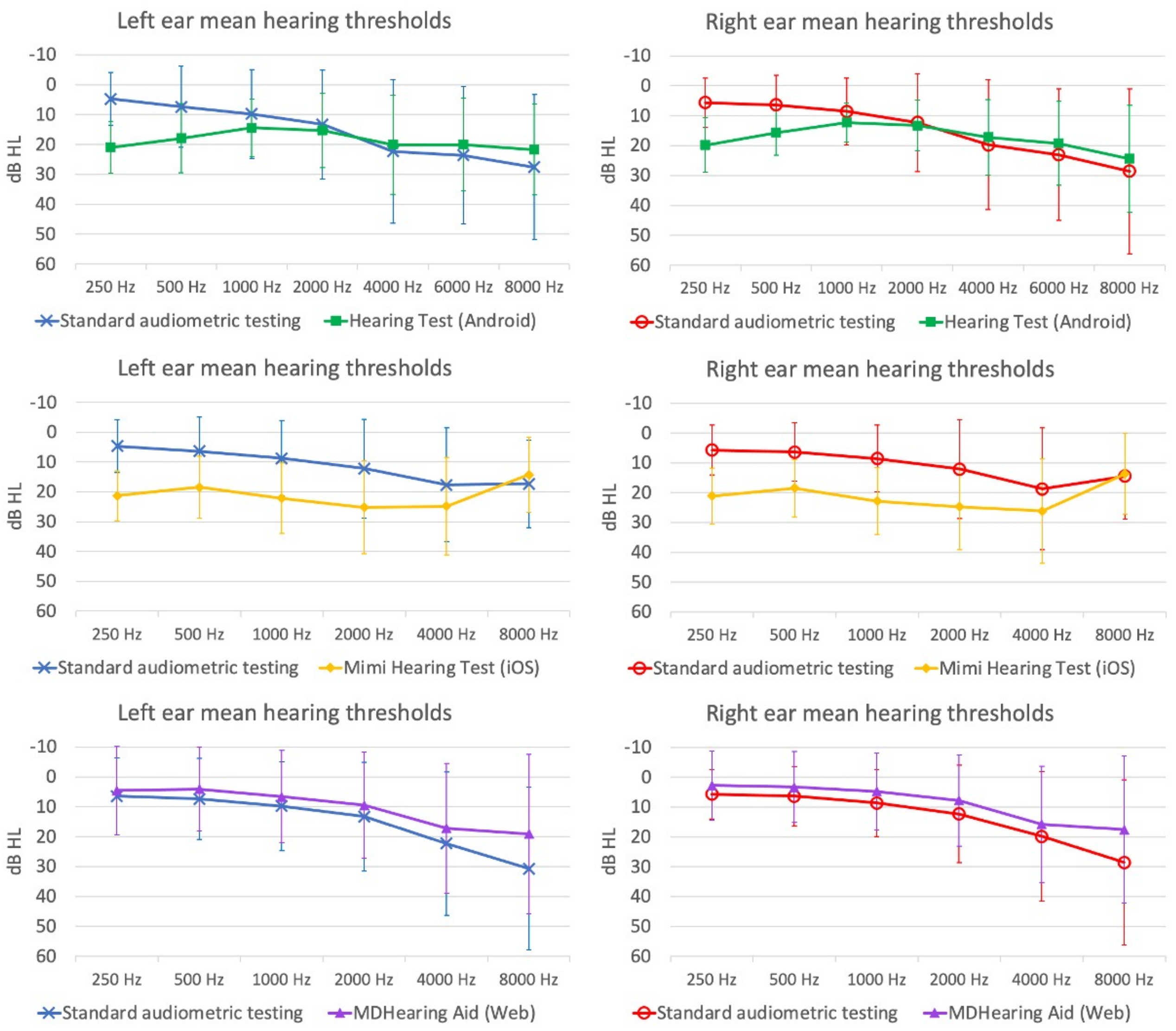


Figure 6.3 Audiograms of mean hearing thresholds obtained from pure tone audiometry and the three apps (participants *N* = 60; ears *N* = 120). Error bar represents 1 *SD*.

Mimi Hearing Test showed generally poor accuracy from 250 to 1000 Hz (ICC: 0.27-0.50), and 4-14% and 15-40% of tested ears had hearing threshold differences within 5 and 10 dB between app testing and standard audiometric testing, respectively. The app showed moderate to good accuracy from 2000 to 8000 Hz (ICC: 0.68-0.85), and 14-38% and 38-69% of tested ears had hearing threshold differences within 5 and 10 dB between app testing and standard audiometric testing, respectively. Overall, Mimi Hearing Test overestimated hearing thresholds (i.e., reduced hearing) across all frequencies. This app showed RMSD values ranging from 8.4 to 17.3 dB across frequencies, with only the one at 8000 Hz (8.4) being within minimum acceptable level. Mean hearing thresholds obtained from Mimi Hearing Test and standard audiometric testing differed by 2 to 16 dB across all frequencies.

Unlike the other two apps, web-based MDHearing Aid test showed moderate to good accuracy from 250 to 8000 Hz (ICC: 0.64-0.85), and 24-67% and 48-84% of tested ears had hearing threshold differences within 5 and 10 dB between app testing and standard audiometric testing, respectively. This app underestimated hearing thresholds (i.e., better hearing) across all frequencies. This app showed RMSD values ranging from 10.1 to 15.8 dB across frequencies, with none being within minimum acceptable level. Mean hearing thresholds obtained from MDHearing Aid test and standard audiometric testing differed by 2 to 11 dB across all frequencies.

6.6.3 Test-retest reliability

Test-retest reliability of the three apps from 250 to 8000 Hz (each app: participants n = 20; ears n = 40) is displayed in Table 6.5. Hearing Test app (ICC: 0.77-0.99) and Mimi Hearing Test (ICC: 0.87-0.98) had good to excellent test-retest reliability across all frequencies, whereas MDHearing Aid test (ICC: 0.66-0.96) had moderate to excellent test-retest reliability across all frequencies.

Table 6.5 Test-retest reliability of the three apps from 250 to 8000 Hz (each app: participants *n* = 20; ears *n* = 40).

	Hearing Test (Android)		Mimi Hearing Test (iOS)		MDHearing Aid (Web)	
	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear
Frequency	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)
250 Hz	0.77 (0.49-0.90)	0.84 (0.64-0.93)	0.87 (0.68-0.95)	0.94 (0.85-0.97)	0.83 (0.62-0.93)	0.66 (0.31-0.85)
500 Hz	0.90 (0.76-0.96)	0.74 (0.46-0.89)	0.96 (0.90-0.98)	0.91 (0.80-0.96)	0.86 (0.68-0.94)	0.68 (0.35-0.86)
1000 Hz	0.95 (0.88-0.98)	0.94 (0.86-0.98)	0.93 (0.82-0.97)	0.93 (0.83-0.97)	0.88 (0.72-0.95)	0.72 (0.42-0.88)
2000 Hz	0.89 (0.74-0.95)	0.98 (0.95-0.99)	0.97 (0.92-0.99)	0.95 (0.88-0.98)	0.92 (0.81-0.97)	0.83 (0.61-0.93)
4000 Hz	0.90 (0.76-0.96)	0.99 (0.96-0.99)	0.98 (0.93-0.99)	0.98 (0.96-0.99)	0.94 (0.85-0.98)	0.89 (0.75-0.96)
6000 Hz	0.99 (0.96-0.99)	0.98 (0.95-0.99)	/	/	/	/
8000 Hz	0.97 (0.92-0.99)	0.97 (0.94-0.99)	0.97 (0.92-0.99)	0.98 (0.95-1.00)	0.96 (0.91-0.99)	0.96 (0.90-0.98)

Note. Slashes indicate ICC value is not applicable to 6000 Hz. ICC = Intraclass correlation coefficient; CI = Confidence interval.

6.6.4 Ecological validity

Mean hearing thresholds obtained from the three apps on Day 1 and Day 2 (Hearing Test app: participants *n* = 25, ears *n* = 50; Mimi Hearing Test: participants *n* = 35, ears *n* = 70; MDHearing Aid test: participants *n* = 60, ears *n* = 120) are summarized in Tables 6.6-6.8. When hearing assessments were replicated in home environment, all apps showed poor ecological validity at low frequencies (Hearing Test app: ICC 0.20-0.27 at 250 Hz; Mimi Hearing Test: ICC 0.34-0.50 at 250 and 500 Hz; MDHearing Aid test: ICC 0.39-0.51 at 250 and 500 Hz). Hearing Test app showed moderate ecological validity from 500 to 8000 Hz (ICC: 0.54-0.76). Mimi Hearing Test showed moderate to excellent ecological validity from 1000 to 8000 Hz (ICC: 0.60-0.95). Web-based MDHearing Aid test showed moderate to good ecological validity from 1000 to 8000 Hz (ICC: 0.58-0.87).

Table 6.6 Hearing thresholds obtained from Hearing Test (Android) app on Day 1 (laboratory environment) and Day 2 (home environment) (participants *n* = 25; ears *n* = 50).

	Left ear hearing threshold (dB HL) (mean ± SD)			Right ear hearing threshold (dB HL) (mean ± SD)		
Frequency	Day 1	Day 2	Left ear ICC (95% CI)	Day 1	Day 2	Right ear ICC (95% CI)
250 Hz	20.9 ± 7.3	15.9 ± 13.7	0.20 (0-0.54)	21.3 ± 11.3	15.8 ± 14.8	0.27 (0-0.59)
500 Hz	17.3 ± 10.2	15.0 ± 12.5	0.57 (0.23-0.78)	16.5 ± 9.5	15.2 ± 12.6	0.58 (0.24-0.80)
1000 Hz	14.6 ± 8.7	14.6 ± 15.0	0.59 (0.24-0.80)	13.5 ± 8.4	14.6 ± 13.7	0.65 (0.34-0.83)
2000 Hz	17.3 ± 13.7	18.1 ± 19.0	0.76 (0.52-0.89)	15.2 ± 10.5	16.7 ± 18.5	0.68 (0.38-0.85)
4000 Hz	21.3 ± 16.0	22.1 ± 20.6	0.69 (0.41-0.86)	18.8 ± 14.2	21.7 ± 20.9	0.72 (0.45-0.87)
6000 Hz	19.6 ± 12.3	27.0 ± 22.4	0.58 (0.23-0.80)	19.4 ± 13.3	25.0 ± 20.7	0.54 (0.19-0.77)
8000 Hz	20.5 ± 12.6	26.0 ± 19.7	0.59 (0.23-0.81)	24.1 ± 17.2	28.0 ± 20.9	0.70 (0.40-0.86)

Note. ICC = Intraclass correlation coefficient; CI = Confidence interval.

Table 6.7 Hearing thresholds obtained from Mimi Hearing Test (iOS) app on Day 1 (laboratory environment) and Day 2 (home environment) (participants *n* = 35; ears *n* = 70).

	Left ear hearing threshold (dB HL) (mean ± SD)			Right ear hearing threshold (dB HL) (mean ± SD)		
Frequency	Day 1	Day 2	Left ear ICC (95% CI)	Day 1	Day 2	Right ear ICC (95% CI)
250 Hz	20.0 ± 7.8	18.7 ± 10.1	0.34 (0.01-0.60)	20.6 ± 9.6	19.6 ± 11.7	0.44 (0.12-0.68)
500 Hz	16.6 ± 7.9	17.3 ± 9.8	0.50 (0.20-0.71)	17.1 ± 9.1	17.3 ± 11.4	0.44 (0.13-0.68)
1000 Hz	20.7 ± 10.0	18.1 ± 12.0	0.60 (0.34-0.78)	20.7 ± 9.5	17.4 ± 12.4	0.67 (0.42-0.82)
2000 Hz	23.1 ± 13.8	20.0 ± 15.9	0.88 (0.73-0.94)	22.8 ± 12.2	19.5 ± 15.6	0.84 (0.67-0.92)
4000 Hz	23.9 ± 17.0	23.8 ± 19.5	0.94 (0.89-0.97)	26.1 ± 17.4	25.5 ± 18.9	0.95 (0.90-0.97)
8000 Hz	13.9 ± 13.3	15.4 ± 14.8	0.86 (0.72-0.94)	12.7 ± 13.1	12.4 ± 13.2	0.92 (0.82-0.96)

Note. ICC = Intraclass correlation coefficient; CI = Confidence interval.

Table 6.8 Hearing thresholds obtained from MDHearing Aid (Web) test on Day 1 (laboratory environment) and Day 2 (home environment) (participants *n* = 60; ears *n* = 120).

	Left ear hearing threshold (dB HL) (mean ± SD)			Right ear hearing threshold (dB HL) (mean ± SD)		
Frequency	Day 1	Day 2	Left ear ICC (95% CI)	Day 1	Day 2	Right ear ICC (95% CI)
250 Hz	3.4 ± 13.0	8.5 ± 13.2	0.51 (0.28-0.69)	2.7 ± 11.6	7.8 ± 11.2	0.39 (0.15-0.59)
500 Hz	2.8 ± 12.0	9.4 ± 12.7	0.49 (0.20-0.68)	3.1 ± 11.8	9.5 ± 13.2	0.41 (0.15-0.61)
1000 Hz	5.4 ± 13.8	9.7 ± 14.4	0.62 (0.42-0.76)	4.5 ± 12.7	9.1 ± 12.8	0.58 (0.36-0.73)
2000 Hz	8.3 ± 16.5	12.5 ± 15.9	0.78 (0.62-0.87)	7.8 ± 15.5	12.2 ± 15.9	0.75 (0.57-0.85)
4000 Hz	16.0 ± 20.9	20.0 ± 20.0	0.85 (0.75-0.91)	15.7 ± 19.3	19.1 ± 18.8	0.80 (0.68-0.88)
8000 Hz	18.9 ± 27.1	23.0 ± 25.0	0.87 (0.78-0.92)	18.9 ± 25.9	24.1 ± 25.9	0.85 (0.74-0.91)

Note. ICC = Intraclass correlation coefficient; CI = Confidence interval.

6.6.5 Usability

Usability of Hearing Test app and MDHearing Aid test were ranked highest with a mean MAUQ score of 5.9 (*SD*: 1.3 for Hearing Test app, 1.2 for MDHearing Aid test), whereas Mimi Hearing Test had a mean score of 5.4 (*SD*: 1.4). The item that scored highest for Hearing Test app and MDHearing Aid test was "The amount of time involved in using this app has been fitting for me" (6.5), while that for Mimi Hearing Test was "The navigation was consistent when moving between screens" (6.2). Regarding the lowest scored items, they were "The app helped me manage my health effectively" (5.1) for Hearing Test app, "The app improved my access to health-care services" (4.8) for Mimi Hearing Test, and "I could use the app even when the Internet connection was poor or not available" (4.0) for MDHearing Aid test.

6.7 Discussion

This study assessed two smartphone-based and one web-based hearing assessment apps, focusing on their performance (sensitivity, specificity, accuracy, test-retest reliability), ecological validity, and usability. Previous validation studies on the Hearing Test app have shown mixed evidence on its accuracy, from no statistically significant differences between hearing thresholds obtained from standard audiometric testing and the app at all frequencies (Rianto et al., 2019) to some significant differences at different frequencies (Asghar et al., 2020; Prithivi et al., 2019; Renda et al., 2016). The ICC estimates of the hearing thresholds obtained from the Hearing Test app compared to standard audiometric testing were found to range from 0.51 to 0.93 (Asghar et al., 2020; Renda et al., 2016; Rianto et al., 2019). Our study revealed a wide range of accuracy from poor to good with an ICC of 0.24 to 0.83 across frequencies. App accuracy was poorer at low frequencies with an overestimation of hearing thresholds below 2000 Hz. This overestimation might be due to ambient background noise and the app's inability to accurately present tones at lower sound levels, as tones presented below 10 dB HL were inaudible even for users with hearing thresholds within the reference range according to participants' feedback and researchers' check. This issue suggests a need for app developers to address this limitation to enhance app accuracy. Nevertheless, 10 dB HL is a low threshold already indicating hearing well within normal limits and thus, being able to test down to 10 dB HL in real-world settings may not be a significant concern.

The mean hearing thresholds on Mimi Hearing Test varied between 2 to 16 dB (*SD*: 7-8 dB) from standard audiometric testing across all frequencies. This result contrasts with previous findings, where the discrepancy was only 2 to 3 dB at low frequencies (Yesantharao et al., 2022). User's reaction time may greatly affect test results, since Mimi Hearing Test is underpinned by Békésy audiometry in which the user is required to press and hold a button when the tone is heard, and release the button when it is no longer audible. Users with longer reaction time may give slower responses when the tone is audible and/or inaudible, resulting in hearing thresholds more deviated from conventional PTA hearing thresholds.

Unlike Mimi Hearing Test, Hearing Test app and MDHearing Aid test utilise a methodology where tones are presented one frequency at a time. Users are instructed to adjust the volume until the tone is barely audible. This approach minimises the likelihood of reaction time as a confounding factor, and it permits users to revisit previous frequencies to refine their threshold levels if needed. Furthermore, from participants' anecdotal reports and the MAUQ responses, the testing time using the Hearing Test app and MDHearing Aid test was shorter than using Mimi Hearing Test, as those two apps allowed users to decide how quickly they would like to proceed in the assessment; whereas the testing duration was fixed in Mimi Hearing Test, assuming that certain number of cycles of frequency sweeping was required to be complete for threshold determination.

Hearing Test app demonstrated the ability to identify hearing loss, as evidenced by its high sensitivity and specificity. Meanwhile, Mimi Hearing Test and MDHearing Aid test had moderate specificity and sensitivity, respectively. Also, predictive values of the apps will be influenced by the prevalence of hearing loss in the sample, e.g., as the prevalence increases, the positive predictive value will increase. Due to the apps' wide range of accuracy, caution is required when interpreting the hearing thresholds recorded at individual frequencies. The degree of hearing loss may be potentially underestimated or overestimated by the apps, especially at lower frequencies where app accuracy is the lowest. Therefore, the Hearing Test app may be considered for screening purposes in adult populations, albeit further validation is warranted. Apart from hearing screening, the app may also be used for monitoring hearing thresholds given its high test-retest reliability.

When the app-based hearing assessments were repeated in home environment, the apps showed poor ecological validity at low frequencies and moderate to excellent ecological validity at mid to high frequencies. Participants using their own smartphones and earphones as well as the testing environment might have affected test results. Due to logistic reasons, provision of standardised smartphones and earphones for use in home environment was not possible. Before starting the test, Mimi Hearing Test would ask which type of earphones is used. Earphone models such as Apple AirPods are shown as supported earphones in which calibration have been performed. Selection of those supported earphones may be crucial in obtaining more accurate test results in the home environment. Ambient noise is another consideration, as environmental noise may more likely pose an effect on the detection of low-frequency tones in the app-delivered tests.

The examination of hearing assessment apps' performance is the first step to improve hearing health awareness and early detection of hearing loss. There are many considerations behind the implementation of these apps in clinical practice. For instance, in lower income areas where resources and support for identified hearing loss are less accessible, the availability of hearing healthcare professionals and funding for follow-up assessment and intervention becomes hugely crucial. The patient care journey should not stop at merely the identification or assessment stage. Overcoming this barrier may be challenging and requires effort from various parties such as the local government, hearing healthcare profession, and patient organisations to collaborate on funding and service provision and patient advocacy.

6.7.1 Limitations

There are a number of limitations in this study to be noted. Firstly, the Android version of Mimi Hearing Test was not examined since it only provided speech-based testing which did not fit the scope of this study. Secondly, caution is required for the generalisation of findings from this study, since factors such as smartphone model, earphone model, testing environment, and ambient sound level may affect test results. The smartphone and earphone models used in this study were from the same brand in an attempt to ensure best compatibility and connectivity between devices. Thirdly, as circumaural earphones may exhibit higher test-retest reliability than insert earphones, we suggest consideration of using insert earphones for the measurement of test-retest reliability in future research. Also, there was potential sampling bias as individuals who were better with technology use of apps and web-based tools might be more inclined to participate in this study. Another potential source of bias was the difference in number of participants with hearing thresholds successfully determined by standard audiometric testing across groups (Android vs iOS vs web-based apps) after out-of-range thresholds were excluded. Additionally, there was a lack of evaluation on the apps' accuracy at characterising more severe degrees of hearing loss due to the large proportion of sample with hearing thresholds within the reference range, and the results are not generalisable to children given the adult sample in this study. It is unclear whether the stimuli generated from the apps are linear at higher output levels. The apps' global validity in testing for a wider range of hearing loss (up to more severe hearing loss) can only be developed with a more diverse sample of individuals with more significant hearing loss.

6.8 Conclusions

This study revealed that Hearing Test app and Mimi Hearing Test had poor accuracy at lower frequencies and moderate to good accuracy at mid to high frequencies, whereas MDHearing Aid test had moderate to good accuracy across frequencies. All apps showed reasonable sensitivity, specificity, test-retest reliability, ecological validity, and usability. Hearing Test app may prove beneficial and useful for remote hearing screening and monitoring for adult users, although further validation is warranted. Given the overall lack of hearing assessment app validation studies, there is a necessity for further research to evaluate the performance and usability of available apps.

CHAPTER 7 – TOWARDS DIGITAL SOLUTIONS FOR TINNITUS: A RANDOMISED CONTROLLED TRIAL OF THE OTO SMARTPHONE APPLICATION (STUDY 5)

7.1 Contribution to overall PhD aim

Aiming at addressing the gaps in the evidence on the effectiveness of commercially available tinnitus smartphone apps, this study employed an RCT design for more systematic evaluation of Oto's effectiveness and usability. This study was the first RCT in which Oto's performance was examined. As same as Study 2 (Chapter 4), this chapter also aims to answer **research question 2** – What is the effectiveness and usability of Oto, a smartphone application for tinnitus management, in reducing tinnitus distress?

7.2 Statement of co-authorship and author contributions

This chapter contains materials from the manuscript under review as indicated below. The signed co-authorship approval form can be found in Appendix 1.

Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Towards digital solutions for tinnitus: A randomised controlled trial of the Oto smartphone application. *Speech, Language and Hearing*.

B. Mui, J. Muzaffar, and G. S. Shekhawat were involved in the study conceptualisation and design. B. Mui recruited participants and conducted data collection. B. Mui and J. Muzaffar were involved in data analysis. B. Mui wrote the original draft of the manuscript and all co-authors were involved in reviewing the draft.

7.3 Abstract

Objective: The aim of this study was to evaluate the effectiveness and usability of the Oto smartphone app in reducing tinnitus severity and distress.

Design: A prospective, unblinded randomised controlled trial with two arms: (i) intervention, and (ii) wait list control. The intervention arm received subscription to Oto. The primary outcome was change in Tinnitus Functional Index (TFI) score from baseline to 6 months.

Study Sample: Australian adults experiencing chronic tinnitus (≥6 months) were recruited online. Of the 207 individuals assessed for eligibility, 96 were eligible to participate (43% female, 62.4 ± 8.6 years old, experiencing tinnitus for 17.4 ± 14.8 years).

Results: The overall TFI score in the intervention group showed statistically significant improvement compared to the control group from baseline to 6 months (mean decrease = 9 points, 95% CI [2, 16], p = .006). A significantly higher proportion of the intervention group (32%) reported clinically meaningful reduction in overall TFI score (≥13 points) than the control group (12%) at 6 months, z = 2.20, p = .030. Significant interaction effects (time x treatment group) in overall TFI score were observed at 6 months, p < .001, Cohen's d = 0.62, and 9 months, p = .002, Cohen's d = 0.54. App usability was rated high on the MAUQ at 5.1 out of 7. The overall dropout rate was 21%.

Conclusions: Use of Oto was effective in reducing tinnitus severity and distress. Future evaluation should consider including a wider range of tinnitus-related outcome measures and collection of qualitative data on user experience.

Keywords: Tinnitus; smartphone applications (apps); randomised controlled trial; mobile health (mHealth); teleaudiology

7.4 Introduction

Tinnitus is an auditory condition where an audible signal is perceived when a corresponding external stimulus is absent (Baguley et al., 2013; Langguth et al., 2013). These auditory percepts of tinnitus can manifest as ringing, buzzing, clicking, or other sound types (De Ridder et al., 2021). Tinnitus is a widespread condition, affecting an estimated 14.4% of adults and 13.6% of children and adolescents globally (Jarach et al., 2022). Its prevalence increases with age, potentially due to a higher incidence of cochlear pathology (e.g., presbycusis) and cumulative noise exposure in the elderly population (Jarach et al., 2022; Lockwood et al., 2002; Nondahl et al., 2011). Besides hearing loss, tinnitus can also emerge from otologic, cardiovascular, neurologic, infectious, and medication-related origins (Baguley et al., 2013; Lockwood et al., 2002). The pathophysiology of tinnitus remains incompletely understood, though it is generally hypothesised to result from abnormal plasticity at various relays along the auditory pathway, and potentially in brain areas beyond the auditory cortex (Elgoyhen et al., 2015).

Approximately 16% of individuals with tinnitus (2.3% of global adult population) experience a bothersome type of tinnitus which can significantly impair quality of life (Jarach et al., 2022). Tinnitus has been associated with numerous comorbidities, such as depression, anxiety, heightened stress, reduced concentration, and sleep disturbances (Crönlein et al., 2016; De Ridder et al., 2021; Jay et al., 2016; Langguth et al., 2011). Furthermore, tinnitus can impose substantial financial burden on individuals with tinnitus and society in terms of treatment costs and loss of productivity. The annual costs for tinnitus care were estimated to be about EUR 2000 to 6000 per patient (Trochidis et al., 2021).

The heterogeneous nature of tinnitus in terms of symptoms, aetiologies, and pathophysiology, has led to the development of various treatments. These include pharmacological interventions, psychotherapy, sound-based treatments, magnetic or electrical stimulation, hearing aids (HAs), auditory training, and complementary and alternative medicine therapies, all of which have been evaluated in randomised controlled trials (RCTs) (Langguth et al., 2023). CBT has emerged as the most effective treatment for improving quality of life and reducing tinnitus-related psychological distress, although a cure remains elusive (McFerran et al., 2019).

Despite its high prevalence, only a small percentage of individuals with tinnitus seek professional help, possibly due to their unawareness of tinnitus services or unavailability of such services and/or providers, and many are left dissatisfied due to insufficient referrals from general practitioners to tinnitus specialists (for example, ear, nose, and throat specialists) (Carmody et al., 2023). An international survey revealed that over 70% of individuals with tinnitus found care services insufficient (Mui et al., 2022). Moreover, in-person tinnitus treatments such as CBT can be costly and time-consuming, limiting their accessibility for many individuals with tinnitus (Demoen et al., 2023). Hence, a need for alternative tinnitus treatment options which are readily accessible and require lower in-person contact arises.

To improve treatment access, there has been a surge in the development of smartphone- and Internet-based apps for tinnitus management (Deshpande & Shimunova, 2019; Kleinjung & Langguth, 2020; Mehdi, Stach, et al., 2020). These apps offer various modalities, including CBT, tinnitus retraining therapy (TRT), and sound therapies (Demoen et al., 2023; Mehdi, Riha, et al., 2020; Nagaraj & Prabhu, 2020). However, of the 250 commercially available tinnitus management apps, only seven have undergone clinical validation (Mehdi, Dode, et al., 2020). Some of these validated apps were developed on the basis of CBT. Similarly, the Oto smartphone app delivers

CBT-based tinnitus therapy, but it also contains multiple modalities including sound therapy, relaxation, and mindfulness. To address the paucity of tinnitus smartphone app validation studies in the literature, our study aimed to evaluate the effectiveness and usability of the Oto smartphone app in reducing tinnitus severity and distress.

7.5 Methods

This study adhered to the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement (Moher et al., 2012) (see Appendix 15 for checklist). Ethical approval was obtained from Flinders University Human Research Ethics Committee (Project ID: 5612), and the trial was registered in the ANZCTR (registration number: ACTRN12623001138673) on 3rd November 2023.

7.5.1 Trial design

This study adopted a two-arm, parallel-group, RCT design with data collection at baseline (T0) and at 1 month (T1), 3 months (T2), 6 months (T3), and 9 months (T4) post-baseline (Figure 7.1). The primary endpoint was set at 6 months after baseline (T3).

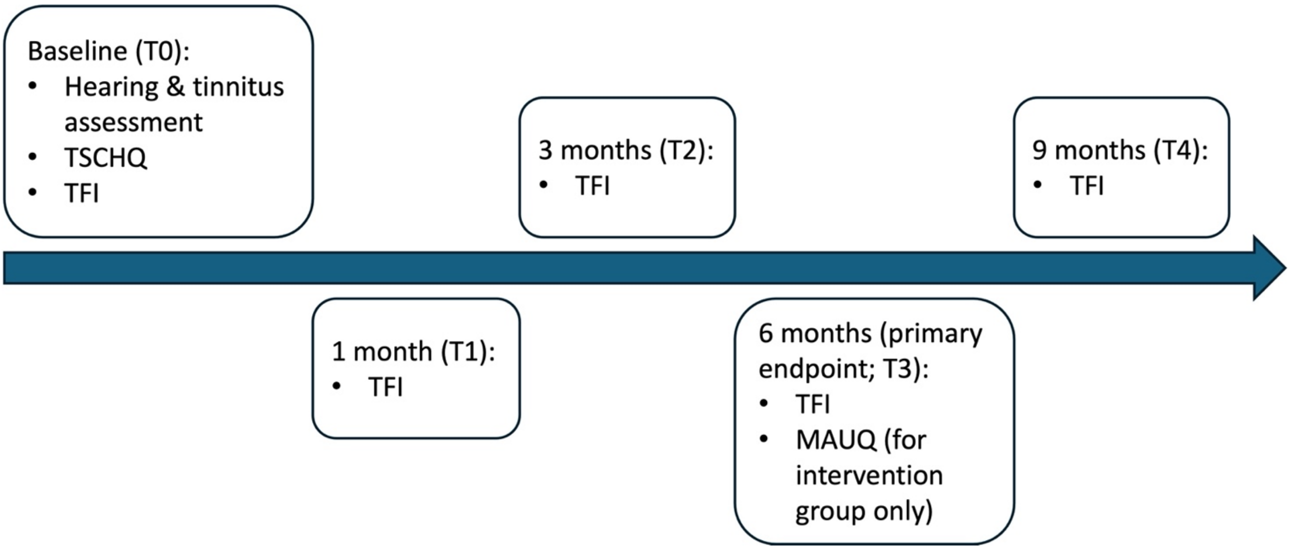


Figure 7.1 Data collection at different timepoints. MAUQ = mHealth App Usability Questionnaire; TFI = Tinnitus Functional Index; TSCHQ = Tinnitus Sample Case History Questionnaire.

7.5.1.1 Pre-baseline screening

Upon registration to participate, interested individuals were required to complete a screening survey on Qualtrics (https://www.qualtrics.com/), which consisted of selected questions from the TSCHQ (Langguth et al., 2007) regarding the duration, pulsatile nature, and laterality of tinnitus, and TFI (Meikle et al., 2012), to determine eligibility. The TSCHQ collects data on the clinical characteristics of participants' tinnitus such as type, laterality, and duration of tinnitus. The TFI measures tinnitus severity and distress under eight subscales: intrusive, sense of control, cognitive, sleep, auditory, relaxation, quality of life, and emotional. Individuals were eligible for this study if they: 1) were 18 years old or above; 2) were experiencing chronic (≥6 months), bilateral, non-pulsatile tinnitus (based on selected screening TSCHQ questions) (this type of tinnitus was selected as unilateral and pulsatile tinnitus is sometimes associated with an identifiable cause such as vascular conditions (Walters et al., 2023)); 3) had access to a smartphone device capable of running the Oto app; 4) were willing to use Oto during the study period; and 5) had at least lower moderate tinnitus severity (determined by scoring 18 points or above in the screening TFI) (Gos et al., 2021). Exclusion criteria were if the individuals: 1) had known impairment likely to impact on their ability to participate in research activities; 2) were enrolled in another tinnitus study; 3) were undertaking another tinnitus intervention; or 4) were awaiting surgical intervention for hearing/tinnitus.

7.5.1.2 Baseline session (T0)

Participants who resided in South Australia were arranged an in-person baseline session with the principal investigator (BM) at Flinders University. During this session, participants first undertook an audiometric testing (otoscopy, tympanometry, and PTA) and tinnitus pitch and loudness matching in a soundproof room. After that, they completed the full version of TSCHQ to garner detailed information on their tinnitus characteristics, and the TFI to record baseline tinnitus severity. Participants were then informed of their allocation to either the intervention or control group. Those assigned to the intervention group were instructed to install the Oto app on their smartphones, given a 9-month free subscription to Oto, and provided with an overview of the app features. They were reminded the self-paced nature of Oto, meaning there was no minimum requirement of daily app usage, although they were suggested to listen to one therapy session each or every other day. As for those assigned to the control group, they were informed that they would not be receiving any treatment for tinnitus during the study period. However, as an incentive and remuneration, the control group participants would be eligible for a 9-month free subscription to Oto once they have completed all follow-up surveys. All participants were also noted that the research team could be contacted via email to answer any questions they might have about this study.

For those who resided outside South Australia and were unable to attend the baseline session in person, they were required to provide an electronic copy of their most recent hearing assessment results signed off by a qualified audiologist to determine group allocation.

7.5.1.3 Follow-up surveys (T1-T4)

All participants completed the TFI again at 1, 3, 6, and 9 months. Intervention group participants also completed the MAUQ (Zhou et al., 2019) at 6 months to rate Oto's usability.

7.5.2 Outcomes

7.5.2.1 Primary outcome measure

The TFI was employed to assess tinnitus severity and distress (Meikle et al., 2012) due to its higher sensitivity to intervention-related changes (Gos et al., 2021). The 25-item TFI consists of eight subscales: intrusive, sense of control, cognitive, sleep, auditory, relaxation, quality of life, and emotional. Scores range from 0 to 100, with higher score indicating greater severity. A 13-point reduction is considered clinically meaningful (Meikle et al., 2012). TFI scores below 18, from 18 to 42, from 42 to 65, and above 65 indicate low, lower moderate, upper moderate, and high tinnitus severity, respectively (Gos et al., 2021). The TFI has a high internal consistency of Cronbach's alpha 0.97 and test-retest reliability of 0.78 (Meikle et al., 2012).

7.5.2.2 Secondary outcome measure

The MAUQ was selected as the secondary outcome measure to evaluate the usability of the Oto app (Zhou et al., 2019). Selection of the MAUQ was based on the limitations of frequently utilised usability questionnaires, e.g., the System Usability Scale (SUS) (Brooke, 1996), which were not designed specifically for mHealth apps (Zhou et al., 2019). The standalone app version of MAUQ for patients was employed and it is an 18-item tool evaluating three aspects of app usability: ease of use, interface and satisfaction, and usefulness. Each item is a 7-point Likert scale from *strongly disagree* (1 point) to *strongly agree* (7 points). A total MAUQ score ranges from 1 to 7 can be calculated by averaging the scores of all items. A higher score indicates higher usability. The MAUQ was reported to have a high internal consistency (Cronbach's alpha 0.91) and strong construct validity and criterion validity (0.72-0.86) (Zhou et al., 2019).

7.5.3 Participants

7.5.3.1 Eligibility criteria

Individuals were eligible for this study if they: 1) were 18 years old or above; 2) were experiencing chronic (≥6 months), bilateral, non-pulsatile tinnitus (based on selected screening TSCHQ questions) (this type of tinnitus was selected as unilateral and pulsatile tinnitus is sometimes associated with an identifiable cause such as vascular conditions (Walters et al., 2023)); 3) had access to a smartphone device capable of running the Oto app; 4) were willing to use Oto during the study period; and 5) had at least lower moderate tinnitus severity (determined by scoring 18 points or above in the screening TFI) (Gos et al., 2021). Exclusion criteria were if the individuals: 1) had known impairment likely to impact on their ability to participate in research activities; 2) were enrolled in another tinnitus study; 3) were undertaking another tinnitus intervention; or 4) were awaiting surgical intervention for hearing/tinnitus.

7.5.3.2 Recruitment

Individuals from all states and territories of Australia were recruited from Facebook advertisements and research team's database. Recruitment started on 13th June 2023 and ended on 21st September 2023.

7.5.3.3 Sample size

Sample size calculation was performed using Stata software (version 17.0) based on a superiority parallel-group trial design. The α was set at 0.025 and power was set at 0.90. The mean difference was set at 13 points since this was indicated as a clinically meaningful reduction in tinnitus severity on the TFI (Meikle et al., 2012). The *SD* was set at 18 points based on previous trials employing CBT as tinnitus intervention (Beukes et al., 2017; Rademaker et al., 2020). The minimal sample size for each group was 48 participants. To account for a potential dropout rate of 15% (Beukes et al., 2017), an additional seven participants were added to each group. Hence, a total of 110 participants would be recruited, with 55 participants in each group.

7.5.3.4 Randomisation

Eligible participants were randomly allocated to either the intervention or control group in a ratio of 1:1. Allocation sequence was generated using Sealed Envelope (https://www.sealedenvelope.com/simple-randomiser/v1/lists). The first author (BM) was responsible for generating the random allocation sequence, enrolling participants, and assigning participants to the two groups. The following stratification factors were applied for even distribution of participants to the two groups: 1) age (≤65 or >65 years); 2) gender (male or female); 3) hearing sensitivity level (determined by baseline audiometric testing) (within normal limits or mild hearing loss and above); and 4) screening TFI score (≤50 or >50 points). Block randomisation using block sizes of four and six was performed. A list length of 110 was generated.

However, as the number of recruited participants (*N* = 96) did not meet the target due to difficulties in promoting this study, the allocation list was not fully utilised, resulting in a nearly 1:1 allocation ratio among groups (50 in the intervention group vs 46 in the control group). Participants were informed that they would have a 50% chance of being allocated to either group, with the control group being put on waiting list for access to Oto after trial completion. Allocation was determined once the participants' hearing sensitivity levels were obtained from the baseline audiometric testing. Due to the trial design, the participants and the principal investigator (BM) were not blinded to group allocation.

7.5.4 Intervention – Oto app features

The Oto app was utilised as the intervention for tinnitus in this study. It was developed by Oto Health Ltd, a UK-based company, which funded this study and Study 2 (Chapter 4). Oto is an app-delivered approach to tinnitus comprising multiple modalities, including CBT, sound therapy, relaxation, mindfulness, and patient education. This app is available on both iOS and Android operating systems. Different components of Oto are detailed below, with screenshots shown in Figure 7.2.

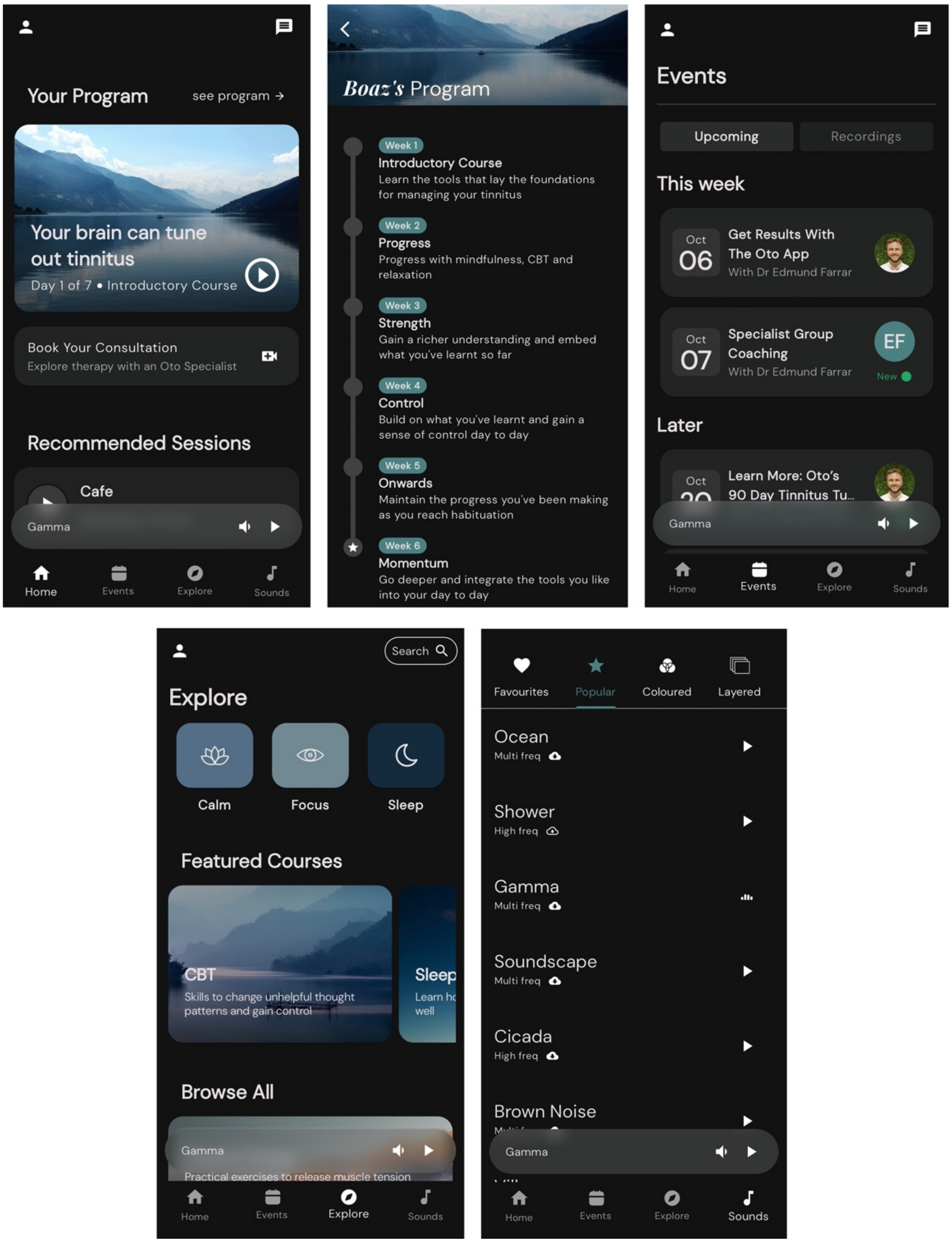


Figure 7.2 Screenshots of the Oto app.

7.5.4.1 Tinnitus habituation assessment

Upon registration to Oto, users are asked to answer 10 questions about their tinnitus experiences so that their current stage of habituation can be estimated. This information will be used for customising the therapy program in Oto. Each question rates the users' experiences with tinnitus, such as their awareness of tinnitus and the impacts of tinnitus on sleep, on a 4-point Likert scale (*rarely*, *sometimes*, *often*, *most of the time*). Descriptions of all four stages of habituation will be provided once all questions are answered, with an indication of the user's current stage. Stage one represents the lowest level of habituation, whereas stage four represents the highest level of habituation. Recommendations such as spending 10 minutes per day on the therapy program, the topics of focus in the program, and additional support from a tinnitus expert via the app are displayed. Users can also select specific goals (calm, focus, and sleep) to customise their therapy program, and this can be modified at any time in the app. The overall goal of using Oto is to progress through the stages and achieve habituation where acceptance of tinnitus is developed and the user does not find it bothersome anymore.

7.5.4.2 Home screen

There are four main screens in Oto. On the *Home* screen, the first feature is the tinnitus therapy program. This program includes six chapters, namely introductory course, progress, strength, control, onwards, and momentum. Each chapter is recommended to be completed in 1 week. The program offers 60 therapy session recordings (2-13 minutes each) covering various topics, including CBT, ACT, mindfulness, relaxation, visualisation, etc. Therapy sessions which have been added to favourites and listened to recently are shown on this screen as well.

Another feature on the *Home* screen is help desk. The help desk provides a collection of articles explaining how to navigate the app, what the therapy sessions entail, and where to seek help beside using Oto.

In addition, under the profile settings, users can manage their goals (calm, focus, and sleep) to customise their therapy program, use a built-in sound meter function to measure ambient noise level and learn about the relationship between noise and tinnitus, access a personal journal where thoughts can be recorded and revisited after listening to a therapy session, and enable captions and set up daily reminders for the therapy sessions.

7.5.4.3 Events screen

The *Events* screen lists all recorded and upcoming free webinars on topics revolving around tinnitus, such as discussion of available tinnitus treatments, tinnitus research updates, sleep strategies, breathing exercises, and TRT.

7.5.4.4 Explore screen

Users can find the complete collection of therapy sessions (116 sessions) here on the *Explore* screen. These sessions include those from the tinnitus therapy program on the *Home* screen, together with additional sessions from which the users may find helpful in managing their tinnitus.

Most of the therapy sessions are categorised into three groups: calm, focus, and sleep, which correspond to the goals the users can set in the app. Other than the sessions shown in each group, there are a few suggested sounds from the *Sounds* screen which may in particular help achieve the goal. Under *Browse All*, all therapy sessions are displayed according to their topics, including physical therapy, mindfulness for sleep, breathing control, CBT, visualise control, success stories, etc. The duration of each session ranges from one to 41 minutes, depending on the topic. For example, stretching exercises are generally shorter and sleep stories are usually longer.

7.5.4.5 Sounds screen

Oto contains a library of 78 sounds which can be found on the *Sounds* screen. These sounds can be played as background sounds while listening to therapy sessions, or as standalone sounds for masking and calming purposes. There are eight groups of sounds to cater to the needs of users with different tinnitus characteristics, namely coloured, layered, urban, binaural, nature, household, transport, and experimental. Additionally, a timer can be set in five-minute intervals to stop the sound at destined time.

7.5.5 Data analysis

Statistical analysis was performed using IBM SPSS Statistics (version 28). Descriptive analysis was performed to obtain mean and standard deviation values. Shapiro-Wilk tests and Mauchly's test were conducted to examine data normality and sphericity, respectively, and Greenhouse-Geisser correction was applied when there was violation of sphericity. Only the participants who completed the TFI at 6 months (T3) were considered as reaching the primary endpoint and those who did not were excluded from the analysis. Missing data at earlier timepoints (i.e., 1 month (T1) and 3 months (T2)) were missing at random and accounted for using multiple imputation with 10 imputed datasets. Mixed ANOVA with time (T0, T1, T2, T3, T4) as the within-subjects factor and treatment group (intervention, control) as the between-subjects factor was conducted to compare the TFI scores across all timepoints and determine the interaction of the above two factors on the TFI scores. Effect sizes and the 95% confidence intervals at the primary endpoint (6 months; T3) were calculated by Cohen's d. A Cohen's d of 0.2 indicates small effect size, 0.5 indicates medium effect size, and 0.8 indicates large effect size (Cohen, 1992). Pairwise comparisons were performed to determine statistically significant differences in the TFI overall and subscale scores between the intervention group and control group at each timepoint and within each group across various timepoints. Two-sample z-tests were performed to compare the proportions of participants reporting a clinically meaningful reduction (i.e., at least 13 points) in the TFI score between the two groups. Statistical significance is defined by a *p*-value lower than .05.

7.5.6 Deviation from pre-trial registration

No changes were made to trial methods after trial commencement.

7.6 Results

7.6.1 Participant characteristics

Of 207 registered individuals, 96 met the inclusion criteria and were randomised into the intervention (*n* = 50) and control (*n* = 46) groups (Figure 7.3). Participants were 43% female and 57% male, with a mean age of 62.4 years (*SD* = 8.6; range: 36-78) (Table 7.1). The majority (70%) resided in South Australia. Regarding their tinnitus characteristics, the participants had been experiencing tinnitus for a mean duration of 17.4 years (*SD* = 14.8; range: 0.8-61) and most of them perceived their tinnitus sounds as tone (46%) and noise (41%). Tinnitus matching revealed a mean tinnitus frequency of 3728 Hz (*SD* = 2073; range: 200-7813) and a mean tinnitus loudness of 43 dB HL (*SD* = 15; range: 12-71). Of all participants, 22% were hearing aid users. The average hearing profiles of both groups are visualised in Figure 7.4.

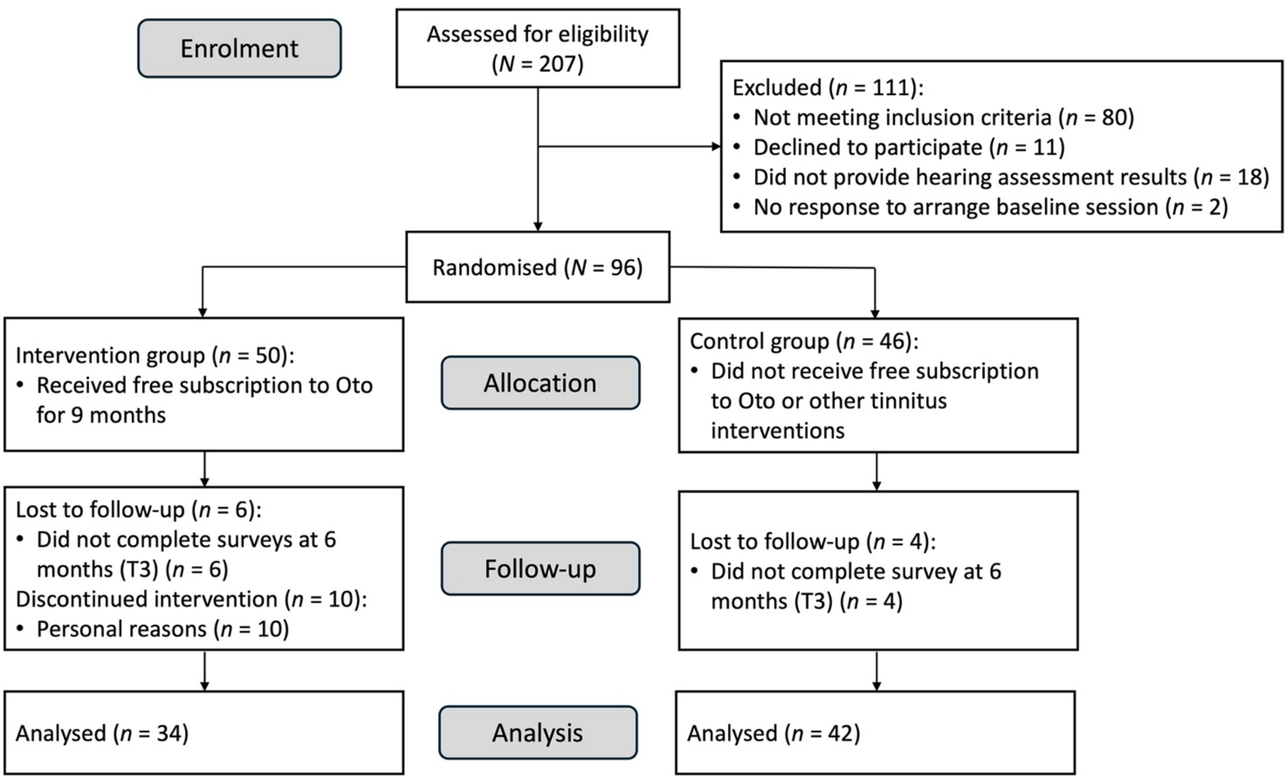


Figure 7.3 The CONSORT participant flow diagram.

Table 7.1 Baseline demographic information and tinnitus characteristics of participants.

Characteristic	Overall (*N* = 96)	Intervention group (*n* = 50)	Control group (*n* = 46)
Gender: *n*(%)			
Female	41 (43)	21 (42)	20 (43)
Male	55 (57)	29 (58)	26 (57)
Age (mean ± *SD*, range; in years)	62.4 ± 8.6, 36-78	62.1 ± 8.0, 38-77	62.8 ± 9.2, 36-78
State/Territory of residence: *n* (%)			
South Australia	67 (70)	41 (82)	26 (57)
Victoria	8 (8)	0 (0)	8 (17)
New South Wales	7 (7)	2 (4)	5 (11)
Western Australia	7 (7)	3 (6)	4 (9)
Queensland	4 (4)	3 (6)	1 (2)
Australian Capital Territory	1 (1)	0 (0)	1 (2)
Northern Territory	1 (1)	1 (2)	0 (0)
Tasmania	1 (1)	0 (0)	1 (2)
Tinnitus duration (mean ± *SD*, range; in years)	17.4 ± 14.8, 0.8-61	19.3 ± 14.3, 1-61	15.4 ± 15.2, 0.8-55
Tinnitus sound type: *n* (%)			
Tone	44 (46)	24 (48)	20 (43)

Noise	39 (41)	21 (42)	18 (39)
Crickets	13 (14)	5 (10)	8 (17)
Tinnitus frequency (mean ± *SD*, range; in Hz)	3728 ± 2073, 200-7813	3218 ± 1910, 200-6133	4536 ± 2103, 872-7813
Tinnitus loudness (mean ± *SD*, range; in dB HL)	43 ± 15, 12-71	40 ± 15, 12-66	47 ± 15, 25-71
Hearing aid user: *n* (%)	21 (22)	11 (22)	10 (22)

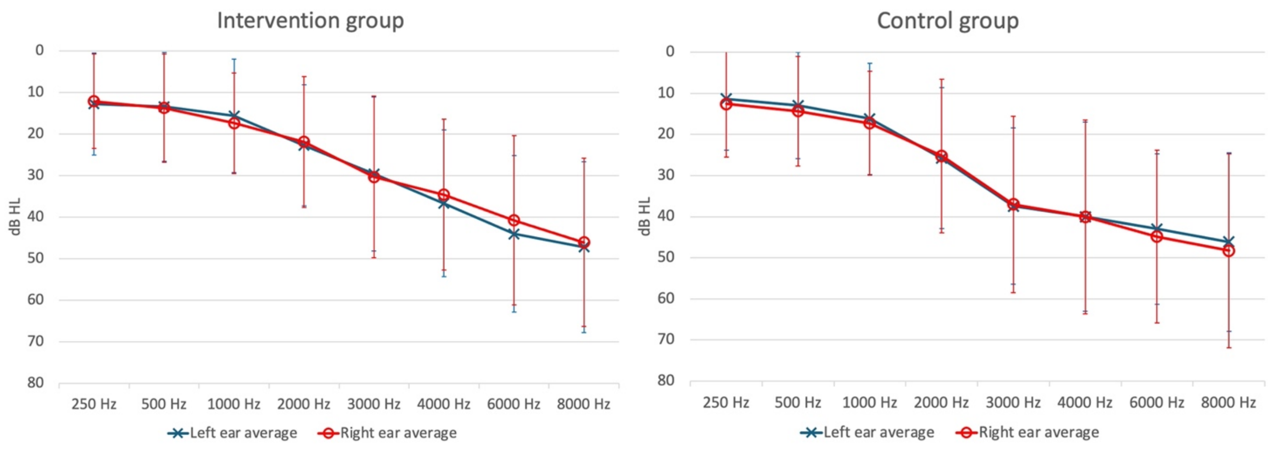


Figure 7.4 Audiograms of the intervention group (*n* = 50) and control group (*n* = 46). Error bar represents 1 *SD*.

7.6.2 Trial retention and dropout rates

Sixteen participants from the intervention group did not reach the primary endpoint (6 months; T3), in which six did not complete the TFI and MAUQ at T3 and another 10 withdrew from the trial due to personal reasons. This resulted in a retention rate of 68% (*n* = 34/50) and dropout rate of 32% (*n* = 16/50) in the intervention group. For the control group, four participants did not complete the TFI at T3, resulting in a retention rate of 91% (*n* = 42/46) and dropout rate of 9% (*n* = 4/46). Overall, the retention rate and dropout rate of this trial were 79% (*n* = 76/96) and 21% (*n* = 20/96), respectively.

7.6.3 Changes in tinnitus severity

Mixed ANOVA results for TFI overall and subscale scores at T3 and T4 are summarised in Table 7.2. Significant interaction effects (time x treatment group) were observed in the overall TFI score at T3 (primary endpoint), $F(2.177, 161.092) = 7.196$, $p < .001$, Cohen's $d = 0.62$ (95% CI [0.27-0.91]), and in subscale scores including intrusive, $F(2.419, 178.976) = 6.956$, $p < .001$, Cohen's $d = 0.61$ (95% CI [0.27-0.88]), sense of control, $F(2.650, 196.103) = 5.314$, $p = .002$, Cohen's $d = 0.54$ (95% CI [0.20-0.79]), sleep, $F(2.678, 198.154) = 4.859$, $p = .004$, Cohen's $d = 0.51$ (95% CI [0.17-0.76]), relaxation, $F(2.397, 177.372) = 7.423$, $p < .001$, Cohen's $d = 0.63$ (95% CI [0.29-0.91]), and quality of life, $F(2.291, 169.519) = 4.255$, $p = .012$, Cohen's $d = 0.48$ (95% CI [0.11-0.75]). Significant interaction effects persisted at T4, e.g., in overall TFI score, $F(2.917, 215.854) = 5.343$, $p = .002$, Cohen's $d = 0.54$ (95% CI [0.21-0.77]).

TFI subscale	6 months (T3)			9 months (T4)		
	F	*p*	Cohen's *d* (95% CI)	*F*	*p*	Cohen's *d* (95% CI)
Overall	7.196	< .001*	0.62 (0.27-0.91)	5.343	.002*	0.54 (0.21-0.77)
Intrusive	6.956	< .001*	0.61 (0.27-0.88)	6.583	< .001*	0.60 (0.29-0.82)
Sense of control	5.314	.002*	0.54 (0.20-0.79)	4.192	.003*	0.48 (0.17-0.67)
Cognitive	1.870	.15	0.32 (0-0.56)	1.266	.29	0.26 (0-0.46)
Sleep	4.859	.004*	0.51 (0.17-0.76)	3.736	.010*	0.45 (0.11-0.66)
Auditory	1.921	.15	0.32 (0-0.60)	1.441	.23	0.28 (0-0.49)
Relaxation	7.423	< .001*	0.63 (0.29-0.91)	5.903	< .001*	0.56 (0.26-0.79)
Quality of life	4.255	.012*	0.48 (0.11-0.75)	3.203	.025*	0.42 (0-0.64)
Emotional	2.448	.074	0.36 (0-0.61)	1.940	.12	0.32 (0-0.52)

Table 7.2 Interaction effects between time and treatment group from mixed ANOVA in TFI overall and subscale scores at 6 months (T3) and 9 months (T4).

Note. Asterisk indicates statistically significant result. CI = Confidence interval.

Pairwise comparisons of estimated marginal means within and between groups at different timepoints are displayed in Figure 7.5. At T0, the two groups did not differ significantly in overall TFI scores (intervention: 44 ± 21; control: 47 ± 19). The control group demonstrated no significant changes throughout the study. The intervention group demonstrated significant reductions from T0 to T3 in TFI overall score (mean decrease = 9 points; 95% CI = 2, 16; p = .006) and intrusive (mean decrease = 13 points; 95% CI = 4, 22; p < .001), sense of control (mean decrease = 16 points; 95% CI = 5, 27; p < .001), sleep (mean decrease = 10 points; 95% CI = 0, 19; p = .034), and relaxation (mean decrease = 11 points; 95% CI = 1, 21; p = .024) subscale scores. The significant reduction in the sense of control subscale score was maintained at T4 (mean decrease = 11 points; 95% CI = 1, 22; p = .033).

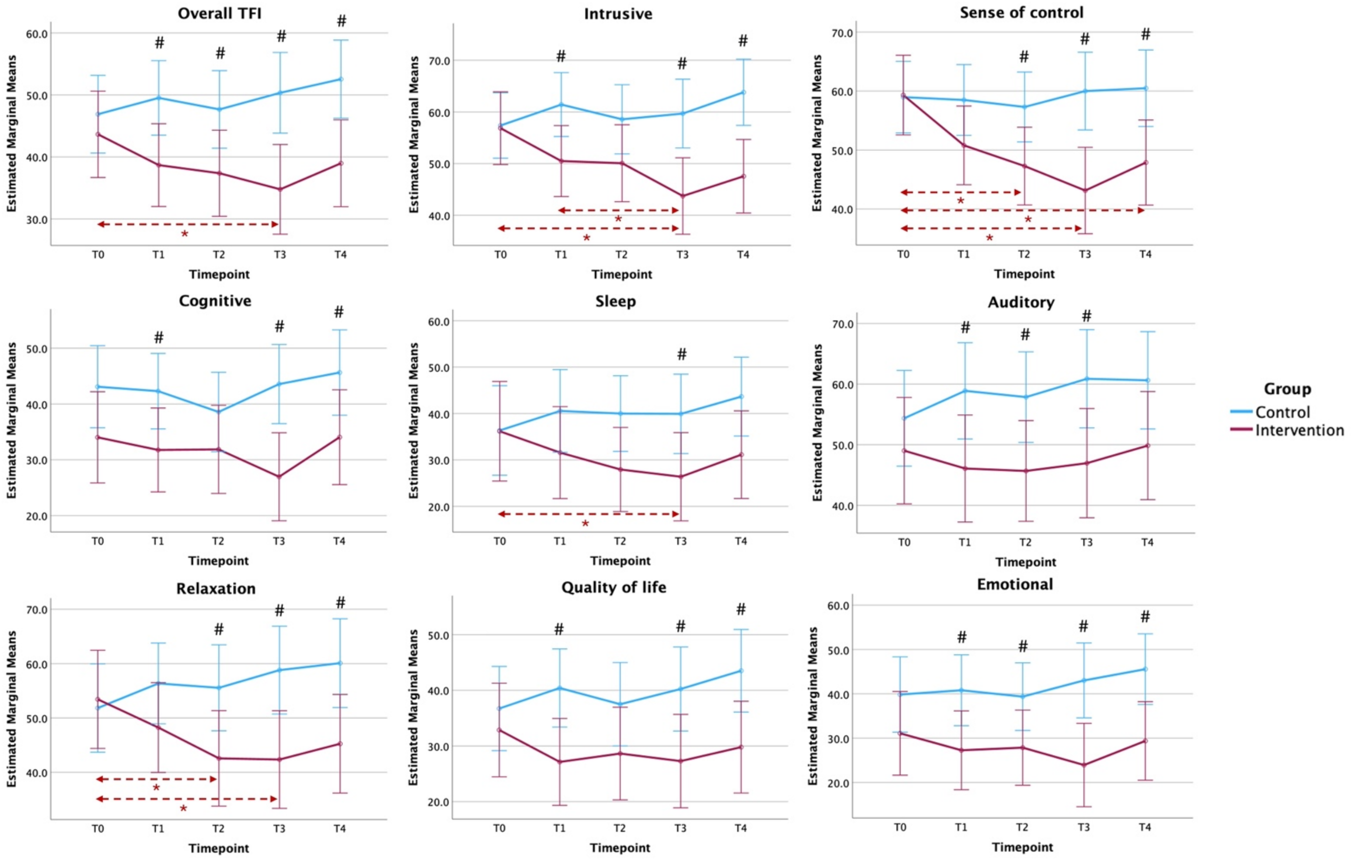


Figure 7.5 Changes in the estimated marginal means of TFI overall and subscale scores of the intervention group and control group from T0 to T4. Hash indicates statistically significant difference in the scores between groups at the same timepoint. Dashed arrow with an asterisk indicates statistically significant difference in the scores within intervention group between the indicated timepoints. Error bar represents 95% CI.

In regard to the differences in the TFI overall and subscale scores between the two groups at each timepoint, the overall (mean difference = 16 points; 95% CI = 6, 25; p = .002) and all subscale scores (mean difference = 13-19 points; p < .05) of the intervention group were significantly lower than those of the control group at T3. The intervention group reported significantly lower TFI overall score (mean difference = 11 points; 95% CI = 2, 20; p = .019) and some subscale scores, e.g., intrusive (mean difference = 11 points; 95% CI = 2, 20; p = .021), quality of life (mean difference = 13 points; 95% CI = 3, 24; p = .014), and emotional (mean difference = 14 points; 95% CI = 2, 25; p = .027), than the control group at as early as T1 (i.e., 1 month since baseline). Furthermore, the significant differences in the TFI overall (mean difference = 14 points; 95% CI = 4, 23; p = .005) and all subscale (except sleep and auditory) scores (mean difference = 12-16 points; p < .05) between the two groups were maintained at T4.

According to the criterion suggested by Meikle et al. (2012), a significantly greater proportion of participants from the intervention group (*n* = 11/34; 32%) reported a clinically meaningful reduction in the TFI overall score (≥13 points) than those from the control group (*n* = 5/42; 12%) at T3, $z = 2.20$, $p = .030$. Similarly, significantly more participants from the intervention group (*n* = 7/34; 21%) exhibited a clinically meaningful reduction in the TFI overall score than those from the control group (*n* = 2/42; 5%) at T4, $z = 2.10$, $p = .034$.

7.6.4 App usability

Oto's overall usability was rated high on the MAUQ at 5.1 out of 7 (*SD* = 1.4; *n* = 32). Regarding the three MAUQ subscales, ease of use was rated the highest (5.8; *SD* = 1.2), followed by interface and satisfaction (5.1; *SD* = 1.4), then usefulness (4.6; *SD* = 1.4). Participants were most satisfied with how easy it was to learn to use Oto (6.1; *SD* = 0.8), the app being easy to use (5.9; *SD* = 1.2), and consistent navigation when moving between screens (5.8; *SD* = 1.2). On the contrary, they perceived the app as less beneficial in terms of improving access to healthcare services (4.0; *SD* = 1.4), functioning without interruption when the Internet connection was poor or unavailable (4.3; *SD* = 1.3), and helping them manage their health effectively (4.4; *SD* = 1.3).

7.6.5 Harms or unintended effects

There was no harm or unintended effect reported during the 9-month study period.

7.7 Discussion

This RCT evaluated the effectiveness and usability of the Oto smartphone app in reducing tinnitus severity and distress. Compared to the control group, which received no tinnitus intervention, the intervention group reported significantly lower tinnitus severity and distress after 6 months of Oto usage, as measured by the TFI.

A clinically meaningful reduction in the TFI score (≥13 points; Meikle et al. (2012)) was observed in 32% and 21% of the intervention group participants at 6 and 9 months, respectively. The drop at 9 months might be attributed to the therapy duration. Oto's tinnitus therapy program is designed for six weeks with one to three therapy sessions each day. Oto might be able to provide shorter-term effects in reducing tinnitus distress when the therapy sessions were recently visited. Compliance to app usage might also decrease beyond the first few months of use, resulting in a drop in perceived effectiveness at 9 months. Previous studies on the use of smartphone apps for tinnitus management demonstrated higher perceived effectiveness. For example, an uncontrolled trial on the use of a sound therapy based tinnitus smartphone app reported a clinically significant improvement in the TFI score in 58% of participants at the 6 months follow-up (Kutyba, Gos, et al., 2022). In another study which compared the effectiveness of an app-based digital polytherapeutic to a sound therapy app as an active control, a significantly higher proportion of the digital polytherapeutic group (65%) had a clinically meaningful decrease in the total TFI score than the control group (43%) at the 3 months follow-up (Searchfield & Sanders, 2022).

From baseline to the primary endpoint (6 months), the mean TFI overall and some subscale (intrusive, sense of control, sleep, and relaxation) scores of the intervention group exhibited a statistically significant decrease, ranging from 9 to 16 points. Notably, the largest decrease of 16 points was observed in the sense of control subscale and a significant decrease in the same subscale was maintained at 9 months. This is not unexpected since Oto was developed upon the basis of CBT, which aims to moderate maladaptive behaviour by substituting negative thoughts and beliefs about tinnitus with positive and constructive cognitions, resulting in an alleviation of tinnitus-related distress (Jun & Park, 2013). As users follow through the therapy sessions in Oto, they can learn the techniques for handling and modifying their negative reactions to tinnitus and hence, gain control over the perception of the condition and find it more manageable. In addition, previous research postulated that cognitive adaptation to chronic health conditions could be influenced by three types of perceived control – general control over health and symptom control were found to have association with positive psychological adjustment, whilst retrospective control had a connection with negative psychological adjustment (Sirois et al., 2006). Moreover, the severity of tinnitus symptoms was identified as a strong moderator of the relationship between symptom control and tinnitus distress, that is, maintaining a sense of control in individuals with more severe tinnitus could lead to better psychological adjustment than their milder-tinnitus counterparts (Sirois et al., 2006). It may therefore be pivotal for individuals with tinnitus, regardless of their tinnitus severity, to develop and maintain a sense of control over the condition to foster a sense of empowerment, mitigate tinnitus-related distress, and accomplish better wellbeing. That said, it could not be ascertained by the current study that whether changes in some or all types of perceived control were captured by the TFI given the limitation in its scope. To fully unravel the potential underlying influence of Oto on perceived control, employment of more specialised outcome measures (e.g., Sense of Control Scale (Lachman & Weaver, 1998)) will be necessary.

An interaction effect between the within-subjects factor (time) and between-subjects factor (treatment group) was revealed at T3 and T4, implying that the changes in TFI scores were dependent on both factors. As the findings suggest, a significant difference in TFI scores was recorded in the intervention group between T0 and T3, and the TFI scores of the intervention group were significantly lower than those of the control group at T3 and T4 as well. Long-term effects of smartphone apps on relieving tinnitus symptoms and distress have rarely been investigated. According to a review of tinnitus smartphone apps validation studies, the timeframe of such studies hardly exceeded 3 months (Mehdi, Dode, et al., 2020). Some recent trials attempted to assess the effectiveness of tinnitus smartphone apps for up to 6 months (Kutyba, Gos, et al., 2022; Seol et al., 2023), and one study described a 9-month intervention period, yet results from the first 3 months were reported as primary outcome (Walter et al., 2023). All of the aforementioned studies demonstrated a significant decrease in tinnitus severity at the study endpoint as a result of app usage. Indeed, the current study is one of the few studies which evaluated the effectiveness of tinnitus smartphone apps in a longer timeframe, and the findings indicate that such effectiveness was evident at 6 months and maintained at 9 months. Although the tinnitus therapy program in Oto consists of sessions spanning approximately 6 weeks, participants were reminded that they could revisit the materials for as many times as needed. Beside the structured therapy program, an additional collection of therapy sessions was available in the app which the participants might find useful. It is plausible that the observed long-term effect of Oto might be attributable to participants revisiting the therapy sessions from which they could benefit, or they have acquired the coping strategies introduced by the app and better habituated to tinnitus so that it appeared less bothersome.

This study reported a Cohen's *d* effect size of 0.62 and 0.54 for the overall TFI score at T3 and T4, respectively, which correspond to a medium effect size. The effect size of tinnitus smartphone apps trials is not frequently reported (Demoen et al., 2023), rendering comparisons within the same app or across apps difficult. Searchfield and Sanders (2022) collated the effect size of their tinnitus smartphone apps trial and other tinnitus trials utilising sound therapy device (Hall et al., 2022), bimodal sound and tongue stimulation (Conlon et al., 2020), and TRT (The Tinnitus Retraining Therapy Trial Research Group, 2019), revealing a wide range from less than 0.1 to 1.01.

These trials employed the same tinnitus severity outcome measure (i.e., TFI) and the effect size reported in the current study is comparable to the partial TRT arm of the TRT trial (The Tinnitus Retraining Therapy Trial Research Group, 2019) and the active control sound therapy app arm of the digital polytherapeutic trial (Searchfield & Sanders, 2022). This indicates that Oto stands as a strong potential intervention for tinnitus among other treatment modalities.

Interestingly, previous research has noted possibilities of improvement in tinnitus distress in wait-list control groups (Hesser et al., 2011). This phenomenon can be due to an anticipation effect in which participants expect symptom relief from receiving treatment in the near future. This was nonetheless not observed in this study as the TFI score of control group did not vary significantly throughout the study period.

The attrition and dropout rates of app-based interventions for chronic disease are known to be typically high, with a pooled dropout rate of 43% from various observational studies and RCTs (Meyerowitz-Katz et al., 2020). Great variation of dropout rates exists across studies and tinnitus smartphone apps trials are no exception, for example, from 14% to 53% (Engelke et al., 2023; Kutyba, Jędrzejczak, et al., 2022). The overall dropout rate of this study was 21% (32% for intervention group and 9% for control group), which is in congruence with the literature. There are numerous possible reasons behind dropouts. For instance, lower level of health literacy, older age, and lower education level were found to be associated with higher dropout rates (Meyerowitz-Katz et al., 2020). Participants may also discontinue using the app if they find it ineffective in alleviating their symptoms. Nevertheless, it is noteworthy that dropouts may not be necessarily equivalent to user dissatisfaction, as some participants may simply stop using the app after experiencing improvement and thus no longer need it (Kalle et al., 2018). It is also worth mentioning that the dropout rate of the control group was much lower than that of the intervention group, likely due to the provision of a free Oto subscription to the control group upon study completion as an incentive for adherence. Implementing incentives to improve retention and reduce dropouts have been exemplified by other studies (Engelke et al., 2023).

Apart from measuring app effectiveness, evaluation of usability can serve as an additional indicator of the app's performance and user experience. The overall usability of Oto was rated high on the MAUQ (5.1 out of 7), which is higher than other apps such as the app-based digital polytherapeutic (4.77) and active control sound therapy app (4.47) reported in the past

(Searchfield & Sanders, 2022). Participants rated the ease of learning how to use Oto highest among all MAUQ items, reflecting its simple and intuitive design for seamless navigation. Moreover, participants were familiarised with the features of Oto with the provision of verbal and written instructions, and they were encouraged to contact the research team if further assistance was required. Although such detailed instructions may not be readily available in the real-world setting, a brief description of Oto's features is shown in the app the first time it is installed. These details may facilitate user familiarisation and satisfaction. On the contrary, participants hoped that the functioning of Oto could stay uninterrupted regardless of Internet connection. Indeed, the therapy sessions and sounds are inaccessible without Internet connection. This limitation can present as a drawback since one of the main purposes of developing app-based tinnitus interventions is to deliver tinnitus care to remote locations where in-person care is less accessible. Compared to their urban counterparts, these remote locations may have less stable Internet access and the exclusivity of online app contents can ostracise these underserved populations. To rectify this shortcoming, improvement in app functionality or provision of offline contents may be warranted.

7.7.1 Limitations

There are a few limitations in this study which should be noted. First, this RCT was not blinded due to the nature of intervention, i.e., participants were aware of either using Oto or being placed in the waiting list as control. Because of resource limitations, the same researcher was responsible for informing participants of their group allocation and collecting data, which might have introduced researcher bias. Second, generalisation of findings from this study to populations with different demographic compositions and tinnitus characteristics should be performed with caution. This study recruited individuals with chronic, bilateral, non-pulsatile tinnitus with lower moderate or above tinnitus severity on the TFI. Effectiveness of Oto in individuals with other subtypes of tinnitus (e.g., acute, unilateral, pulsatile) could not be demonstrated by this study and warrants further investigation. Third, participants' responses might be biased, as the subscription to Oto was provided for free. Compliance measures were lacking as well so data on compliance in terms of app usage were largely unavailable. Lastly, an initial design of inclusion of focus groups was in place to collect qualitative data on user experience. This was aborted because of challenges in participant recruitment, i.e., too few participants responded to the invitation. Future evaluation of app performance and user experience and satisfaction should consider incorporation of qualitative data collection methods, e.g., focus groups and interviews.

7.7.2 Future directions

While this study focussed on the primary outcome of tinnitus severity and distress reduction through Oto usage, future research should consider: (i) incorporating outcome measures for tinnitus-associated comorbidities (e.g., stress, anxiety, and depression) to provide a more holistic evaluation of the app’s efficacy; (ii) investigating potential predictors of treatment success, such as age and digital literacy, using a larger sample size to enhance statistical power and generalisability; and (iii) developing more accurate measures of active user engagement. While backend data provides usage information, self-reported methods (e.g., diaries and user logs) may better elucidate the relationship between app usage patterns and treatment outcomes.

These considerations in future trials would contribute to a more nuanced understanding of digital interventions in tinnitus management and potentially inform personalised treatment approaches.

7.8 Disclosure of interest statement

This study was funded by Flinders University and Oto Health Ltd. Boaz Mui (first author) is a current PhD candidate at Flinders University and his PhD is jointly funded by Flinders University and Oto Health Ltd. Jameel Muzaffar (second author) is the Chief Scientific Officer at Oto Health Ltd and he had no access to the participants or data.

CHAPTER 8 – DISCUSSION

The overall aim of this PhD was to enhance teleaudiology service delivery through evaluation of web-based and smartphone-based interventions which are designed taking stakeholder perceptions into account. The research presented in this thesis was conducted in a series of five studies which delved into multiple facets of teleaudiology implementation. Due to the connections and shared research questions between Study 1 and Study 3 as well as Study 2 and Study 5, the following sections are structured to first discuss the findings and implications of the above paired studies, followed by a general discussion of all studies.

8.1 Summary of key findings and original contribution to knowledge of Study 1 and Study 3

The perceptions of the hearing healthcare stakeholders in Australia, including clients, clinicians, students, academics, and industry partners, towards teleaudiology were explored in Study 1 and Study 3, using different methodologies. Participants also expressed their opinions, both positive and negative, on their individual experiences with teleaudiology before, during, and after the COVID-19 pandemic.

Findings from Study 1 could be categorised into six aspects based on the survey structure and the roles of the stakeholders: 1) knowledge of teleaudiology, 2) teleaudiology appointments, 3) teleaudiology apps, 4) learning and teaching teleaudiology, 5) providing teleaudiology products and support, and 6) perceptions of teleaudiology. This study revealed that clients had a poorer grasp of the idea of teleaudiology than the other four stakeholder groups, as 55% of clients were able to describe what teleaudiology entails, while over 90% of the other four stakeholder groups were able to do so. Notably, 12 (7%) clients possessed no knowledge of teleaudiology because they simply had never heard of it before. Regarding the use of teleaudiology appointments and apps, a large discrepancy was found between clients and clinicians. Experiences with teleaudiology appointments and apps were shared by 85% and 66% of clinicians, respectively, whereas only 7% and 26% of clients, respectively, reported having similar experiences. Teleaudiology appointments were recognised for their advantages such as the reduced need for travelling and higher service accessibility. However, clients and clinicians found it challenging when communication difficulties occurred during those appointments with a lack of stable Internet connection. As for teleaudiology apps, their ease of use and user-friendliness were appreciated by clients and clinicians, but the greatest barriers to expanding their uptake were clients' unawareness and unfamiliarity with technology. Teleaudiology education at universities was reported to be existent by 80% of students and academics, albeit to a fairly limited extent. Both groups of stakeholders attributed the insufficient coverage of teleaudiology in the curriculum to low teleaudiology uptake rates in placement clinics and lack of teaching materials. Industry partners (n = 6/366; 2%) constituted the smallest portion of participants in Study 1, and they thought the increased provision of training and demonstration to clinics and clinicians, policy changes, and reimbursement guidelines would enable better teleaudiology uptake. When asked whether teleaudiology services should be promoted and used more often, half of the clients agreed while a majority (70%) of clinicians and all industry partners agreed.

Study 3 furthered the exploration of Australian-based hearing healthcare stakeholders' teleaudiology experiences and perceptions with the use of semi-structured interviews. As such, rich qualitative data were captured, giving rise to six themes revolving around teleaudiology use. Those themes included: 1) barriers to and facilitators of teleaudiology uptake, 2) advantages and challenges of using teleaudiology, 3) additional considerations when using teleaudiology, 4) teleaudiology education at university, 5) recent development in improving teleaudiology uptake, and 6) attitudinal changes in post-pandemic teleaudiology uptake. Barriers such as poor digital literacy and confidence among clients and clinicians and unreliable access to technological devices and Internet were identified. Clients' and clinicians' preferences were also highlighted as a determinant of teleaudiology uptake. It should be noted that some clients and clinicians might just prefer in-person service delivery, whatever the reasons behind such preference might be. This preference might have stemmed from their previous experiences with teleaudiology or expectations of receiving or delivering care remotely. Although it is a good idea to improve teleaudiology and its applications, there will be a proportion of clients who prefer in-person service delivery and they should be triaged appropriately. It should also be acknowledged that teleaudiology may not be suitable for all clients and service types, as discussed further below.

On the contrary, receiving support from other stakeholders and the risk of the COVID-19 pandemic and its associated health concerns facilitated teleaudiology uptake. The ability of overcoming geographical barriers rendering less travel needs and communication difficulties arisen during remote consultations were the most suggested advantages and challenges of using teleaudiology, respectively. Clinicians thought teleaudiology might not be applicable to all types of services, e.g., diagnostic assessment might be more complicated to be performed remotely due to its requirements for calibrated equipment and testing conditions. Teleaudiology as a means to complement, rather than substitute, in-person services were underscored by more than one stakeholder group.

Similar to Study 1, the inadequate amount of teleaudiology education was highlighted by students and academics, potentially due to a lack of infrastructure, equipment, and placement clinics which implemented teleaudiology in their routine clinical practice. Development in an attempt to promote teleaudiology uptake was nonetheless observed, in which encouragement from management level and the development and deployment of the Australian Teleaudiology Guidelines were the most mentioned. Stakeholders' attitudinal changes in the post-pandemic climate were mixed, with most of them expressing an optimistic outlook on future teleaudiology uptake and some leaving an uncertain or negative note on their possibilities of engaging in teleaudiology from here onwards.

It is evident from the literature that exploration of hearing healthcare stakeholders' perceptions towards teleaudiology, either prior to or in the midst of the COVID-19 pandemic, focussed heavily on clinicians and clients (Allen, 2020; Chong-White et al., 2023; Eikelboom & Atlas, 2005; Eikelboom et al., 2022; Galvin et al., 2022; Ravi et al., 2018). Viewpoints from other stakeholders, such as students, academics, industry partners, parents or carers of children receiving hearing care via teleaudiology, and practitioners from other disciplines or other clinical personnel who are involved in the provision of teleaudiology services, have been rarely investigated and poorly understood. It is reasonable to speculate that the reason behind this skewed research emphasis is due to hearing healthcare providers/clinicians and clients being the primary users of teleaudiology and thus, how they perceive the service delivery process and quality is of utmost concern and importance, which can directly guide the refinement of such service delivery.

Nevertheless, other stakeholders may play subtle yet equally pivotal and irreplaceable roles under the scheme of implementing teleaudiology. For instance, universities provide learning opportunities for future clinicians to hone their practical skills and cumulate clinical competence. Students who have had plentiful practice using teleaudiology may become stronger advocates for remote care once they become clinicians. To achieve this, academics need to acknowledge the significance of teleaudiology as well for it to be taught as in-depth as other topics. Besides, industry partners not only supply audiological equipment and products, but also impart knowledge crucial to safe and effective use of such products to clinics and clinicians. In order to devise the best strategies for implementing teleaudiology, the significance of including the voices of all key stakeholders should not be overlooked. For the purposes of addressing this research gap, Study 1 and Study 3 were the first studies to delve into the perceptions of students, academics, and industry partners – stakeholders who were otherwise overlooked in previous research. In summary, these studies attempted to incorporate the stakeholders' opinions and needs to evaluate, inform, and improve current hearing healthcare service delivery via teleaudiology.

8.2 Selection of methodologies for Study 1 and Study 3

Study 1 and Study 3 shared a common research aim, which was to explore the perceptions of Australian-based hearing healthcare stakeholders towards teleaudiology implementation. Both studies could be considered exploratory research in which attempts to describe and explain matters such as a phenomenon or an event are made (Adams et al., 2007). Exploratory research is usually where new perspectives are uncovered upon interactions with the individuals involved in a certain circumstance (Jain, 2021). This type of research is widely seen in different research fields to probe and understand perceptions, motivations, and behaviours, including social sciences (Stebbins, 2001), health sciences (Rusu et al., 2021), business and management (van Dun et al., 2017), retailing and consumer services (Pantano & Vannucci, 2019), manufacturing (Chiarini et al., 2020), and so forth.

Study 1 was a mixed-methods study employing a set of five similarly structured questionnaires which consisted of both quantitative and qualitative questions. Meanwhile, Study 3 was entirely qualitative in nature, using individual semi-structured interviews conducted online for data collection. Surveys and interviews are some popular tools for data collection in exploratory research due to different reasons (Jain, 2021). Surveys, possibly the most widely used tool for data collection, can be conducted on large samples at relatively low costs, especially when distributed online (Adams et al., 2007; Babbie, 2011; Fowler, 2014). Interviews, on the other hand, enable a higher level of personalised interaction between the respondent and the researcher, and often result in a vast amount of information (Adams et al., 2007; Jain, 2021). However, these data collection tools do present with shortcomings, for example, surveys' susceptibility to low response rates, and interviews' time-consuming process with less flexibility around the timing of data collection (Adams et al., 2007; Fowler, 2014; Jain, 2021). Considering the different strengths and weaknesses accompanying different research methods, it is suggested that employing a combination of research methods may serve better purposes (Babbie, 2011; Fowler, 2014). Hence, after a consideration of available timeframe and resources, surveys and interviews were selected as the research methods in Study 1 and Study 3 to cohesively gain broader and more nuanced insights into stakeholders' perceptions and attitudes towards teleaudiology use.

8.3 Key barriers to teleaudiology uptake

Seven key barriers to teleaudiology uptake have been identified in this PhD research and are summarised in Figure 8.1. These barriers are discussed in detail below.

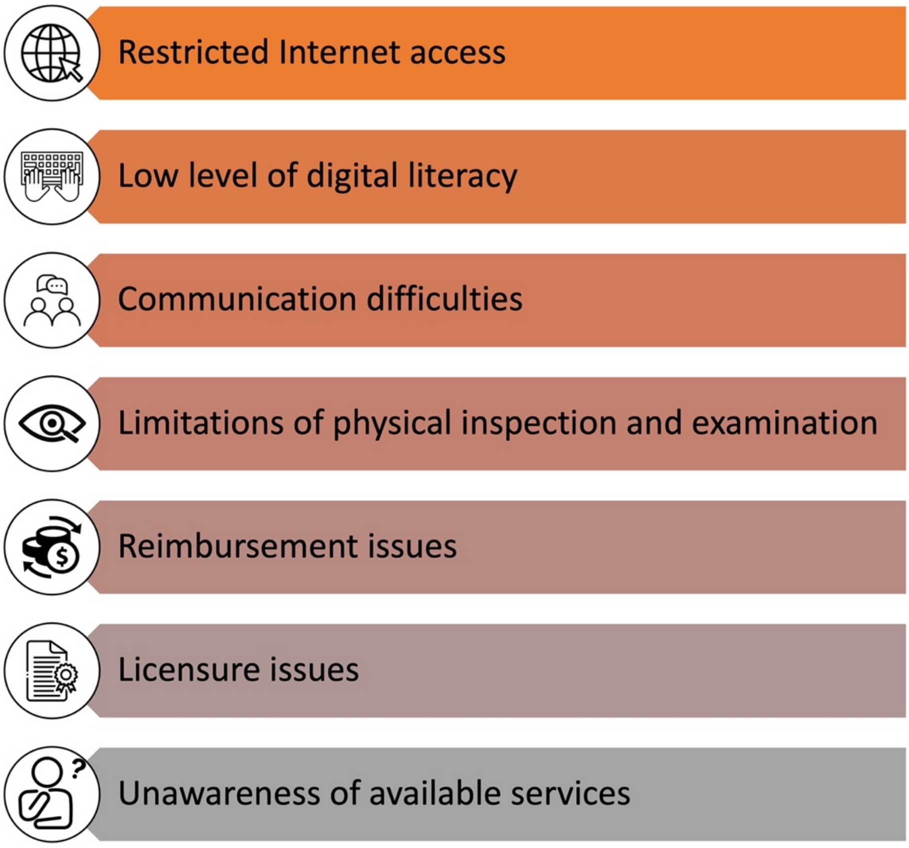


Figure 8.1 Key barriers to teleaudiology uptake.

8.3.1 Restricted Internet access

Due to the digital nature of service delivery via teleaudiology, stable high-speed Internet connection is of absolute importance particularly for synchronous teleaudiology care models, e.g., real-time consultations. Even for audiology services that are delivered in the store-and-forward manner, e.g., home-based otoscopy followed by clinician’s review, require secure and stable Internet connection for images to be uploaded and transmitted with minimally compromised resolution. Poor Internet connection has been identified as a key barrier to teleaudiology uptake in Study 1 and Study 3, as in previous audiology studies (Binkhamis et al., 2024; D'Onofrio & Zeng, 2021; Gajarawala & Pelkowski, 2021; Ramkumar et al., 2023). Not surprisingly, the same barrier not only applies to audiology, but also to other medical and allied health disciplines under the telehealth umbrella (Almuslim & AlDossary, 2022; Gajarawala & Pelkowski, 2021; Naik et al., 2022; Triana et al., 2020; Waldrop et al., 2022).

Internet access in Australia has become pervasive over the past two decades. According to the data from the Australian Bureau of Statistics, the proportion of households with Internet access increased from 56% in 2005 to 86% in 2017 (Australian Bureau of Statistics, 2018). In 2017, 88% of the households located in major cities had access to the Internet, whereas a slightly lower percentage (77%) of households located in remote areas had such access (Australian Bureau of Statistics, 2018). The unmatched coverage of Internet connection in urban and remote locations can be attributable to the cost-ineffectiveness of installing data cables as the population density is low, the distance from urban locations is long, and the terrain presents with substantial challenges (Steele & Lo, 2013). This is obviously not ideal, given that residents in remote locations are in direr needs of telehealth services than their urban counterparts, mainly due to the greater shortage of healthcare providers where they live. As an initiative to deploy high-speed broadband infrastructure across the nation, the national broadband network (NBN) was launched in 2009 (National Broadband Network (NBN) Co, n.d.). The NBN rollout was declared to be complete in 2020 and afterwards, additional fundings have been allocated to improve NBN delivery (Australian Government Minister for Communications, 2022). Besides, the $380 million Mobile Black Spot Program was initiated in 2015, targeting mobile telecommunication service improvement in regional and remote areas (Australian Government Infrastructure Australia, 2023). Internet access is, unfortunately, an infrastructural barrier to telehealth uptake which may only be effectively prevailed over by legislative means. With the broadband and mobile connectivity highlighted as one of top five infrastructure gaps in regional Australia and persistent fundings for advancements, it is hopeful that Internet access will become less hindering to telehealth uptake in this country (Australian Government Infrastructure Australia, 2022).

It is worth mentioning that uncertainties around patients' access to devices with video capacity, access to Internet connection, and ability to pay Internet or cellular plan costs existed among physicians (Kalicki et al., 2021). It is unclear whether the same occurs in the hearing healthcare industry. This, nonetheless, accentuates the importance of understanding clients' capability of receiving care via teleaudiology before settling on the service delivery mode (remote versus in-person). Hearing healthcare providers should beware of making assumptions about clients' access to Internet or telecommunication devices, for instance, not every client dwelling in urban areas has stable high-speed Internet connection. There is a need for open discussions between clients and hearing healthcare providers about technological requirements, alongside other considerations, beforehand.

8.3.2 Low level of digital literacy

Healthcare services leveraging ICT inevitably necessitates end users demonstrating basic Internet and technological skills. Poor digital literacy among patients has been suggested as a major barrier to utilisation of teleaudiology and in a broader scope, telehealth (Bennett & Campbell, 2021; Jang-Jaccard et al., 2014; Kalicki et al., 2021; R. Le et al., 2023; Rasekaba et al., 2022; Triana et al., 2020). Findings from Study 1 and Study 3 corroborate such suggestion.

Digital literacy is described as "*the ability to access, manage, understand, integrate, communicate, evaluate and create information safely and appropriately through digital technologies*" (UNESCO Institute for Statistics, 2018). Combining with the concept of health literacy, which is defined as "*the degree to which individuals can obtain, process, understand, and communicate about health-related information needed to make informed health decisions*" (Berkman et al., 2010), the term "eHealth literacy" has been coined pertinent to one's ability to leverage information from technological sources for health purposes (Norman & Skinner, 2006). Digital literacy does not simply constitute one type of skill. Instead, it is considered to be comprised of six literacy domains: traditional literacy, information literacy, media literacy, health literacy, computer literacy, and scientific literacy (Norman & Skinner, 2006).

Present evidence on the factors contributing to limited digital literacy is on the whole consonant. Old age and lower education level or socioeconomic status are typically associated with low level of digital literacy (Choi & Dinitto, 2013; Lopez de Coca et al., 2022; Ng et al., 2022; Tennant et al., 2015). Residents of rural areas also tend to exhibit poorer digital literacy, predominantly because of the lack of exposure and knowledge of technology (Rasekaba et al., 2022). Nevertheless, exceptions have been observed, e.g., patients with high socioeconomic status may not be as digitally literate as expected (Livingood et al., 2022). Furthermore, age may not appear to be a defining factor of a person's acceptability and willingness to use telehealth (Banbury et al., 2018; Lam et al., 2020), and individuals with a very low level of digital literacy may in fact be the biggest beneficiaries of telehealth interventions (Jacobs et al., 2016). Hence, conjecture about patients' digital literacy based on their demographics or socioeconomic status may not always hold true, and mismatch between eligible patients and telehealth opportunities may preclude patients from accessing the benefits which they may not be able to enjoy otherwise in in-person encounters.

Digital literacy has been recognised as a super social determinant of health due to its implications for other social determinants of health, e.g., employment (Sieck et al., 2021). Considering the significance of gauging patients' digital literacy, various screening tools have been developed in an attempt to systematically assess and quantify digital literacy. A review by Sakumoto and Krug (2023) shortlisted five tools for patient and clinician evaluation: Digital Literacy Self-Assessment Tool (DLSAT), Electronic Health Literacy Scale (eHEALS), Digital Health Care Literacy Scale (DHLS), Telehealth Literacy Screening Tool (TLST), and University of Alabama-Birmingham Technology Comfort Survey (TCS). It was revealed that patients and clinicians held different perspectives when selecting an optimal digital literacy screening tool with regard to its relevance, user experience, engagement, and comprehensibility (Sakumoto & Krug, 2023). In addition, patients' digital literacy is not regularly explored, and sometimes presumed by clinicians, in clinical encounters. The scarcity of such practice is reflected by a clinician in Study 3 expressing an inclination for the incorporation of a digital literacy screening instrument in clinical practice to better delineate clients' candidacy for teleaudiology services, implying that assessment of digital literacy is largely lacking in current practice.

8.3.3 Communication difficulties

Communication in either verbal or non-verbal form has been perceived as more challenging in teleaudiology consultations comparing with in-person consultations (Parmar et al., 2022; Saunders & Roughley, 2021). Since a majority of clients attending consultations have certain degrees of hearing impairment, communicating in a remote fashion can possibly exacerbate miscommunication and create additional stress. Technological failures can further aggravate communication difficulties, as the lag in transmission of audio and visual signals can lead to overlapped conversations and misheard information (Parmar et al., 2022). Regarding non-verbal cues, it is easy to postulate that phone consultations relay an extremely insubstantial number of non-verbal cues, such as intonation and pauses between conversations. In contrast, videoconferencing allows speakers to pick up facial expressions and body language, which may provide useful contextual meanings. Video calls are, however, not without their limitations, as patients have reported difficulties seeing member of staff on a small screen (Saunders & Roughley, 2021). Individuals with vision impairment may find video calls more challenging than those with normal vision as well. Furthermore, some patients might perceive communication via video as less comfortable than in-person (Jenkins-Guarnieri et al., 2015), though others might feel otherwise (Barsom et al., 2021). That said, the inclusion of third parties such as family members or assistants at the patient side may facilitate communication, since they can act as another pair of eyes and ears to relay information, from the clinicians to the patients and vice versa. This can be one of the considerations when arranging teleaudiology consultations, particularly for patients who are expected to experience greater communication difficulties.

Communication problems are a common barrier to telehealth uptake shared between the audiology profession and other health professions. An internal medicine study by Gordon et al. (2020) revealed that some patients were hesitant about asking questions and speaking up during telehealth consultations. Some of them also felt less in control of the conversation because the practitioner was rushing through the consultations. Presence of other personnel during the consultation could deter patients from sharing personal details openly, but in other circumstances the personnel could contribute to the communication by repeating and explaining information the patients missed (Gordon et al., 2020). Language barrier has been identified as another factor impeding communication during telehealth encounters (Almuslim & AlDossary, 2022; Gifford et al., 2021; R. Le et al., 2023; Naik et al., 2022). For example, a large-scale nationwide survey study conducted in the USA revealed that Spanish-speaking Latino adults were more likely to report language concerns as a barrier to telehealth, alongside the dearth of interpreters and the gaps in their own digital literacy (R. Le et al., 2023). As a remedy for such language gap, a recommendation of utilising clinic team members as translators was made if they spoke the patient’s language (Madden et al., 2020; Wu et al., 2020). This practice, however, requires extra caution as the accuracy of translation is of paramount importance, especially when medical terminology is involved. In terms of non-verbal cues captured by remote communications, the absence of such cues can prove detrimental to the understanding of patients' health status. In particular, difficulties in discovering and evaluating crucial non-verbal cues, such as subtle physical signs and odour, might undermine the quality of care received by mental health patients (Perry et al., 2020).

8.3.4 Limitations of physical inspection and examination

Physical inspection and examination of the ears and hearing devices constitute an indispensable component of hearing care, providing information necessary for accurate diagnosis and troubleshooting. Audiological assessment usually begins with otoscopy, a procedure in which a handheld otoscope is used to visualise the details of ear canals and the information obtained can assist in the diagnosis of ear conditions (Rebol, 2022). Conditions such as cerumen obstruction, exostosis, tympanic membrane perforation, external ear canal infection (otitis externa), middle ear infection (otitis media), and presence of foreign bodies can be identified through otoscopy (Rebol, 2022). On certain occasions, depending on the severity of the above conditions, it can result in a hearing loss and a referral to an ENT specialist is sometimes warranted. Internet and smartphone technology has enabled otoscopy to be performed remotely, via both real-time and store-and-forward models. In a real-time teleaudiology consultation, photos and videos of ear canals can be captured by conventional otoscopy and video-otoscopy, respectively, and the clinician can interpret the findings instantaneously; whereas in a store-and-forward model, photos and videos of ear canals can be saved and sent for clinician's review at a different time. Otoscopy can be performed on the client's side with the help of a trained facilitator or parents/caregivers for paediatric clients (D'Onofrio & Zeng, 2021). However, image and video quality is critical to accurate diagnosis, and the quality of images captured by non-otolaryngology-specialist facilitators was reported to be highly heterogeneous (failure rate of 7% to 81.9%) (Metcalfe et al., 2021). Parent-performed video-otoscopy could vary greatly from physician-performed video-otoscopy (Shah et al., 2018), but provision of training sessions could improve the video quality acquired by parents (Erkkola-Anttinen, Irjala, Laine, Tähtinen, et al., 2019). Otoscopy is conventionally performed with the use of specialised otoscopes which may not be accessible by the general population. The invention of smartphone-enabled otoscopes allows home-based otoscopy via the use of a modified otoscope head attached to the smartphone camera, yet image quality remains an underlying problem when performed by non-clinicians (Moshtaghi et al., 2017; Rebol, 2022). In addition, recent introduction of artificial intelligence algorithms and machine learning models to smartphone-based video-otoscopy exhibited high reliability and accuracy in the diagnosis of acute otitis media in children, paving way for the potential transformation of care for patients with this condition (Shaikh et al., 2024).

Apart from examination of the ears, teleaudiology may make inspection of hearing devices challenging. HAs, for example, have various minute parts which may require magnification for close inspection during troubleshooting. Damage or blockage in those mechanical parts, including the vents, microphones, switches, battery compartments, receivers, and earmolds/domes, can induce malfunction of the HA (Ricketts et al., 2019). Oftentimes in a HA follow-up/review appointment, when a complaint of malfunctioning HA is raised, the first step is to inspect the external parts or hardware of the device to pinpoint the origin of problem (Krumenacker, 2019). Most of the time, this can be done fairly easily and efficiently in person, when the clinician is able to handle and check the HA physically. When this procedure needs to be performed remotely, its effectiveness significantly depends on the way the device is shown by the client and the camera resolution on client's side. Instructing clients to troubleshoot can be an intricate task as well, and markedly so if they have dexterity issue or severe hearing loss, rendering it strenuous for them to follow instructions with their HAs out of their ears. Besides, as an integral part of the HA fitting process, real-ear measurements are required to verify whether a HA's output matches the prescribed target (Taylor & Mueller, 2021). A small probe tube is precisely placed in the client's ear canal at a position that is neither too far nor too close from the tympanic membrane (Taylor & Mueller, 2021). This verification testing will not be feasible via teleaudiology without a trained facilitator next to the client.

Clinicians from Study 3 have expressed uncertainties in utilising teleaudiology for diagnostic testing in infants because of the difficulties checking the placement of testing equipment. The ABR test is used to determine infants' and children's hearing sensitivity primarily due to their young age and incapability in partaking in behavioural testing (Rouillon et al., 2016). To conduct the ABR test, a specific electrode montage is required – the positive electrode is positioned on the forehead and the negative and ground electrodes are positioned on the mastoid bones on both sides (Kaga, 2022). A conductive abrasive gel is also used to prepare the skin for electrode placement beforehand. The preparation step and precise placement of electrodes are imperative for acquiring reliable results, and the test will not start when the impedance is higher than 5 kΩ (Kaga, 2022). Even with the presence of a trained assistant, clinicians were tentative of the preparation quality, not because they lacked trust in the assistant, but rather preferring to perform the test hands-on to ensure standardised quality of care. Moreover, clinicians have commented on the difficulties checking the electrode placement on a small computer screen. These limitations bring into question the accuracy of test results, leaving teleaudiology a less preferable option for diagnosing hearing loss in the paediatric population.

Physical examination has the same, if not greater, importance in other medical fields (Balestra, 2018; Gajarawala & Pelkowski, 2021). For instance, patients with diabetes questioned their quality of care when the practitioners could not physically examine numbness or pain on the patients' bodies in telehealth consultations (Gordon et al., 2020). Patients and physicians also believe that physical examination possesses healing power and aids rapport and trust building (Kelly et al., 2019). Notwithstanding that telehealth consultations have undoubtedly posed obstacles on conducting exhaustive physical examination, guidelines and protocols have been developed to inform meaningful and effective virtual physical examination (Benziger et al., 2021; Hansen et al., 2021; Yih et al., 2022). With technological advancement, virtual and in-person physical examination may hold equal value in the future, benefitting patients who opt for telecare.

8.3.5 Reimbursement issues

Reimbursement issues have been identified as a long-standing barrier to teleaudiology uptake by the studies presented in this thesis and previous studies (Kimball et al., 2018; Ramkumar et al., 2023; Ravi et al., 2018; Swanepoel, Clark, et al., 2010). Reimbursement policies vary substantially across countries and even across states within a single country. Take the USA as an example, patients may be reimbursed through Medicare, Medicaid, or private insurance plans for the audiological services they received (American Speech-Language-Hearing Association, n.d.-b). Medicare is a federal-run program for people who are 65 years old or above and some of those under 65 with certain disabilities or conditions, whereas Medicaid is jointly run by federal and state governments for people with limited income and resources (U.S. Department of Health and Human Services, 2022b). State governments are in charge of their own Medicaid programs and thus, the eligibility requirements and service coverage may differ between states (American Speech-Language-Hearing Association, n.d.-a). Medicare telehealth benefit has been expanded since 2020 in light of the COVID-19 pandemic. However, as historically many in-person audiological services were not covered by Medicare, those services provided via telehealth remained noncovered in spite of the aforementioned benefit expansion. Most of the audiological services covered by Medicare are diagnostic in nature, omitting rehabilitation services such as HA services and management of tinnitus or vestibular disorders (Jilla et al., 2021). Current Medicare-authorised telehealth services encompass primarily diagnostic procedures, e.g., PTA, speech audiometry, acoustic immittance testing, tinnitus assessment, and so forth and this coverage is temporary through 31st December 2024 (American Speech-Language-Hearing Association, n.d.-c). In other words, such telehealth service coverage is subject to change unless permanent changes are made to Medicare policies.

In relation to the Medicaid program in the USA, the federal government provides flexibility to the state governments to establish their own standards, resulting in widely variable service coverage (American Speech-Language-Hearing Association, n.d.-a). It was reported that Medicaid covered children as beneficiaries nationally to receive assessment and intervention for hearing loss, while adult patients in only 22 out of 50 states were covered for hearing care (Jilla et al., 2021). Different modes of telehealth service delivery are also differentially covered by Medicaid across the states, e.g., live video, audio-only, or store-and-forward services may not be covered in certain states (Center for Connected Health Policy, 2023). Variability exists among private insurers and insurance plans as well (Jilla et al., 2021).

Similar to the reimbursement regime in the USA, Australians may receive subsidised hearing care with reimbursement via public and private schemes. The government-funded Medicare program covers a variety of diagnostic hearing and vestibular assessments conducted solely in person, which means Medicare benefits are inapplicable to those services provided via telehealth (Australian Government Department of Health and Aged Care, 2024c). Other than Medicare, the Australian government has established a funded program dedicated to hearing care, the HSP. People who are pensioners, veterans, members of the Australian Defence Force, aged below 26 years, eligible Aboriginal or Torres Strait Islanders, living in remote areas, requiring specialist hearing services, or having certain disabilities are eligible for the HSP (Australian Government Department of Health and Aged Care, 2024a). The HSP covers a wider range of audiological services which can be provided via telehealth, including hearing device fittings, unaided and aided client reviews, and rehabilitation (Federal Register of Legislation, 2023). Unlike the Medicare in the USA, the HSP coverage of teleaudiology services is predominantly rehabilitative in nature. Most of the telehealth-based diagnostic procedures, especially for new clients, are largely excluded from the HSP. In regard to private insurance plans, the situation is the same as in the USA – coverage of teleaudiology services varies from insurer to insurer and policy to policy.

With such complexity in teleaudiology reimbursement policies around the globe, it is fathomable that the reimbursement issues around telehealth by and large may be equally, if not more, convoluted. Indeed, challenges in navigating reimbursement have been emphasised as a key barrier to telehealth utilisation in healthcare sectors such as respiratory medicine (Raghu & Mehrotra, 2023), nursing (Gajarawala & Pelkowski, 2021), and general medicine (Weinstein et al., 2014).

8.3.6 Licensure issues

Interestingly, licensure issues have been suggested as a barrier to teleaudiology implementation in the literature (D'Onofrio & Zeng, 2021; Ravi et al., 2018) but not in Study 1 and Study 3. On a broader level, licensure laws were also identified as an area calling for reform for seamless implementation of telehealth and telemedicine (Raghu & Mehrotra, 2023; Weinstein et al., 2014). This phenomenon which was observed in other studies but not in this PhD could be ascribed to the differences in licensure laws between countries. For example, each state in the USA has its own licensure requirements for audiologists to practice in person and via teleaudiology (American Academy of Audiology, n.d.). When providing services via teleaudiology, the audiologist must be licensed in both the states where the audiologist is located and the client is located (American Speech-Language-Hearing Association, n.d.-d). As one can imagine, the costs incurred on audiologists in the process of obtaining multiple licences across states become higher, which can in return deter them from adopting teleaudiology. In an attempt to facilitate the interstate practice of audiology, the American Speech-Language-Hearing Association (ASHA) and its state regional organisations established the Audiology & Speech-Language Pathology Interstate Compact (ASLP-IC) in 2022 (Audiology & Speech-Language Pathology Interstate Compact, n.d.). In April 2024, the ASLP-IC has been enacted into law in 31 states, with the legislation pending in another eight states. It is expected that audiologists in the ASLP-IC member states can start submitting applications for compact privileges in late 2024 to early 2025 to practice in person and via teleaudiology in those states.

On the contrary, licensure requirements in Australia are much more streamlined and standardised. Although the country consists of eight states and territories, the licensing of hearing healthcare practitioners is governed by professional bodies, instead of state governments or organisations. For anyone to deliver audiology services, either in person or via teleaudiology, under the government-funded HSP, they must be a qualified audiologist or audiometrist registered under Audiology Australia, the Australian College of Audiology, or the Hearing Aid Audiology Society of Australia (Australian Government Department of Health and Aged Care, 2024b). As long as the audiologist or audiometrist remain a qualified practitioner under any of those professional bodies, they are allowed to provide services listed in the HSP to clients living in any state or territory, regardless of the service delivery mode (in-person or remote). It is because of this disparity in the history of licensing regulations between Australia and other countries which gives rise to the aforementioned difference in study findings. Despite Australia is in a well-set position to rid clinicians of licensure concerns, it is nonetheless encouraging to see other countries' continuing endeavours in ironing out such issues for better implementation of teleaudiology.

8.3.7 Unawareness of available services

On some occasions, patients are unable to access telehealth services simply because they lack the awareness of available telehealth services. They have no knowledge of this existing service mode and therefore do not possess the ability to request for telehealth service options. This is evident in Study 1 and Study 3 in which clients reported their unawareness of available teleaudiology services or apps as a barrier to the utilisation of such services or apps. Like many other barriers to telehealth uptake, the observation of unawareness of available telehealth services among patients is not confined to a single country or health profession. In fact, reports from countries such as Australia (St Clair & Murtagh, 2019), the UK (Campling et al., 2017), the USA (Kichloo et al., 2020), and Japan (Paudel et al., 2023), and Israel (Penn & Laron, 2023) indicated a universal dearth of effort in publicising telehealth, despite its widespread applications and promising benefits. Most notably, a telehealth satisfaction study conducted in the USA in 2019 revealed that 74.3% of consumers were unaware of telehealth services or believed that their healthcare providers did not offer this option (Truex, 2019). In rural and suburban areas to where telehealth services were purposefully targeted, 72% and 70.3% of consumers, respectively, lacked awareness of such services (Truex, 2019). Some patients might not even be familiar with the terms "telehealth" or "telecare" (Campling et al., 2017). Client participants from Study 1 shared similar thoughts, as some of them never heard of teleaudiology previously and were not introduced to the idea of receiving hearing care remotely. This barrier to telehealth uptake calls for a pressing need for further promotion, advocacy, and marketing campaigns to increase the publicity of telehealth services. As the gatekeepers of clinical service provision, clinicians and healthcare providers also play an essential role in offering and educating patients on telehealth as an alternative means of care delivery.

8.4 Key facilitators of teleaudiology uptake

The four key facilitators of teleaudiology uptake identified in this PhD research are shown in Figure 8.2 and further discussed below.

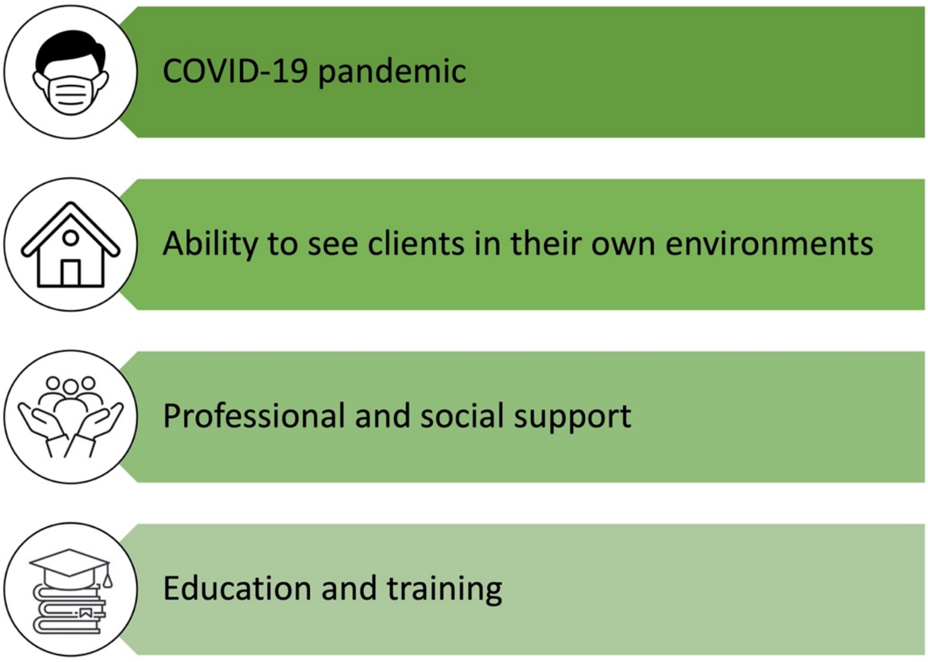


Figure 8.2 Key facilitators of teleaudiology uptake.

8.4.1 COVID-19 pandemic

In the pre-COVID-19 times, telemedicine services were largely underused. Even in countries with the highest usage of telemedicine such as Australia and Canada, remote consultations only constituted 0.1% to 0.2% of all in-person consultations (Hashiguchi, 2020). Telehealth and telemedicine acquired unprecedented popularity since the outbreak of the COVID-19 pandemic in 2019 due to their ability to deliver undisrupted care in the midst of lockdowns and social restrictions (Baum et al., 2021; Taylor et al., 2021). Government of numerous countries responded swiftly to the instantaneously surging demand for telehealth services by relaxing regulatory restrictions and financially incentivising telehealth use. For example, the USA waived the restrictions on limiting Medicare telehealth service providers to those located in rural areas only, and allied health workers were allowed to conduct telehealth consultations in countries such as Germany and Iceland (Organisation for Economic Co-operation and Development, 2023). In terms of financial incentives, countries including the UK, Korea, and Belgium started reimbursing synchronous telehealth consultations through government schemes, and countries including the USA, Ireland, and Estonia provided payment add-ons for telehealth services to cover ancillary costs associated with equipment procurement and maintenance, technical support, and so forth (Organisation for Economic Co-operation and Development, 2023).

Despite the endeavours to facilitate telehealth uptake globally during the COVID-19 pandemic, there were concerns about telehealth adoption rate reversing to pre-pandemic level once the pandemic is over. In relation to teleaudiology particularly, it was proposed that teleaudiology service use might decline when pandemic-related enablers, including maintaining client and staff safety and increased funding, no longer exist (Bennett, Kelsall-Foreman, et al., 2022b). Indeed, in large-scale studies with enormous sample sizes (i.e., hundreds of millions), decreases in telehealth encounters were observed in 2021 when in-person encounters became available again (Bartelt et al., 2023; Ferguson et al., 2024; Office of the Assistant Secretary for Planning and Evaluation, 2023). Although telehealth encounters had dropped since the spike at the beginning of the pandemic, their utilisation rates still remained higher than pre-pandemic levels across primary care, subspecialty care, and mental health services (Ferguson et al., 2024). Most notably, video-based encounters remained at near-peak levels of 11% to 13% (Ferguson et al., 2024). In fact, telemedicine policies were temporary and subject to review from time to time in various countries, but some countries are working towards developing permanent legislation frameworks and payments for telehealth services (Organisation for Economic Co-operation and Development, 2023). With the reinstatement of in-person healthcare services in the post-pandemic landscape, it seems unavoidable for certain groups of service users to withdraw from telehealth and return to status quo. Nonetheless, it is clear that the benefits of telehealth are being recognised and there has been a gradual shift in service delivery modality towards a new equilibrium where in-person and remote care are both welcomed. The COVID-19 pandemic opened up opportunities for us to witness and assess the feasibility of utilising telehealth, and whether it can persist very much depends on stakeholders’ actions hereafter.

8.4.2 Ability to see clients in their own environments

Seeing clients in the clinical setting alone has its own advantages and shortcomings. For some diagnostic testings sensitive to surrounding noise levels, performing the testings at the clinic where equipment and facilities are confidently up to calibration standards appears to be a better option than home environments where such parameters are less controllable. Consulting clients outside the clinic, however, may provide invaluable insights into their lives and lifestyles which are otherwise unobservable at the clinic. For example, according to the findings from Study 1 and Study 3, clients and clinicians appreciated teleaudiology-enabled HA fitting review and finetuning in clients' home environments. Clinic rooms represent a more or less ideal environment for verbal communications since the venues are typically quiet or acoustically treated. Yet, this acoustic characteristic also renders clinic rooms less realistic in simulating real-life conversations. HA users may encounter challenges when communicating in diverse situations, such as when background noise is present or when conversing in group settings (Aazh et al., 2015; Gallagher & Woodside, 2018). Hearing needs in different situations are usually addressed with the use of multi-memory HAs which allow the configuration of individual programs suited to each listening situation, e.g., activating noise reduction when listening in background noise (Pasta et al., 2022). Those programs and technical features can assist HA users to some extent, but the aforementioned onerous listening situations are hard to replicate at clinics, implying that it is unattainable to trial the HA programs immediately after configuration or adjustment. If the HA users notice any additional problems after testing the HA programs in reality, they will need to make another appointment to finetune their HAs.

On the contrary, teleaudiology allows HA finetuning when clients are virtually in any location or situation. Although it may be less feasible to conduct a consultation with undue background noise (e.g., in a bar), reviewing and finetuning HAs at clients' home environments can already better address certain unique listening needs, say when watching television or talking to family members. Moreover, clinicians can observe the clients' home environments via video calls and provide suggestions on environmental and acoustic modifications in the interest of effective listening, for instance, the adoption of soft furnishings and sound-absorbing panels to reduce sound reverberation (Reinten et al., 2017).

Another interesting example from Study 3 is the possibility of finetuning HAs remotely when the client is in a car. The client frequently found it strenuous listening to her sister when riding in her car. Listening in a car can be particularly challenging for individuals with hearing impairment, as various kinds of noise (e.g., noise from the road, engine, radio, music, and wind) can dampen the signal-to-noise ratio inside the car. Being unable to face the speaker constantly when driving may burden the communication as well. As such, a clinician participant from Study 3 attempted connecting to the client's HAs and finetuning them remotely. Eventually, the clinician was able to investigate, understand, and resolve the client's listening needs in this unique setting and they were both satisfied with the outcome. This would not have been possible without the help of teleaudiology.

Outside the field of audiology, the benefits of seeing patients in their own environments by the use of telehealth and telemedicine have also been acknowledged. Primary care physicians recognised that patients with mental health conditions might receive better care from home (DePuccio et al., 2022). For example, patients with anxiety or depression may not have the stamina to go out and attend in-person appointments. The comfort of seeing the physician from the patients' homes may empower them to discuss more sensitive health topics (DePuccio et al., 2022). Furthermore, video visits allow physicians to evaluate the home settings, lifestyles, and behaviours of patients and other people in the household more comprehensively. For instance, occupational therapists may assess patients' mobility and identify tripping hazards, and allergists may identify potential sources of allergies in the home environment (Hasselfeld, n.d.). Additionally, patients with an Indigenous background or residing in remote and rural areas may feel more culturally safe consulting physicians in their own environments via telehealth (Royal Australasian College of Physicians, 2020). That said, one of the downsides of seeing patients in their own environments is the privacy concerns arisen from unavoidably involving other people such as family members or carers at the patient side. Risks including a lack of personal space for confidential conversations and sensitive health information being overheard have been reported as challenges of telehealth services (Houser et al., 2023).

8.4.3 Professional and social support

Multidisciplinary management is an effective means to better coordinate healthcare professionals to provide efficient care and improve patient outcomes (Epstein, 2014). Arranging an in-person consultation in which multiple professionals are present in the same location at the same time can be complicated. With the emergence of telehealth, the obstacles of delivering multidisciplinary care are considerably mitigated. Conducting a virtual consultation puts no limitation on all attendees' physical location and specialists can join the consultation whenever they are needed. This advantage over in-person consultation has encouraged telehealth uptake, especially for the management of more complex medical conditions. Cystic fibrosis is one example, as patients with cystic fibrosis often require care from physicians, nurses, respiratory therapists, dietitians, social works, and so forth (Gifford et al., 2021). The implementation of telehealth in multidisciplinary visits has been reported as feasible and up to six patient care team members could be accommodated in a single visit (Varghese et al., 2021). Similar application in the paediatric population has also been reported. A study in the USA showed that children who required gastroenterological and nutritional care could be attended to efficiently by paediatric gastroenterologists, nurse practitioners, dietitians, and social workers via telehealth visits (Gleghorn et al., 2022). Additional strengths of receiving multidisciplinary care through telehealth include instant clarification of professionals' advice to ensure consistency and efficient use of interpreters (Gleghorn et al., 2022). The same is applicable to the audiology profession, as guidance on the provision of multidisciplinary care for the management of hearing impairment has been proposed (Hoi et al., 2021), and the Australian Teleaudiology Guidelines encourage the involvement of multiple healthcare professionals in teleaudiology consultations as well (Audiology Australia, 2022b).

Sometimes, the success of telehealth/teleaudiology consultations depends on the presence of patient-site facilitators and the values they add to the process. Clinical procedures with hands-on elements, such as otoscopy and placement of testing equipment on the client in a teleaudiology consultation, require a facilitator on the client's side to be another pair of hands for the clinician to perform the testing remotely (Krumm, 2016). The role of patient-site facilitators can be served by a wide range of personnel, for example, allied health workers, community health workers, students, family members, and community members (Coco et al., 2020). Moreover, the employment of local healthcare workers in rural areas not only fulfilled the purpose of increasing the accessibility of audiological services in those areas, but also accomplished the task in a timely and cost-effective way (Ramkumar et al., 2013a). In addition, delivering care via telehealth with the assistance of patient-site Indigenous health workers may facilitate and enhance culturally appropriate care (Caffery et al., 2018).

As discussed previously, digital literacy is one of the key barriers to telehealth uptake. Stereotypically less digital literate populations such as the elderly may encounter more challenges when accessing and utilising technology. Previous research has indicated that social support plays a significant role in facilitating telehealth use among older adults (Chung et al., 2021; Rasekaba et al., 2022). Individuals who were living with family or friends and received technical support from more digitally competent individuals including family, friends, and assisted living facility staff, were more likely to utilise telehealth services (Chung et al., 2021). Thus, telehealth uptake is dependent on the professional and social support available to the patients. The greater the extent of support they have access to, the better their telehealth uptake rate and potential health outcomes will be.

8.4.4 Education and training

For the individuals who are less familiar and confident with telehealth, education and training have been reported to facilitate their telehealth acceptance and uptake. As a precursor to accessing telehealth services, one must be sufficiently digitally literate to leverage technology for various purposes, e.g., attending virtual appointments, navigating applications, etc. The self-efficacy in the use of digital devices (e.g., tablets) among the elderly, who are often associated with lower technological competence, has been shown to improve through a training program (Gatti et al., 2017). The training program consisted of 10 in-person group lessons focussing on explanations of specific tablet functions and hands-on practice with the aid of trainers, tutors, and peers. This learning experience enabled the participants to feel more empowered and autonomous and encouraged them to learn how to utilise technology (Gatti et al., 2017). With respect to telehealth, people's interest and confidence in accessing telehealth can also be increased through education. Jezewski et al. (2022) designed an education program comprising a 20-minute presentation and several written guides about telehealth, targeting low-income older adults. At the end of the program, the participants displayed increased understanding and confidence in using telehealth services, and eagerness to learn more about telehealth in the future (Jezewski et al., 2022). Interestingly, participants who received education in person reported higher willingness to use telehealth in the future than those who received education at home (i.e., provided with a paper version of the presentation and written guides), suggesting in-person education might be more advantageous (Jezewski et al., 2022).

Education and training do not only facilitate telehealth uptake from the patients' perspective. In fact, other stakeholders or telehealth users may benefit as well. For instance, telemedicine training was identified as a contributor to successful virtual urology consultations (Naik et al., 2022). Similarly, hearing healthcare clinicians in Study 3 indicated that receiving training sessions from clinical coaches about new teleaudiology platforms helped familiarise them before putting the platforms to use. Furthermore, other participant responses in Study 3 suggested circumstances under which education and training improved teleaudiology uptake. For example, as an integral part of quality service delivery, front of house staff were adequately trained in the preparation and facilitation of virtual consultations. Even clinical observations can be regarded as a form of training, as audiology students can accumulate experience and develop clinical skills from taking a passive observer role in teleaudiology consultations. This kind of learning opportunities holds exceptional importance in preparing students for future teleaudiology engagement. It is therefore apparent that the impacts of education and training on telehealth/teleaudiology uptake are multi-faceted – different stakeholders are able to benefit from them, resulting in improved acceptance, confidence, and uptake of telehealth/teleaudiology.

8.5 Other potential determining factors of teleaudiology uptake

The additional factors influencing telehealth uptake presented below have been reported by previous studies. Although the effects of these determining factors might not be distinctly reflected in Study 1 and Study 3, they may still be pertinent to teleaudiology uptake and thus, a discussion on these factors is worthwhile.

8.5.1 Race and ethnicity

Racial or ethnic minority groups have been reported to less likely use telehealth services, mainly due to their generally lower socioeconomic status (Albon et al., 2021). For instance, lower rates of video consultation among Black and Latino patients were observed and it could be attributed to their decreased access to broadband Internet, digital devices, and reliable mobile phone data plans (Eberly et al., 2020). Besides, language barriers present as an obstacle to using telehealth services for non-English speaking patients (Albon et al., 2021; Eberly et al., 2020).

The increasing visibility of telehealth in the healthcare realm may elicit various cultural perception and responses in patient groups with diverse racial or ethnical backgrounds. For example, in some Middle Eastern countries, the preference for a physical presence in medical visits is emphasised and a resistance to change is recorded (Al-Samarraie et al., 2020). Clinical consultations between opposite genders are against the traditional and cultural beliefs of some patients, even when the consultations are performed virtually (Abdulaziz et al., 2012). In countries where numerous spoken languages and cultural practices exist (e.g., Turkey and Iran), communication between healthcare providers and patients can prove complicated as well (Al-Samarraie et al., 2020).

The concept of machismo, which is associated with masculinity, is commonly shared by Hispanic men (Sobralske, 2006). When translated to healthcare, machismo can contribute to their reluctance to seek healthcare services because of embarrassment and stigma (Getrich et al., 2012). It can be deduced that the negative impacts of machismo on Hispanic men's health-seeking behaviours are equivalent regardless of the way the healthcare services are delivered (in-person vs via telehealth). Moreover, the Latino community may be less accepting of Western medical practices, rendering telehealth a less preferred option when medical care is needed (Ramirez et al., 2021).

Interestingly, lower telehealth use was found among Asian American patients comparing with their White counterparts, despite high rates of broadband Internet access and technology use in the former group (Eberly et al., 2020). This disparity was proposed to arise from the Asian American patients' dissatisfaction with their doctors as they lacked understanding on the patients' backgrounds and values and the patients did not feel properly respected (Lee et al., 2010; Ngo-Metzger et al., 2004). Additionally, the elevated racism against the Asian American community amidst the COVID-19 pandemic might have contributed to their decreased willingness to seek care (Eberly et al., 2020).

To combat these issues, the provision of affordable and reliable Internet services and digital devices will help bridge the socioeconomic gaps in racial or ethnic minorities (Eberly et al., 2020). The employment of interpreters during telehealth consultations has been repeatedly recommended to alleviate language barriers (Albon et al., 2021). Positive dimensions of patients' cultural backgrounds can be tapped into when devising strategies to improve telehealth uptake. For example, family holds significant importance in the Hispanic culture, and younger and digitally literate family members can be encouraged to champion and assist in telehealth use of older patients (Getrich et al., 2012; Ramirez et al., 2021). The involvement of health workers from the same ethnic and cultural background as the patients, e.g., the presence of an Indigenous health worker during telehealth consultations, can also help healthcare providers more thoroughly understand patients' personal circumstances and health needs (Caffery et al., 2018). Indigenous health workers can advocate for the community members' needs, especially when they are too shy or overwhelmed to communicate with the healthcare providers (Caffery et al., 2018).

8.5.2 Patient personality and psychological traits

Past research has investigated the relationship between patient personality traits and telehealth uptake. Those studies mostly adopted the Big Five model (also known as the five-factor model), which categorises personality traits into five groups: extraversion, agreeableness, conscientiousness, openness, and neuroticism (Saucier & Goldberg, 1996), to determine whether the patient personality traits exhibited effects on how well the patients embraced telehealth. For example, in a study of the adoption of a diabetes self-management app, it was revealed that openness to experience was positively associated with app uptake, whereas extraversion was negatively associated with app uptake (Su et al., 2020). Openness to experience was also found to be a predictor of persistent app use. Similarly, openness to experience was reported to be correlated to higher acceptance of hypertension mHealth apps (Breil et al., 2019) and better adherence to a mindfulness and relaxation self-care app among cancer patients (Mikolasek et al., 2018). Another study examining Brazilian patients' attitudes towards telehealth uptake reported slightly different results. This study suggested that plasticity, which is a higher-order personality dimension consisting of extraversion and openness (Feist, 2019), had a mediating effect on such attitudes (Catalina et al., 2021). To put it differently, patients who possessed the personality traits of extraversion and openness tended to show more positive attitude towards telehealth uptake. It is logical to deduce that higher openness to experience will result in greater disposition to telehealth use because those patients are more willing to expose themselves to new experiences and may be more actively looking for novel approaches to receiving care. In relation to extraversion, Su et al. (2020) postulated that patients displaying this personality trait might prefer receiving in-person care and support from social circles so as to satisfy their social desires, rather than accessing care via an app. It is also noteworthy that personality traits may be predictors of patient satisfaction of telehealth interventions, as higher satisfaction was reported to be correlated to higher agreeableness and lower conscientiousness and extraversion (Cieślik et al., 2023).

Aside from the big five personality traits, van Schalkwijk et al. (2024) profiled the psychological characteristics of patients with cardiac conditions who received care via telehealth. The authors concluded that higher level of distress and pessimism and lower level of mental health were associated with more negative attitude towards telehealth, while pessimism was a predictor of lower future telehealth uptake. The proposed explanation for these findings was similar to that for the openness to experience personality trait in the aforementioned studies – patients who were more pessimistic might be less open to new experiences and hold more reserved and negative attitude towards telehealth (Kashdan, 2010).

Based on the research studies discussed above, the personality traits and psychological profiles of patients may present as useful predictors of their telehealth uptake. Understanding and perhaps gauging these patient characteristics may facilitate and empower patients' acceptance, continued use, and satisfaction of telehealth services. In addition, modalities of telehealth service delivery customised to match individual patient needs may be better selected with confidence and efficiency, e.g., introverted patients may be more inclined to receive care by means of apps (Su et al., 2020).

8.6 Strategies to improve teleaudiology uptake

Based on the previous discussion on the key barriers to and facilitators of teleaudiology uptake, there is a multitude of strategies and measures which may be implemented to the current service delivery model to improve teleaudiology uptake in the future. These strategies are summarised in Figure 8.3.

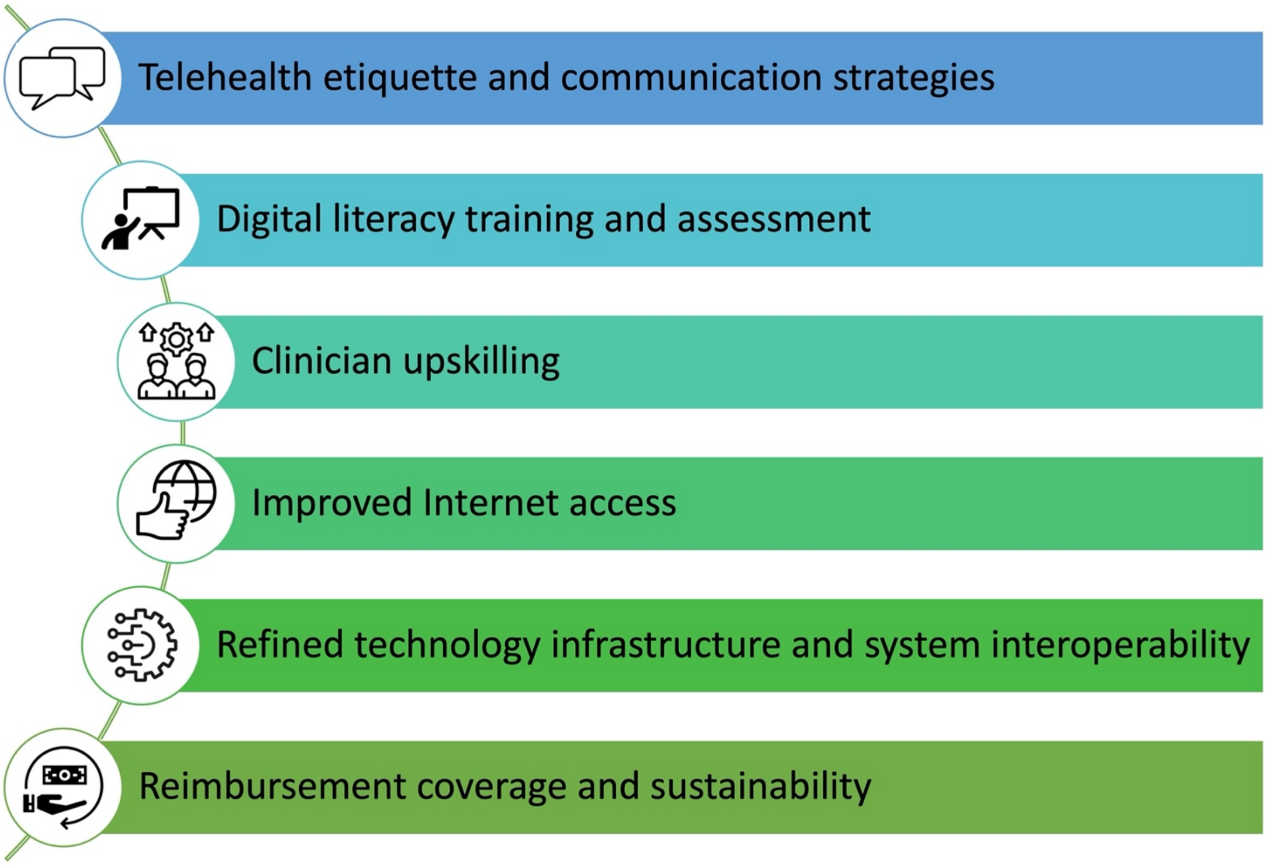


Figure 8.3 Strategies to improve teleaudiology uptake.

8.6.1 Telehealth etiquette and communication strategies

Telehealth etiquette is described as a set of critical soft skills crucial for successful communication, both verbal and non-verbal, during telehealth encounters (Gustin et al., 2020). Remote communication using software, even when conducted via video calls, can prove challenging due to various reasons. Firstly, extra attention should be paid to the room set-up on both the clinician's and client's ends (Gustin et al., 2020). The background should be kept as minimalistic as possible so that it does not appear distracting. On some occasions when the background is not ideal, virtual backgrounds available on some videoconferencing platforms may be used. Moreover, the lighting and ambient sounds in the rooms need to be considered and more so for those who are visually and/or hearing impaired. Clinicians should set up the cameras in a way where they are positioned in the centre of the video feed and adequately close to the cameras.

Secondly, careful considerations should be taken when selecting clothing options so that clinicians do not appear to be distracting (Gustin et al., 2020; Haney et al., 2015). Even though clinicians may be conducting the consultation from home, they should always dress professionally as they would in an in-person consultation. Bright colours, bold patterns, or shiny materials can look distracting on camera and should be steered clear of. Some jewellery (e.g., clanking bracelets) can produce unnecessary noise which can be amplified on the microphone and should be avoided as well (Haney et al., 2015).

At the start of the consultation, the clinician and patient should spend time on introducing all individuals present on both sides and discussing the goals and expectations of the consultation (Gustin et al., 2020; Haney et al., 2015). It should be emphasised that patient privacy is ensured during the telehealth consultation and patient consent needs to be acquired beforehand. In addition, small talk can be useful for ice breaking and rapport building, especially in telehealth consultations where personal connection may be perceived as more distant (Gustin et al., 2020; James, 2020).

Given the concerns suggested by some patients regarding the lack of eye contact and clinician attention during telehealth consultations (Gordon et al., 2020), clinicians should look into the camera instead of the screen while talking so that eye contact can be achieved. Clinicians can also notice clients verbally when they need to look away (e.g., reading client records) to avoid neglecting perceptions. Similar to in-person consultations, clinicians should refrain from distracting behaviours such as pen clicking or table tapping, and phones should be turned off or switched to silent mode as well.

A study by Gordon et al. (2020) revealed that patients could face difficulties trying to speak up or raise questions during telehealth encounters. The authors proposed the development of patient education materials and healthcare provider policies to create an encouraging environment for patients to speak up. Patients can be prompted beforehand to prepare a list of questions and issues they want to ask the clinicians to facilitate discussion. Furthermore, clinicians should practice active listening and constantly check patients' understanding. These practices, along with nodding, leaning in, and words of understanding, help express interest and empathy to make the encounter a more pleasant experience (Gustin et al., 2020).

For those who struggle to follow conversations and understand speech, live captioning can be a potent tool to facilitate communication. Videoconferencing platforms such as Zoom or Microsoft Teams provide live transcription or captioning function transferring speech to text in real time.

Caution should be, nonetheless, exercised before adopting any of those platforms for telehealth purposes, since they may not be up to the required data security and patient confidentiality standards. Alternatively, speech-to-text apps separate from the videoconferencing platforms may be employed. For example, the National Acoustic Laboratories (NAL) in Australia, which is a government-funded research institution, developed a live speech captioning tool named NALscribe during the COVID-19 pandemic (National Acoustic Laboratories, n.d.). Originally aimed at ameliorating communication problems in the presence of face masks and social distancing, though only available on the iOS operating system at the moment, this smartphone-based app allows adjustable font sizes and currently supports 11 languages. Transcripts can be saved in the app for review, but an auto-erase feature is also available to ensure data privacy is upheld by removing captions after a set period.

8.6.2 Digital literacy training and assessment

As a major barrier to teleaudiology uptake, poor digital literacy among clients has deterred them from utilising technology and accessing teleaudiology services, and rendered clinicians hesitant about offering such services to a broader population. Digital literacy training spanning skills ranging from using smartphone and email to using social media and specific apps can be provided to individuals who are less familiar with technology to empower and encourage their technology use. Such training programs can be provided by educational institutions, professional associations, not-for-profit organisations, or through the community. For example, digital literacy training sessions and resources are available in the public libraries of different states of Australia (State Library of Queensland, n.d.; State Library of South Australia, n.d.; State Library of Western Australia, n.d.). Not only limited to senior citizens, but everyone is also welcome to access these community-based resources. In order to maximise the benefits of community-based digital literacy training, Detlor et al. (2022) proposed a conceptual framework under which the staff should be well-trained, the funding should be sustainable, the end users should be effectively engaged, and the program performance should be appropriately measured.

Understanding clients' access to and knowledge of the Internet and technological devices is the first step to determining their suitability for teleaudiology services. Unfortunately, clinicians may not consider asking their clients about this information as a regular procedure in their clinical routine, let alone systematically assessing client digital literacy (e.g., using standardised and validated questionnaires). With the absence of such information, marginalised and low-income communities may be further disadvantaged when teleaudiology does not present as a viable option to themselves (Sundar, 2020). There is currently no consensus on a screening tool most suitable for assessing telehealth literacy (Sakumoto & Krug, 2023). The development of tailored telehealth literacy screening tools co-designed by researchers, clinicians, and patients will potentially facilitate telehealth literacy assessment and its subsequent uptake (Sakumoto & Krug, 2023). Professional associations (e.g., Audiology Australia) may also consider formalising the assessment of clients' digital/telehealth literacy as a mandatory step prior to teleaudiology consultations to promote teleaudiology uptake. On a broader scope, amassing digital literacy data on a population level will enable the identification of digital skill gaps and disparities and the monitoring of changes in these metrics over time (Sieck et al., 2021).

8.6.3 Clinician upskilling

Although telehealth has entered mainstream healthcare under the acceleration of the COVID-19 pandemic, clinicians are often undertrained to fully realise its implications and potentials (Knott et al., 2020; Thomas et al., 2022). Some clinicians are deemed digital natives due to their background of being born into the digital age and growing up with pervasive technology use (Wang et al., 2013). Thus, they are frequently under the assumption of being naturally confident and competent in technology use, and this would apply to delivering healthcare services via digital means. However, comfort and familiarity with technology for everyday use do not necessarily translate to healthcare purposes. In fact, virtual interaction skills need to be acquired through structured training (Pathipati et al., 2016). Clinician training and upskilling is therefore an important means of promoting telehealth uptake.

Delivering care via virtual approaches requires a skillset different from in-person approaches. Slovensky et al. (2017) proposed an organisational framework for designing telehealth training and education programs for clinicians. The authors identified five core telehealth competencies, namely digital communication skills, technology literacy and usage skills, telehealth products and services, regulatory and compliance issues, and technology business care. These competency areas encompass critical skills and knowledge related to effective virtual communication means, how and when to use specific telehealth tools for specific purposes, interdisciplinary team collaboration, regulation and liability, and evaluation of telehealth products and services from the clinical and business perspectives (Slovensky et al., 2017). A wide range of approaches can be implemented in this training, including digital on-call training, workshops, and webinars.

Fickenscher and Pagliaro (2021) further expanded the list of core telehealth competencies by suggesting 10 essential elements for training clinicians to deliver virtual care. The significance of additional areas such as psychology of virtual communications, effective technology assessment, health informatics, artificial intelligence and machine learning, and social media was highlighted. Successful implementation of telehealth training and education programs will require the collaboration between stakeholders, e.g., professional associations, industry, educational institutions, and clinicians (Fickenscher & Pagliaro, 2021). It is noteworthy that such training programs should be structured as continued learning rather than auxiliary workshops (Fickenscher & Pagliaro, 2021; Slovensky et al., 2017).

The Ida Institute, which is a Danish-based organisation championing for person-centred hearing care for over 15 years, has developed a wide range of resources to help people manage their hearing loss and educate hearing healthcare professionals across the globe. They have created a series of online modules aiming at supporting education from which university educators and hearing healthcare professionals can draw inspirations. Among the modules, there is one tailored to teleaudiology service delivery (Ida Institute, n.d.-b). This module starts off by explaining the background of teleaudiology with examples of currently available tools, e.g., web-based and app-based hearing tests. It then explains the importance of teleaudiology in modern hearing care, and how it can be implemented into each of the six stages in the Ida Circle, a model indicating patient's behavioural change (pre-contemplation, contemplation, preparation, action, maintenance, and relapse) (Ida Institute, n.d.-a). Next, a variety of factors from the client, provider, stakeholder, licensing, and technological perspectives are suggested as a recipe for successful teleaudiology implementation. To wrap up, a step-by-step guide and the Ida Telecare Tools are provided to facilitate the development of an implementation plan and prepare clients for virtual appointments.

The availability of training and education programs in Australia specific to telehealth is scanty, let alone those targeting teleaudiology service delivery. One example of the Australian university-led telehealth training programs available to healthcare providers is offered by The University of Queensland's Centre for Online Health (UQ-COH) (Centre for Online Health, n.d.). Based on their extensive training experience, UQ-COH designed a variety of telehealth training and services addressing topics such as video consultation techniques and troubleshooting, videoconferencing platform navigation, real-life examples of telehealth implementation, and exploration of optimal integration of telehealth into routine practice. These services can be accessed in the form of in-person and virtual workshops as well as self-guided learning materials on an online training portal. In this way, healthcare providers are given the flexibility of attending training sessions which span from hours to days according to their work schedule regardless of their physical locations. Furthermore, UQ-COH offers a telementoring program aiming at supporting the delivery of telehealth services in sectors such as palliative care and elder care (Project ECHO, n.d.).

There is an apparent need for more telehealth training and education programs in Australia in order to improve telehealth uptake. More specifically, the exceedingly insufficient availability of training dedicated to teleaudiology service delivery calls for a collaborative initiative among hearing healthcare stakeholders to co-design training frameworks and models. Professional associations which administer clinician credentialing and professional development (e.g., Audiology Australia and the Australian College of Audiology) may also incentivise teleaudiology training by assigning continuing professional development (CPD) points to it, similar to the training sessions on other clinical skills.

8.6.4 Improved Internet access

As alluded to in *Key barriers to teleaudiology uptake* (Chapter 8.3), limited Internet access, particularly in rural and remote areas, is highly influential in people's access to telehealth services. Many governments have devised nationwide plans and allocated fundings to upgrade telecommunication infrastructure. As mentioned earlier, the Australian government introduced the NBN in 2009, promising terrestrial fibre network coverage for 93% of Australian premises by 2020 (Alizadeh et al., 2024). Over the years, billions of fundings have been invested in the NBN project and the government acknowledges the need for ongoing NBN upgrades after rollout completion. The most recent round of upgrades announced in 2022 showed a policy shift towards regional upgrades, aiming to narrow the existing urban-regional divide (Alizadeh et al., 2024).

Another example is the ultra-fast broadband (UFB) initiative launched by the New Zealand government in 2010. This initiative set a target of a UFB network coverage of 75% of the New Zealand population with a funding of NZD $1.4 billion over 10 years (Beltran, 2012; Webb et al., 2014). Additional government-led programs have been deployed to address connectivity constraints in rural and remote New Zealand. For instance, the ongoing NZD $430 million Rural Broadband Initiative and Remote Users Scheme are providing better Internet and cellular connectivity across the country (New Zealand Government Ministry of Business Innovation & Employment, 2022).

Meanwhile, most of the broadband infrastructure projects in the USA have been led and invested by private firms instead of the government (Landgraf, 2020; Skiti, 2020). Publicly-owned broadband network run by municipal governments or multiple stakeholders has been gathering interest in an attempt to improve broadband connectivity in rural areas (Koch, 2018; Whitacre & Gallardo, 2020). Moreover, national programs such as the Federal Communications Commission's Lifeline program (Federal Communications Commission, 2023) and Broadband Technology Opportunities Program (BTOP) (United States National Telecommunications and Information Administration, 2020) have provided subsidies to low-income individuals who may not be able to afford broadband service otherwise.

The pathway to Internet access equity is often sinuous and the rollout of broadband projects is full of challenges. For example, the NBN project in Australia has received complaints from the public which could lead to abrupt political decisions and experienced delays in rollout progress (Alizadeh et al., 2024). Similarly, the broadband development in rural New Zealand and the USA persistently lagged behind that in urban areas (Alizadeh et al., 2024; Mack et al., 2021). Inadequate consumer awareness and variations in qualification process across states and service providers hindered the effectiveness of the Lifeline program in the USA (Sieck et al., 2021). The halt in fundings allocated to programs such as the BTOP also impacted the sustainability of such broadband connectivity programs (Sieck et al., 2021). Given the dynamic environment in which Internet and broadband service projects are developed and implemented, the importance of sustainable fundings from the government and collaboration between the government and service providers cannot be emphasised enough. It is through changes in policy and telecommunication infrastructure will the urban-regional divide be confidently ameliorated, which in return may not only improve healthcare delivery but also other societal and economic aspects in this digital era.

8.6.5 Refined technology infrastructure and system interoperability

Telehealth/teleaudiology uptake can be constrained by the lack of suitable ICT infrastructure (e.g., videoconferencing platforms) and/or the inability to utilise it in an effective way. In order to overcome this constraint, increased effort has been seen in some countries including Australia (Healthdirect Australia, 2020), the UK (Crouch, 2021), and Switzerland (Nittas & von Wyl, 2020), to improve telehealth infrastructure via collaboration between governments, professional associations, and videoconferencing providers. During the peak of the COVID-19 pandemic, healthdirect Australia acquired fundings from the Australian Government Department of Health to make its video consultation platform available for all GPs in the country, with no cost incurred on the practitioners (Healthdirect Australia, 2020). In the UK, the National Health Service (NHS) partnered up with Attend Anywhere to build a video consultation platform for all NHS trusts in 2020 (Crouch, 2021). Later in 2021, Attend Anywhere merged with Induction Healthcare, adding an app streamlining practitioner communication and a patient portal to its service area (Lydon, 2021). Likewise, Switzerland has been lobbying for increased use of its telehealth infrastructure and the Swiss Medical Association collaborated with a videoconferencing provider to deliver free telehealth services during the pandemic (Nittas & von Wyl, 2020).

Video consultation platforms which have been funded by governments, endorsed by professional associations, and employed nationwide should be made available to other health professions to promote telehealth on a whole. To better illustrate, professional guidelines such as the Australian Teleaudiology Guidelines do not provide any recommendation on equipment, devices, platforms, software, or apps due to the vast range of options available (Audiology Australia, 2022b). The intention of not imposing limits on healthcare providers' choices of ICT infrastructure is sensible as each provider may operate their business and practice in a different way. However, the lack of recommendations may also befog providers' decision since there are too many options and an informed decision is more difficult to achieve without professional and proper guidance. Using existing video consultation platforms which have been piloted and endorsed can reduce the cost of developing new platforms from scratch and the time needed for test run and troubleshoot. Also, professional associations of other healthcare sectors may make videoconferencing provider recommendations backed by solid evidence for their practitioners. This will likely clear the uncertainty around how to select a reliable videoconferencing provider and promote telehealth uptake.

Interoperability between systems will be another aspect to strive for if telehealth/teleaudiology uptake is to be fostered. This is of notable importance when considering the storage, sharing, and transfer of patient health records. Multidisciplinary team management is a common practice in hearing healthcare and other healthcare sectors, and the efficiency and safety of patient record sharing must be ensured no matter services are delivered in person or virtually. Data collected by various healthcare providers such as clinics and hospitals may be stored in different electronic systems. Higher interoperability and compatibility between those systems will allow more convenient and prompt access to patient health records and test results. In fact, the utilisation of electronic health record has been reported to benefit patient care (King et al., 2014) and enhance telehealth uptake (Ranganathan & Balaji, 2020). One caveat of interoperable systems lies within the data sharing regulations as patient data security may be violated if such regulations are not abode by. Governments may need to review the data sharing regulations of their own countries and amend them if they see fit to prioritise personal information protection.

8.6.6 Reimbursement coverage and sustainability

The HSP in Australia covers a range of services, albeit predominantly rehabilitative, provided via telehealth (Federal Register of Legislation, 2023). Diagnostic assessment performed via telehealth has not been included in the HSP. Nevertheless, the Australian Teleaudiology Guidelines indicate that services such as otoscopy, hearing screening, audiological assessment, and tinnitus assessment can be performed safely and effectively via synchronous or asynchronous modes of telehealth (Audiology Australia, 2022b). Although supported by strong research evidence, the provision of those diagnostic services through virtual means is limited by the lack of funding for reimbursement, putting marginalised and underserved client populations in disadvantage. Expansion of reimbursement funding to diagnostic services may encourage hearing healthcare providers to review their current practice and consider wider implementation of teleaudiology to suit clients' needs.

Apart from the service type, the mode of teleaudiology service delivery is another consideration for reimbursement funding structure reform. Currently, the services reimbursable through the HSP appear to be required to be delivered synchronously, e.g., by video consultation. This requirement is inferred rather than stated explicitly under the HSP, as it only specifies that the services "can be completed via telehealth" without detailed elaboration (Federal Register of Legislation, 2023). In this sense, services delivered via the asynchronous mode of teleaudiology are not covered by the HSP. This may also simply reflect the fact that procedures which can be performed asynchronously, e.g., otoscopy and hearing screening, have not been covered by the HSP yet. Expanding the reimbursement coverage under the HSP to more service types and modes of service (asynchronous and remote monitoring) has been recommended previously (Eikelboom et al., 2021; Woods & Burgess, 2021).

In countries where the reimbursement schemes are different from that in Australia, the same recommendations from the above are applicable to improving teleaudiology uptake. For example, the coverage of teleaudiology services in the USA Medicare program can be extended beyond diagnostic services to include rehabilitative services such as hearing device fitting and tinnitus management (Jilla et al., 2021). In addition, the sustainability of reimbursement funding needs to be ensured so that teleaudiology can be permanently integrated into routine practice instead of a one-off stopgap solution during pandemic times. This is particularly crucial for countries in which reimbursement fundings for teleaudiology services is temporary, e.g., the USA (American Speech-Language-Hearing Association, n.d.-c). Ongoing and permanent allocation of fundings to teleaudiology services is pivotal to the motivation of providing virtual care and continuing uptake of teleaudiology (Audiology Australia, 2020).

8.7 Telehealth and teleaudiology education

The significance of telehealth education has been acknowledged by multiple professional associations, even before the COVID-19 pandemic when telehealth uptake was hugely scarce. In the USA, the American Medical Association (AMA) established policies in 2016 encouraging the inclusion of telehealth in undergraduate and postgraduate medical programs (American Medical Association, 2016). The nursing profession shared similar notion, as the National Organization of Nurse Practitioner Faculties (NONPF) announced its official support for incorporating telehealth into nurse practitioner curricula in 2018 and enumerated telehealth competencies to guide strategic refinement of the curricula (National Organization of Nurse Practitioner Faculties, 2018). Advocacy of this sort was not pervasively seen in Australia. Although telehealth has been steadily garnering interest from clinical and research perspectives, little breakthrough was noted in educational settings regarding the integration of telehealth in the curricula.

Prior to the COVID-19 pandemic, telehealth education was sporadic in spite of some professional associations’ recommendations and support in certain countries. A review by Edirippulige and Armfield (2017) identified nine studies detailing telehealth education and training programs offered by universities in Australia, the USA, the UK, Brazil, and Japan/Pacific Islands. These programs targeted undergraduate and postgraduate students as well as healthcare providers for CPD purposes. The program content, duration, and learning activities varied greatly across programs (Edirippulige & Armfield, 2017). Figures from the USA showed somewhat more ubiquitous telehealth education programs – the Association of American Medical Colleges (AAMC) and Liaison Committee on Medical Education (LCME) surveyed medical schools in the country and discovered that about 50% to 58% incorporated telehealth as a topic (Association of American Medical Colleges, 2018; Waseh & Dicker, 2019).

The onset of the pandemic necessitated the integration of telehealth into educational settings mainly for two reasons: 1) to ensure the safety of all involved individuals in alignment with social distancing requirements while maintaining continuity of education, and 2) to equip students with skills and experiences essential for the foreseeable demand for telehealth practice during and beyond the pandemic. Increased integration of telehealth into curricula was observed in different institutions and healthcare professions (Chike-Harris et al., 2021; Johnson et al., 2021). Furthermore, telehealth competencies were outlined by the AAMC as a roadmap for medical schools and teaching hospitals to shape their education programs, nurturing medical students to deliver high-quality care via telehealth (Association of American Medical Colleges, 2021). However, a standardised curriculum framework was yet to be developed and inconsistency still persisted across education programs (Chike-Harris et al., 2021).

Recommendations on the topics to be included and the best practices for utilising telehealth for educational purposes have been noted by several studies. For example, concepts and skills pertinent to telehealth, such as communication, professionalism and etiquette, digital literacy, and legislation, should be taught and practiced throughout the program (Chike-Harris et al., 2021; Iancu et al., 2020). A list of suggested learning activities in accordance with the AAMC's Core Entrustable Professional Activities has been created in the hope that medical students can hone their telehealth-related competencies in a uniform manner (Iancu et al., 2020). Telehealth also facilitates multidisciplinary team involvement in the education and training process, and the benefits of such learning experience have been recognised and recommended (Erickson et al., 2015; Rutledge et al., 2014). With regard to engaging students in telehealth visits as a form of training, previous studies have described the preparation and procedures undertaken to yield positive learning experience and outcomes. To name a few, access to encrypted telehealth platforms and a private space, setting goals and expectations, development of "webside manner", availability of communication methods between the student and the educator during the visit, and feedback and debriefing are some of the imperative components of integrating students into telehealth visits (Johnson et al., 2021; Wamsley et al., 2021).

After completing the telehealth education programs, a majority of students expressed high satisfaction, willingness to use telehealth in future practice, and hope of telehealth inclusion in future curricula (Brockes et al., 2017; Bulik & Shokar, 2010; Chike-Harris et al., 2021; Golub et al., 2021). In particular, some medical students perceived telehealth education as advantageous because they could better understand patients' home environment during telehealth visits, and observing visits remotely was a unique experience with higher participation flexibility and efficiency (Golub et al., 2021). Conversely, learning opportunities might be restricted by the inability to conduct physical examination and reduced clinical autonomy, and patient outcomes might become suboptimal due to poorer rapport building (Golub et al., 2021).

At present, a range of telehealth education and training programs are available in Australia, targeting students and healthcare providers. These programs are offered by government agencies (Australian Digital Health Agency, n.d.), professional associations (Australian College of Rural and Remote Medicine, n.d.), and universities (Centre for Online Health, n.d.; Charles Sturt University, n.d.). In fact, UQ-COH offers core and elective telehealth courses at undergraduate and postgraduate levels, elaborating on the clinical applications, implementation strategies, and the social, ethical, and legal facets of telehealth (Centre for Online Health, n.d.).

In comparison with the medical and nursing telehealth education programs, teleaudiology education appears to be in a more preliminary state. Findings from Study 1 corroborate this observation, as 60% of the surveyed students indicated that they received a limited amount of teleaudiology education at university, whereas 30% received none at all. One academic from Study 3 pinpointed the generic accreditation standards as a barrier to teleaudiology integration into the curriculum. Without a list of skills and competencies recommended by professional associations (e.g., Audiology Australia), it leaves plenty and perhaps too much scope for universities to decide which teleaudiology topics should be included, rendering it onerous to kickstart a teleaudiology-inclusive curriculum. As nowadays teleaudiology is gaining traction, more guidelines or standardised framework provided by the accrediting body (Audiology Australia) may accelerate the integration of teleaudiology into existing curricula and foster upcoming clinicians to become competent in leveraging technology for care delivery.

In addition, several strategies which have been demonstrated to contribute to successful telehealth education may be relevant to teleaudiology education. Firstly, emphasis has been placed on debriefing and feedback upon telehealth visit education session completion (Golub et al., 2021; Johnson et al., 2021; Wamsley et al., 2021). Receiving constructive feedback alongside reflective exercise are imperative to the development of students' professional skills, growth mindset, and feedback-seeking habit (Ramani et al., 2019). Secondly, the importance of education program outcome evaluation has been underscored (Chike-Harris et al., 2021). Program performance, student satisfaction, and learning outcomes are indicative of a program's effectiveness in execution. These parameters can be evaluated in various ways, such as student course appraisals, surveys, assignments, and exams. It is noteworthy that a student from Study 3 mentioned that clinical teleaudiology exams were in place to assess students' performance in virtual consultations. Recent introduction of this assessment to the curriculum demonstrates the university's determination to reinforce the important role of teleaudiology in the current audiology landscape. There is still a long way ahead before teleaudiology can be fully incorporated in university curricula. Recent initiation and development of teleaudiology education programs is undoubtedly welcomed, but future evolvement of such programs is dependent on the support from stakeholders such as universities, professional associations, and healthcare providers.

8.8 Future research directions (Study 1 & Study 3)

Based on the above discussion on the findings from Study 1 and Study 3 and the limitations of these studies, some suggestions are provided below for consideration in future research. These suggestions will hopefully enrich the perspective and scope of research on hearing healthcare stakeholders' perceptions and attitudes towards teleaudiology, both in Australia and other countries, and promote teleaudiology uptake via identifying and understanding users' needs in the post-pandemic environment.

8.8.1 Use of behavioural change models

Considering using or providing teleaudiology services as a behaviour, low teleaudiology uptake at present calls for strategies to drive behaviour change if the uptake is to be improved. The COM-B model is a widely employed framework to conceptualise how a behaviour (B) interacts with internal and external factors including capability (C), opportunity (O), and motivation (M) (Michie et al., 2011). For a behaviour to occur, all of the above factors are essential – the individual needs to possess the capability (physical and psychological ability) to engage in the activity, the social and physical opportunity external to the individual prompting the behaviour needs to be present, and the brain processes (automatic and reflective) which motivate and direct the behaviour are required. In order to modify a behaviour, change needs to be made to at least one of these factors. By delving into the capability, opportunity, and motivation behind a particular behaviour, which is teleaudiology uptake in this context, the factors influencing the behaviour pattern among the studied population can be conceptualised and potential strategies can be devised to alter this behaviour pattern. In fact, the COM-B model is part of the broader behaviour change wheel (BCW) framework, in which intervention functions and policy categories are included to aid the selection of behaviour change interventions (Michie et al., 2011). Each intervention function corresponds to at least one of the three factors in the COM-B model, e.g., education can be utilised to target changes in capability and motivation. Both the COM-B model and the BCW framework have been recognised for their usefulness in mapping behaviour and its influencing factors, as well as the potential interventions and policies to modify the behaviour.

The COM-B model and the BCW framework have been deployed to investigate various behaviours and inform methods for potential behaviour change in the context of audiological practice. Examples include but are not limited to HA usage (Barker et al., 2016), delivery of group audiological rehabilitation programs (Bennett, Eikelboom, et al., 2022), provision of hearing impairment-related mental health information (Bennett et al., 2023), and smartphone-connected listening device uptake (Maidment et al., 2019). A few previous studies on teleaudiology uptake also used the COM-B model to guide the exploration of clinician attitudes and barriers to and facilitators of teleaudiology uptake (Bennett, Kelsall-Foreman, et al., 2022a; Chong-White et al., 2023). The above studies demonstrated that the COM-B model and the BCW framework could be effectively incorporated in the development of surveys and interview guides to delineate and address behaviours of interest. Hence, such practice can be applied to unveiling other facets of teleaudiology uptake, e.g., attitudes and perceptions of infrequently studied stakeholders such as students, academics, and industry partners.

Beside the COM-B model and the BCW framework, other behaviour change models may be adopted to shed light on teleaudiology uptake as well. For instance, the Theory of Planned Behaviour (TPB) states that a behaviour occurs under the influence of three components: behavioural beliefs (beliefs about the anticipated consequences of the behaviour), normative beliefs (beliefs about the normative expectations of other individuals), and control beliefs (beliefs about how easy or difficult it is to perform the behaviour) (Ajzen, 1991). The TPB has been applied to a range of public health and political science research (Bosnjak et al., 2020). Another example is the Social Cognitive Theory (SCT), which consists of several components directing behaviour engagement, such as behavioural capability, observational learning, reinforcements, expectations, and self-efficacy (Bandura, 1989). Applications of the SCT were first seen in the field of psychology and subsequently expanded to other research fields including public health (Godin et al., 2008), education (Burney, 2008), mass communication (Bandura, 2001), and information science (Middleton et al., 2019). That said, not all constructs of the behaviour change models are applicable to teleaudiology research and each model has its own limitations. Therefore, integrated use of different behaviour change models may yield the best outcomes in addressing the research questions (Boston University, 2022).

8.8.2 Investigation of other underlying factors influencing teleaudiology uptake

As discussed previously, there are some factors (race/ethnicity and personality traits) which have been shown to influence telehealth uptake and their potential effects on teleaudiology uptake are unclear. In order to determine whether differences in teleaudiology uptake exist between clients from different racial or ethnical backgrounds, population-level data will need to be collected from large-scale studies to perform meaningful comparisons and analyses. If such differences are spotted, exploration of challenges unique to certain racial or ethnic groups is warranted, e.g., language or cultural barriers, and teleaudiology implementation strategies can be specifically devised to address these challenges and narrow the teleaudiology use divide.

Likewise, examining the potential correlation between client personality traits and teleaudiology uptake, acceptance, and satisfaction may generate novel insights to facilitate more effective use and provision of teleaudiology services. Client personality traits can be evaluated through standardised use of validated questionnaires such as the Trait Self Descriptive Inventory (TSD) (Darr, 2009). By profiling clients' personality traits, prediction of their attitudes towards and satisfaction of teleaudiology use may become more straightforward, encouraging hesitant clients to try teleaudiology services with more solid evidence and benefitting those who will likely respond better to virtual care.

8.9 Summary of key findings and original contribution to knowledge of Study 2 and Study 5

Study 2 and Study 5 laid the groundwork for examining the feasibility, effectiveness, and usability of a novel multi-modal app-delivered therapy for tinnitus – the Oto app. This portion of research in this PhD program was conducted through two longitudinal controlled studies, first a feasibility study (Study 2), followed by an RCT (Study 5).

The feasibility of utilising the Oto app in tinnitus management was examined in Study 2, based on the trial acceptability, deliverability, and effectiveness. Out of the 166 adults (aged 18 years or above) with chronic tinnitus (≥6 months) invited, 62 (37%) eventually participated in this study. The overall retention rate, as defined by completion of surveys at the 3-month timepoint, was 87%. In other words, the overall dropout rate was 13%. The effectiveness of Oto in reducing tinnitus severity and distress was gauged based on the changes in the participants' TFI scores across baseline and the 1-month and 3-month timepoints. Three kinds of data analyses were performed as indicators of the app's effectiveness. First, by comparing the number of participants across the intervention group and the control group who reported an absolute reduction in the TFI scores, there were significantly more Oto users (n = 13; 52%) than non-users (n = 6; 21%) reporting a reduction on the TFI at 1-month and 3-months. Second, when the criterion of an at least 13-point reduction on the TFI (clinically meaningful reduction as suggested by Meikle et al. (2012)) was applied, four (16%) participants from the intervention group met such criterion at 1-month and 3-months, whereas four (14%) and two (7%) participants from the control group met the same criterion at 1-month and 3-months, respectively. This finding indicated that there was no significant difference in the percentage of participants reporting a clinically meaningful reduction in the TFI scores between groups. Third, one-way repeated measures ANOVA was performed, revealing insignificant changes in the TFI overall and subscale scores within the intervention group across all timepoints, and a significant increase in the TFI overall and auditory and quality of life subscale scores within the control group from baseline to 1-month and 3-months.

In addition to the aforementioned key findings from Study 2, app usage data were also analysed to gain insights into how extensively the app was accessed by participants. A great diversity in the frequency and extent of app usage among Oto users was observed. Out of the 100 tinnitus therapy sessions available in Oto, the intervention group listened to 45 (*SD*: 42) of those in average. Oto users completed an average of 46% (*SD*: 35%) of the structured five-week tinnitus habituation program which consisted of 52 therapy sessions. The sound library was accessed with an average duration of 14 minutes (*SD*: 23), and the average duration of app usage, including all app features, was 48 hours (*SD*: 95). It was noteworthy that a significantly higher percentage of tinnitus habituation program was completed by female Oto users (62% completion) than male users (30% completion). Apart from app usage data, user feedback was obtained to shed light on Oto's ease of use, user satisfaction, and the app features which were helpful or needed improvement. Oto's ease of use and user satisfaction were rated 3.7 and 2.8 out of 5 on a five-point Likert scale, respectively. Oto users found the diversely themed therapy sessions and sound library helpful, and suggested adjusting the duration of some of the therapy sessions and offering a more structured tinnitus habituation program.

Study 5 more systematically evaluated the effectiveness and usability of Oto using a two-arm, parallel-group, RCT design. Of the 207 registered individuals, 96 fulfilled the eligibility criteria and were randomised into the intervention group and control group. Measurement of participants' tinnitus severity were conducted at baseline (T0), 1 month (T1), 3 months (T2), 6 months (T3), and 9 months (T4), with T3 defined as the primary endpoint. An overall retention rate of 79% and dropout rate of 21% was recorded at T3. Regarding Oto's effectiveness in reducing tinnitus severity, mixed ANOVA with time (T0, T1, T2, T3, T4) as the within-subjects factor and treatment group (intervention, control) as the between-subjects factor indicated a significant interaction effect between the two factors in the overall TFI score at T3 and T4. Pairwise comparisons of TFI overall and subscale scores at different timepoints further revealed a significant reduction in the TFI overall and intrusive, sense of control, sleep, and relaxation subscale scores within the intervention group from T0 to T3. When compared to the control group, the intervention group had significantly lower TFI overall and all subscale scores at T3. App usability as measured by the MAUQ showed high overall usability (5.1 out of 7).

First released in 2020, Oto is one of the newest commercially available smartphone apps targeting at mitigating the impacts and distress caused by tinnitus. The introduction of Oto, together with two rigorously designed trials (Study 2 and Study 5), to the existing abundant yet largely unvalidated body of tinnitus smartphone apps hold significant research and clinical values. According to previous systematic reviews, although research evidence reflected promising effectiveness of smartphone apps as intervention for tinnitus, less than 10% of the 200 tinnitus-related smartphone apps had been validated in peer-reviewed trials (Mehdi, Riha, et al., 2020;

Nagaraj & Prabhu, 2020). Under the dearth of validated tinnitus smartphone apps and well-designed validation studies, Study 2 and Study 5 addressed this research gap, offering a modern alternative to tinnitus management accessible at people's fingertips.

8.10 Modifications in methodology from Study 2 to Study 5

As a preceding phase of the larger-scale RCT (Study 5), Study 2 was designed as a feasibility study to garner preliminary understanding on the trial acceptability, deliverability, and effectiveness of the Oto app. The execution of such feasibility study holds considerable values since Oto is a relatively new smartphone app for tinnitus management and no trial has been conducted to systematically examine its effectiveness. Prior to designing the main study, parameters including the feasibility of recruitment, randomisation, retention rate, assessment procedures, and implementation of intervention need to be estimated (Whitehead et al., 2014). Estimation of these study parameters can provide insights into the possibility of implementing a full-scale study. It was also apparent through Study 2 that a subsequent RCT was feasible as reflected by its reasonable recruitment and retention rates, albeit some modifications were made when designing Study 5 to improve the trial's validity. These modifications are summarised in Table 8.1 and described as follows.

Table 8.1 Modifications in methodology of Study 5 as informed by Study 2.

Modifications in methodology	**Study 2**	**Study 5**
Study nature	Feasibility study	RCT
Eligibility criteria	Aged over 18 years Any type and duration of tinnitus	Aged over 18 years Chronic (≥6 months), non-pulsatile, bilateral tinnitus Lower moderate or above tinnitus severity
Randomisation	Fixed sequence based on recruitment order	Block randomisation with stratification factors including age, gender, hearing sensitivity level, and initial tinnitus severity
Outcome measure tool for app usability	5-point Likert scale	MAUQ
Sample size	62	96
Study duration	3 months	9 months

Eligibility criteria were relatively simple in Study 2, as individuals aged over 18 years who were experiencing tinnitus were deemed eligible. The type and duration of tinnitus were not under consideration during recruitment, meaning that individuals with acute (<6 months) or chronic (≥6 months) tinnitus and all types of tinnitus (e.g., both subjective and objective) were included in this study. When designing Study 5, more restricted inclusion criteria were applied to focus on individuals with tinnitus characteristics of interest. Specifically, individuals with chronic (≥6 months), non-pulsatile, and bilateral tinnitus were considered eligible participants in Study 5. Moreover, they had to exhibit lower moderate or above tinnitus severity to ensure their tinnitus was bothersome to certain extent and there could be room for improvement after using Oto. These additional inclusion criteria rendered recruitment more difficult and eventually recruited participants were fewer than planned, yet the study was more tightly controlled with reduced variability in participant tinnitus characteristics. Meanwhile, exclusion criteria remained unchanged for both studies – individuals who were undertaking another tinnitus intervention or awaiting surgical intervention for hearing or tinnitus were deemed ineligible.

Randomisation of participants was performed in both studies using different approaches. In Study 2, participants were randomly allocated to either the intervention or control group by a fixed sequence based on their recruitment order. Although this simplistic randomisation approach rendered less control over the even distribution of participants with comparable demographic characteristics among groups, the gender and age distribution in both groups were evaluated afterwards to mitigate this shortcoming. On the contrary, a more elaborate randomisation approach was employed in Study 5 to minimise allocation bias. In addition to age and gender, other participant characteristics such as hearing sensitivity level and initial tinnitus severity were included as parameters for block randomisation. This could further ascertain that the participant composition in the intervention and control groups was more commensurate as compared to Study 2, and any change in tinnitus severity measured throughout the study period could be more likely attributable to the intervention itself instead of differences in demographic or tinnitus characteristics intrinsic to the participants.

Furthermore, a change was made to the outcome measure tools in Study 5. App usability was measured in Study 2 in a somewhat more arbitrary way with the question “Do you find Oto easy to use?” on a 5-point Likert scale. In order to extensively outline various aspects of app usability, the MAUQ was employed in Study 5 to shed light on Oto’s ease of use, interface and satisfaction, and usefulness (Zhou et al., 2019). The rationale behind the selection of the MAUQ was it being psychometrically validated and displaying high internal consistency and validity. Repeated use of the same standardised questionnaire in potential future research can also allow comparisons of app usability within and between smartphone apps for tinnitus management.

Lastly, since Study 5 was an RCT aiming to evaluate Oto’s effectiveness in reducing tinnitus severity with the reporting of intervention effect size, its study design was slightly different from the feasibility study (Study 2). For instance, the sample size increased from Study 2 to Study 5 as indicated by sample size calculation and the study duration was lengthened from three months to nine months as well. Previous literature revealed that tinnitus smartphone app validation studies rarely assessed app effectiveness beyond three months of app use (Mehdi, Dode, et al., 2020), implying that evidence on the long-term effectiveness of such apps is still largely lacking. As such, Study 5 was designed to address this research gap by evaluating Oto's transient and long-standing effectiveness for up to nine months.

8.11 Potential factors influencing treatment response

8.11.1 Pathophysiological heterogeneity of tinnitus

For most, if not all, treatments for health conditions or diseases, different patients may respond variably (e.g., different rates of symptom improvement and recovery time), even when the same treatment is undertaken. Inevitably, this variability in treatment response has been observed in tinnitus trials and its effects may be more extensive than on other health conditions due to the high heterogeneity of tinnitus. Tinnitus is manifested in a wide range of ways across patients in terms of its perceptual characteristics and comorbidities (Kleinjung & Langguth, 2020). For example, tinnitus can be perceived as constant or fluctuating, permanent or intermittent, pulsatile or non-pulsatile, and the pitch, loudness, type, and localisation of sound can vary as well (Landgrebe et al., 2010). Besides, comorbidities such as concomitant hearing loss, vertigo, hyperacusis, anxiety disorders, depression, and sleep disorders may present with tinnitus (Landgrebe et al., 2010). Such diverse clinical presentation of tinnitus reflects its heterogeneity, indicating that multiple forms or subtypes of tinnitus likely exist. To put it another way, it is probable that more than one pathophysiological mechanism of tinnitus gives rise to various tinnitus subtypes. In fact, a number of potential pathophysiological mechanisms have been proposed in an attempt to explain the generation of tinnitus. Those mechanisms detail pathology in different locations in the peripheral and central auditory systems and even in the non-auditory regions of the brain, e.g., alteration in neuronal firing rates and synchrony, and maladaptive auditory-somatosensory plasticity (Gentil et al., 2019; Sedley, 2019; Wu et al., 2016). Despite the increasing research effort in understanding the pathophysiology of tinnitus, complete consensus is yet to be achieved with limited knowledge yielded based on human models (McFerran et al., 2019).

As the pathophysiological mechanism of tinnitus in each patient can differ, their response to a single tinnitus treatment may be anticipated to vary as well. Tinnitus patients and clinicians alike are thus faced with the conundrum of pinpointing a treatment specific to the patient's unique pathophysiological mechanism which can be expected to attain the best effectiveness and outcomes. In fact, a majority of the tinnitus research conducted with the aim of developing or evaluating treatments recruited individuals with idiopathic subjective tinnitus (McFerran et al., 2019). This type of tinnitus refers to non-pulsatile tinnitus not associating with other medical conditions, e.g., Meniere's disease. The classification of idiopathic subjective tinnitus is nonetheless not homogeneous enough in most cases. One example is tinnitus accompanied by sensorineural hearing loss. Hearing loss is known to be a precursor of tinnitus, yet a sensorineural hearing loss can be the result of many causes, including ageing, noise exposure, ototoxicity, etc. It is therefore unwise to regard tinnitus induced by sensorineural hearing loss as a single type of tinnitus. There are possibly different distinct underlying pathophysiological mechanisms which give rise to the "same" idiopathic subjective tinnitus. This potential heterogeneity of sample in seemingly homogeneous tinnitus trials jeopardises the trial accuracy. Subtle effects of tinnitus treatments in certain sample subgroups may stay undetected, and the trials may be prone to false negative results (Landgrebe et al., 2010).

The limitation of isolating a truly homogeneous sample may account for the differences in treatment response within the intervention group in Study 2 and Study 5. Although Study 5 had stricter eligibility criteria (non-pulsatile, bilateral tinnitus), it was almost impossible to ensure all participants experienced the same type of tinnitus. The heterogeneity of tinnitus in the sample was also inferred from the diverse measurements of tinnitus matching, i.e., a wide range of tinnitus pitch and loudness was reported. As a consequence, some participants might have responded better to the use of Oto, and some might find it unhelpful at all. That said, it seems impractical at present to strive for an entirely homogeneous sample, given the lack of thorough understanding on well-defined pathophysiological mechanisms and challenges in trial execution. Specifically, an immense amount of time and other resources may be required to recruit a sufficiently homogeneous sample. Until further advancement is accomplished with regard to the identification and classification of pathophysiological mechanisms and tinnitus subtyping, the heterogeneity of tinnitus remains a shortcoming of most tinnitus trials.

By acknowledging the hindering effects of tinnitus heterogeneity on tinnitus research, international collaborative endeavour has been reported to collect standardised data from tinnitus patients which may facilitate tinnitus subtyping. The earliest online database showcasing systematically collected tinnitus patient data is the Tinnitus Archive established by the Oregon

Hearing Research Center (Oregon Health & Science University, 2007). This database contains data sets comprising tinnitus history, attribute, severity, and assessment results from 1630 patients between 1981 and 1994. Two decades later, the Tinnitus Research Initiative (TRI) database was founded, aiming at collecting standardised data sets internationally and facilitating the delineation of tinnitus subtypes (Landgrebe et al., 2010). Patient data such as audiological and tinnitus assessment results, patient characteristics, tinnitus severity, treatments received, and treatment outcomes have been collected from about 3000 patients in 11 countries (Tinnitus Research Initiative, n.d.). With expanding tinnitus databases, hopefully tinnitus subtyping can be achieved through cluster analysis, predictors for treatment response to specific treatments can be identified, and individualised treatments can be devised based on each patient profile.

8.11.2 Expectations and anticipatory effects

Participants' expectations of treatment effectiveness or success might have contributed to treatment outcomes. It has been previously reported that patients' expectations are related to the outcomes of treatment for various health conditions such as obesity (Armitage et al., 2015), cancer (Nestoriuc et al., 2016), and heart disease (Habibović et al., 2014). Patients who have positive treatment expectations may achieve better outcomes, and those who have negative expectations may perceive less benefits from the treatment. In the context of Study 2 and Study 5, participants who were more optimistic about the effectiveness of Oto might have been more amenable to and benefited more from using the app, and subsequently displayed a greater reduction in tinnitus severity. In contrast, some participants might have been disappointed by futile treatments in the past and held sceptical attitudes towards Oto, and their negative expectations might have resulted in more negative treatment outcomes.

Patients' expectations are known to be a key driver in the placebo and nocebo effects (Laferton et al., 2017). The nocebo effect is the opposite of the placebo effect and refers to the adverse outcomes or reduced subjective benefits arisen from negative expectations or perceptions of a treatment (Colloca & Barsky, 2020). Due to the study design of Study 2 and Study 5, there was no placebo or sham treatment as the control group received a "wait list" treatment in which no tinnitus treatment was provided throughout the study period. The participants were not blinded as well since they were well aware whether they were using Oto or not. Hence, the placebo effect was extremely unlikely to be present in Study 2 and Study 5. However, in studies which evaluate other treatment modalities for tinnitus (e.g., pharmaceuticals, brain stimulation) where placebo and nocebo effects are probable, the influence of patients' treatment expectations may play a more significant role in treatment outcomes.

In similar fashion, patients' anticipations prior to receiving the treatment can affect their responses to treatment and treatment outcomes. Their behaviour under the pre-treatment condition can be altered in anticipation of treatment, confounding the true pre-test or baseline measures (Ariel et al., 2021). These anticipatory effects can introduce bias to pre-test measures, leading to underestimation or overestimation of treatment effect. Though such pre-test artefacts are unavoidable, several approaches have been suggested to mitigate their effects, one being the quantification of anticipatory effects by increasing measurement points (Ariel et al., 2021). This approach is especially advantageous to distinguish, measure, and correct for the anticipatory effects in the pre-test stage before treatment commencement.

8.11.3 Other prognostic factors

In order to identify prognostic factors which can be used to predict tinnitus treatment outcomes, there have been studies investigating the relationships between treatment response and various patient parameters, such as demographic variables, tinnitus characteristics, hearing sensitivity, and emotional status (Theodoroff et al., 2014).

In a non-controlled study evaluating the outcome of a multimodal cognitive-behavioural treatment, the responders and non-responders of the treatment were revealed to only differ in terms of age and the extent of psychosocial stress (Graul et al., 2008). Interestingly, education level was found to be a predictor of ICBT success (Rodrigo et al., 2021). More specifically, participants with a master's degree or above showed greater reduction in tinnitus severity than those with high school education or lower, and the authors ascribed the finding to the level of literacy skills required for understanding the therapy materials. Patient gender was posited as a predictor of treatment response, although the evidence was mixed depending on the treatment modality (Ivansic et al., 2022; Van der Wal et al., 2020).

Regarding tinnitus characteristics, participants in a transcranial magnetic stimulation trial who had shorter tinnitus duration and lower hearing thresholds (normal hearing ≤ 20 dB HL) tended to respond better to the treatment (Kleinjung et al., 2007). Participants' tinnitus severity before undergoing ICBT was reported to be associated with treatment success, as those who had more severe tinnitus at baseline responded better to the treatment (Rodrigo et al., 2021). In trials where

TRT was employed as the treatment modality, participants with higher levels of tinnitus loudness and severity exhibited better treatment response (Herraiz et al., 2007; Koizumi et al., 2009). Likewise, tinnitus patients who underwent customised music therapy with higher baseline tinnitus severity, shorter tinnitus duration, and higher anxiety levels reported greater improvement (Liu et al., 2023). Conversely, Ariizumi et al. (2010) demonstrated that TRT recipients who had lower levels of tinnitus loudness and positive attitude towards the treatment showed more favourable outcomes. In addition, another trial combining tinnitus masking and TRT reported that self-report of hearing problems and localisation of tinnitus predicted treatment success (Theodoroff et al., 2014). Participants who reported big to very big hearing problems (as opposed to mild to moderate problems) and perceived tinnitus as in their head (as opposed to in their ears) were more likely to respond to the treatment.

Given the limited research conducted to unveil the prognostic factors of tinnitus treatment outcomes and the variability in current evidence, definitive conclusions are yet to be drawn on which factors can confidently predict treatment success. Furthermore, the predictors of treatment success may vary between treatment modalities, as each treatment modality may target a different pathophysiological mechanism of tinnitus. That said, previous studies appear to show somewhat convergent findings for certain prognostic factors, e.g., higher baseline tinnitus severity is generally associated with treatment success. More research in this direction is needed to entangle the association between patient factors and treatment outcomes and facilitate the stratification of patients into treatment modalities best suited for them.

8.12 Tinnitus clinical guidelines in different countries

There exist various clinical guidelines for the assessment and management of tinnitus across countries, albeit with some inconsistency with respect to recommendations for assessment methods and treatment approaches (Fuller et al., 2017). In the following, the clinical guidelines in Australia will be discussed in detail supplemented with an overview of the guidelines in a selection of countries.

8.12.1 Australia

Audiology Australia, the professional body governing the accreditation of audiologists in Australia, published the most updated version of the Professional Practice Guide in 2022 (Audiology Australia, 2022a). This guide details recommendations for the safe practice of a range of clinical procedures, including tinnitus assessment and management. The recommended assessment procedures encompass detailed case history and audiological examination, including otoscopy, PTA, tympanometry, acoustic reflex assessment, speech perception testing, otoacoustic emissions (OAEs), and ABR. Moreover, use of standardised questionnaires, e.g., THI, TFI, and Hospital Depression and Anxiety Scale (HADS), is recommended to measure self-reported impacts of tinnitus on everyday life. It is noteworthy that psychoacoustic measures of tinnitus, such as pitch and loudness matching and minimum masking level, are not recommended due to their ineffectiveness in yielding reliable results beneficial to the evaluation of tinnitus experience.

Regarding management approaches, the Audiology Australia Professional Practice Guide suggests the use of counselling to educate clients on the mechanism of tinnitus perception and ways to alleviate negative reaction to tinnitus (Audiology Australia, 2022a). Hearing protection, coping strategies, and emotional support can be discussed with the involvement of cognitive-behavioural techniques. If hearing impairment is identified, the fitting of hearing devices (e.g., HA, sound generator, and assistive listening device) can be considered to improve hearing and mask tinnitus. Notably, the guide mentions the employment of mobile phone apps for the purpose of sound enrichment. A multidisciplinary approach is consistently emphasised by the guide to achieve client-centred care, and referral to other medical and allied health professionals, such as psychologist, physiotherapist, and sleep specialist, is recommended should the client seek further assistance.

Aside from the practice guide specifically targeting audiologists, there are other clinical guidelines in Australia which offer recommendations to GPs if they encounter patients presenting with tinnitus. Compared with the Audiology Australia Professional Practice Guide, these guidelines are not as elaborate, yet assessment procedures and management options are still covered. One example of these guidelines was developed by the Royal Australian College of General Practitioners (Esmaili & Renton, 2018). Same as the aforementioned guide, this guideline recommends taking case history and performing audiological assessment as part of the investigation. However, the suggested audiological assessment is rather rudimentary (i.e., tuning fork testing) and a more comprehensive assessment is recommended to gain better understanding of the patient's hearing status. Auscultation of the head and neck areas can also be performed if pulsatile tinnitus is reported. Magnetic resonance imaging (MRI) and computed tomography (CT) are mentioned as assessment approaches only when certain indications are met, e.g., unilateral and pulsatile tinnitus, asymmetric hearing loss, focal neurological abnormalities, etc. As for management options, after the endeavour of identifying the underlying cause, bothersome tinnitus can be intervened by sound therapy, CBT, and HA fitting. Involvement of an audiologist and/or a psychologist is warranted if these options are pursued. Additionally, prescription of medications for tinnitus-related anxiety and depression is discouraged by this guideline.

8.12.2 The UK

The clinical guideline for tinnitus in the UK was developed by the National Institute for Health and Care Excellence (NICE) (Lewis et al., 2020). Audiological assessment comprises an important step in the investigation of tinnitus as hearing loss may coexist with tinnitus. Imaging is only recommended for patients presenting with pulsatile tinnitus, unless patients with non-pulsatile tinnitus have symptoms suggestive of other pathologies. Standardised use of questionnaires (e.g., TFI) is recommended for the measurement of tinnitus severity and distress. Discussion on the impacts of tinnitus on quality of life and sleep is also preferred.

Recommendation for HAs in the NICE guideline is different from other guidelines. In the NICE guideline, communication difficulties are taken into consideration in addition to hearing loss. This results in a graded recommendation for HAs: tinnitus patients with a hearing loss and communication difficulties should be offered HAs; tinnitus patients with a hearing loss but without communication difficulties can be considered for HA fitting; and tinnitus patients without a hearing loss should not be offered HAs. Besides, psychological interventions delivered by psychologists such as CBT, ACT, and mindfulness-based therapies can be considered. In particular, a stepped approach is suggested if a patient requires additional support. This approach begins with digital tinnitus-related CBT, then continues with group-based psychological interventions, and ends with individual tinnitus-related CBT. Furthermore, drug treatment is not recommended in congruence with other guidelines.

8.12.3 Other European countries

Based on a systematic review of the clinical guidelines for tinnitus in the USA and a collection of European countries (Denmark, Germany, Sweden, and The Netherlands), inconsistency in the assessment and treatment of tinnitus was uncovered (Fuller et al., 2017). This prompted the need for a uniform guideline across European countries for tinnitus patients to be assessed, referred, and treated in a timely fashion. As such, a group of multidisciplinary experts from different parts of Europe collaborated in the development of a standardised guideline (Cima et al., 2019).

In this guideline, the essential assessment procedures entail detailed patient history, ear, nose, and throat examination, and audiological testing. Otoscopy can provide useful information for the exclusion of underlying medical conditions causing tinnitus, e.g., wax obstruction, tympanic membrane perforation, otitis media, etc. Recommended audiological testing ranges from PTA, tympanometry, acoustic reflex assessment, speech audiometry, to sound tolerance. Unlike the Audiology Australia Professional Practice Guide, psychoacoustic measures of tinnitus such as pitch and loudness matching and minimum masking level, are suggested to be performed. Apart from the above essential diagnostic procedures, additional assessments including high-frequency audiometry, OAEs, ABR, vestibular testing, imaging, and dental examination can be considered if clinically indicated. Patient's tinnitus severity and its impacts on daily life can be quantified using questionnaires such as the Tinnitus Questionnaire (TQ), THI, TFI, and HADS.

Treatment options for tinnitus are categorised into: "strong recommendation for", "weak recommendation for", "no recommendation", and "recommendation against" according to the evidence base aggregated from systematic reviews and RCTs. Among all included treatment options, CBT is the only one that is strongly recommended. Moreover, it is evident that self-help CBT interventions, both in-person and Internet-based, are effective in reducing tinnitus distress (Nyenhuis, Golm, et al., 2013). HA and CI fitting can be considered for tinnitus patients who have concomitant hearing loss and fulfil the candidacy criteria, but those without hearing loss should not be offered either. Contrary to the Australian-based guidelines, this collective European guideline does not recommend sound therapy or TRT due to the lack of high-level evidence for their effectiveness. The same applies to neurostimulation treatments (non-invasive or otherwise) and acupuncture, whereas drug treatments and dietary supplements are recommended against. Additionally, the provision of correct and accurate information about tinnitus is of paramount importance. Discussing topics such as the causes of tinnitus, habituation, relaxation, hearing protection, and common misunderstandings can empower and engage patients in the journey of care.

8.12.4 The USA

The American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) published the clinical practice guideline for tinnitus in 2014 (Tunkel et al., 2014). Its evidence-based key action statements for the assessment and treatment of tinnitus are graded into: “strong recommendation”, “recommendation”, “option”, and “no recommendation”. To assess complaints of tinnitus, patient history, physical examination, and comprehensive audiological testing are recommended. Imaging is strongly recommended against unless patients have unilateral or pulsatile tinnitus, asymmetric hearing loss, or focal neurological abnormalities. Differentiation of bothersome tinnitus from non-bothersome tinnitus and chronic tinnitus (≥ 6 months) from acute tinnitus is crucial in prioritising treatment.

With regard to treatment options, CBT, HA evaluation, and education and counselling are recommended. Sound therapy is optional, meaning clinicians may consider this treatment with strong patient preference. There is no recommendation for acupuncture considering limited high-quality evidence on its benefits and harms. Lastly, drug treatments, dietary supplements, and transcranial magnetic stimulation should not be recommended for the routine treatment of patients with chronic bothersome tinnitus.

8.12.5 Japan

The Japanese clinical practice guidelines for diagnosis and treatment of chronic tinnitus was published by the Japan Audiological Society in 2019, aiming to inform standardised and evidence-based evaluation and medical treatment of tinnitus among otolaryngologists (Ogawa et al., 2020). Recommendations are presented as: “strongly recommended”, “recommended”, and “no recommendation” based on the level of evidence. The diagnostic assessment recommended by this guideline is comparatively less comprehensive than other guidelines, as only PTA, tinnitus pitch matching, and loudness balance test are included. Use of tinnitus questionnaires is recommended and those which have been validated and translated into Japanese (e.g., THI) are preferred. Moreover, imaging can be considered for patients with unilateral hearing loss and pulsatile tinnitus and interestingly, for the diagnosis of depression.

Similar to other guidelines, educational counselling and CBT are prioritised by this guideline as treatment options for tinnitus. Nevertheless, there was a paucity of CBT providers and no report of tinnitus-related CBT trials in Japan was available at the time of guideline development. Tinnitus patients with hearing loss are strongly recommended HAs. TRT and sound therapy can be considered, especially given the higher accessibility of sound therapy (using HAs or sound generators) than CBT in Japan. Except the clear recommendation against drug treatments, this guideline seems more lenient in which alternative treatments such as acupuncture, laser treatment, and transcranial magnetic stimulation may be considered despite the inadequate evidence on the effectiveness of these treatments.

8.12.6 Avenue of future clinical guidelines for tinnitus

Systematic reviews of the current tinnitus clinical practice guidelines across the globe unveiled notable disparities in the guideline development process, methodology, recommendations, and reporting standard (Langguth et al., 2023; Meijers et al., 2023). Part of these disparities are explicably attributable to the differences in cultural influences and socioeconomic factors between countries (Meijers et al., 2023). However, recommendations for treatment options, particularly those backed by low-quality evidence, tend to be less unanimous across guidelines. Furthermore, developing a guideline is a time-consuming and costly process, and an innovative treatment can arguably take 10 years or longer to be recommended by a guideline (Langguth et al., 2023). This pitfall can hinder the willingness of investing in innovative treatments and such treatments may render obsolete by the time of recommendation. To address this issue, a digital and open access guideline available internationally has been proposed to increase the dynamicity and timeliness of recommendations (Meijers et al., 2023).

Guidelines are also encouraged to include recommendations/needs for research (e.g., in the NICE guideline) under the circumstance of inconclusive evidence, rather than simply recommending against innovative treatments (Langguth et al., 2023). For treatments with limited evidence base, e.g., Internet-based or smartphone-based tinnitus interventions, this suggestion advocates for guideline committees to stay unbiased towards established (or innovative) treatments, and facilitates the production of high-quality evidence for new treatments in future trials.

In order to ensure transparency and high level of reporting, guidelines are suggested to adhere to and report the use of reporting tools such as the AGREE Reporting Checklist (Brouwers et al., 2016). Involvement of tinnitus patients in guideline development is underlined as well, since the ultimate goal of such guidelines is to rid patients of the debilitating impacts of tinnitus (Langguth et al., 2023; Meijers et al., 2023). For instance, tinnitus patients may regard the diminution of tinnitus *per se* as an important treatment outcome, yet clinicians may consider a reduction in tinnitus awareness and tinnitus-related emotional distress as improvement (Husain et al., 2018). Through understanding tinnitus patients' beliefs, diverging opinions on treatment success can be taken into account when devising and shaping the directions of guideline recommendations.

8.13 Future research directions (Study 2 & Study 5)

From the experience earned from conducting Study 2 and Study 5 as well as their limitations and implications, the following suggestions are made in the hope of enhancing future research rigor and quality. Furthermore, provided that there exists a significant gap between the great number of smartphone apps for tinnitus management and the scarce amount of research in app validation, the directions discussed here may help expand and steer the scope of tinnitus mobile health (mHealth) research, contributing to a richer body of evidence for the advancement of tinnitus care.

8.13.1 Increasing the variety of outcome measures

In Study 2 and Study 5, the primary outcome was the change in tinnitus severity and distress, and thus the TFI was adopted as the instrument for outcome measurement. Usability of Oto was considered another important indicator of user experience and satisfaction, hence Likert-scale questions and the more structured MAUQ were included at the study endpoint of Study 2 and Study 5, respectively, to gauge this secondary outcome.

In fact, tinnitus can impose multifaceted effects on the individual's everyday life. For instance, tinnitus can disturb sleep pattern and decrease emotional wellbeing and quality of life (Langguth, 2011). In spite of the marginal coverage of tinnitus' impacts on sleep and emotional status in the TFI, thorough investigation on these aspects can only be performed with the use of elaborate questions. Widely employed validated questionnaires such as the HADS (Zigmond & Snaith, 1983) can be used for the measurement of levels of tinnitus-related depression and anxiety; the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) and Sleep Quality Scale (SQS) (Snyder et al., 2018) for sleep; and the Quality of Life Scale (QOLS) (Burckhardt & Anderson, 2003) and short version of World Health Organization Quality of Life (WHOQOL-BREF) (The WHOQOL Group, 1998) for health-related quality of life. It is noteworthy that most of these questionnaires are not tinnitus-specific (Van Hoof et al., 2022). Selection of questionnaires will depend on the outcome in question, depth and breadth of questions, and relevance of questions under the context of tinnitus. Moreover, the length of outcome measures is another consideration, as overlong questionnaires can appear redundant and deter participants from responding and adhering to the study.

The MAUQ was employed as a tool for the measurement of Oto's usability as the secondary outcome of Study 5. This questionnaire has been validated against other frequently used usability questionnaires, namely the SUS (Brooke, 1996) and Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 2002). The validation study of the MAUQ assessed the appropriateness of its questions, their similarity with the SUS and PSSUQ, and the performance of MAUQ (Zhou et al., 2019). However, there was no description of normative data or score ranges indicative of app usability level. To put it differently, only overall or subscale scores can be calculated and for example, it can be difficult to determine whether a score of five out of seven indicates fair or good usability. That said, it is conceivable that normative data ranges can only be established upon large sample sizes and/or multiple usability studies. Such ranges may also vary slightly depending on the type of mHealth apps under investigation. The research team which designed the MAUQ indeed suggested augmentation of data from other studies utilising the same questionnaire for its refinement and further psychometric analysis (Zhou et al., 2019). Moreover, the MAUQ can be applied to several timepoints throughout a multistage app development usability study so that antecedent usability data can be used for direct comparisons and guide app development. Another potential possibility is the utilisation of other usability questionnaires which are designed specifically for mHealth apps and have been psychometrically evaluated with provision of normative data. Unfortunately, the MAUQ is first of its kind to be proved of high reliability and there has been an absence of novel usability questionnaires for mHealth apps ever since. As described above, development and validation of usability questionnaires and derivation of normative data ranges can be a laborious process. Thus, until better alternatives arise, collection of normative data using the MAUQ seems to be the most feasible approach.

Other than subjective self-reported outcome measures, objective measures including audiometric testing and psychoacoustic measurement of tinnitus ought to be conducted on all participants to establish complete hearing and tinnitus profiles. This was not possible in Study 5 because this study was nationwide and participants who were living outside South Australia could not travel to Adelaide for an in-person testing. This limitation was however mitigated by requesting a copy of previous hearing assessment results from those participating remotely. Unfortunately, psychoacoustic measurement of tinnitus (e.g., pitch and loudness matching) is not performed in routine clinical practice, so part of this data was missing due to geographical and clinical constraints. Making previous tinnitus assessment results as a prerequisite for participation in this study would risk ineffective recruitment from other states and so the results thereof were not deemed mandatory for participation. It is recommended that if studies of the same nature are to be conducted on a national level, collection of demographic and audiological data may be facilitated by the collaboration of multiple teams/centres/clinics. Standardised outcome measures and testing procedures also need to be ensured for meaningful comparison and analysis of data. As mentioned in *Potential factors influencing treatment response* (Chapter 8.11), such practice can potentially produce useful insights into delineating the difference in treatment response among participants, contributing to tinnitus subtyping, and developing individualised interventions best suited to patient needs.

8.13.2 Use of ecological momentary assessment (EMA)

The perception of tinnitus can change from day to day, or even at different times within the same day, in various ways. For example, the presence of tinnitus can be intermittent (i.e., it comes and goes), its acoustic properties such as pitch and loudness can fluctuate, and due to the intricate relationship between tinnitus and emotional state (e.g., stress, anxiety, and depression), any fluctuation in emotional state can possibly arouse or suppress tinnitus symptoms (Baguley et al., 2013). As such, any measurement of tinnitus symptoms, severity, and distress in a longitudinal study is only a reflection of that moment in time. Even when such measurements are performed at multiple timepoints throughout the study period, a majority of the nuanced variation in tinnitus between the timepoints can easily go unnoticed. This limitation is shared by all of the reported tinnitus intervention trials (using smartphone apps and beyond), without the exception of Study 2 and Study 5. It is nevertheless impossible to collect real-time tinnitus data at all times unless some sort of wearable device or implantable microchip which can safely and precisely measure tinnitus symptoms and distress is invented. This is where EMA, a sampling methodology aiming at collecting real-time data and significantly increasing data points, comes into place as an alternative in an attempt to track the course of tinnitus symptoms and distress.

EMA, also known as the experience-sampling method, is a research approach first developed for observing and capturing the patterns of an individual's daily experience, including activities, thoughts, and emotions (Csikszentmihalyi, 2014). The feasibility of implementing EMA in tinnitus symptoms monitoring has been investigated by a few studies (Goldberg et al., 2017; Schlee et al., 2016; Wilson et al., 2015). These studies focussed on measuring the fluctuations in tinnitus symptoms and distress (e.g., loudness, awareness, and bother) using EMA questions delivered either via a website or a smartphone app. Participants were prompted to answer the EMA questions generally four times per day for two to four weeks, and the response rates were found to be high (80% or above), showing that EMA was an acceptable methodology for the longitudinal assessment of tinnitus symptoms and distress. Although the usefulness of EMA in capturing real-time tinnitus data has been demonstrated, the scope of the aforementioned studies only limited the use of EMA to a measure uncoupled from a tinnitus intervention. In other words, the feasibility of incorporating EMA in tinnitus intervention trials was unclear until the report by Gerull et al. (2019).

In their study, Gerull et al. (2019) evaluated the effectiveness of a web-based auditory-intensive cognitive brain training program in alleviating tinnitus symptoms and distress over a course of 12 weeks. EMA was employed as the sampling methodology, and each participant was asked to complete the survey seven times a day during the preintervention and postintervention periods and four times a day during the intervention period. Participants' compliance with EMA was high (median of 87%) and there was no negative side effect of EMA reported overall. In another study by Engelke et al. (2023), app-based EMA was introduced to the trial which examined a smartphone app delivering structured counselling and sound therapy. Similar to past studies, a good compliance of 79% with EMA was observed. More importantly, this study compared the changes in EMA of tinnitus distress and THI scores, and revealed that notwithstanding the strong association between these two variables, the THI appeared to be more sensitive to change than EMA of tinnitus distress. This difference in sensitivity to change may warrant different thresholds for the two tools when a clinically meaningful improvement in tinnitus distress is to be defined. Additionally, the authors suggested conducting further studies to validate the feasibility of EMA in detecting changes in tinnitus symptoms in intervention trials (Engelke et al., 2023).

Collecting data by the EMA approach can indeed be beneficial in several ways, namely the reduction in recall bias, high ecological validity, and identification of fluctuating temporal pattern of tinnitus symptoms and distress (Schlee et al., 2016). Because all EMA responses are an exact manifestation of tinnitus symptoms and distress at that very moment (or at least the past hour or so), the effect of recall bias when answering EMA questions is remarkably smaller than questionnaires (e.g., TFI) which ask respondents to summarise their tinnitus experience in the past week. The benefit of high ecological validity is fairly comprehensible, as EMA occurs in real-life situations (as opposed to clinically controlled environment) which better demonstrate the individuals' actual experience with tinnitus. Furthermore, it has been shown that tinnitus symptoms and distress can fluctuate significantly from day to day (Engelke et al., 2023). With the use of EMA, any underlying temporal pattern of tinnitus perception (e.g., worsened/improved tinnitus at specific time of the day) or association between tinnitus and other emotional factors (e.g., stress-induced tinnitus arousal) can be more clearly disentangled. Given the above benefits of EMA and the evidence of its feasibility and acceptability in tinnitus intervention studies, future research can consider adopting EMA as one of the sampling methodologies to evaluate novel interventions.

8.13.3 Qualitative data collection through focus groups/interviews

Garnering information on user viewpoint and experience is a crucial step in recognising the strengths and weaknesses of a product or service and implementing proper adjustment to improve it. This kind of information can be collected either via quantitative approaches, such as ranking on a numerical scale in questionnaires, or qualitative approaches, such as open-ended questions in questionnaires, interviews, or focus groups.

Qualitative research systematically dissects people's experience, motivation, and way of behaving in social phenomena and what those phenomena mean to them (Teherani et al., 2015). Structured or semi-structured interviews and focus groups are some frequently employed approaches in qualitative research. Conventionally, interviews and focus groups are conducted in person. However, with technological advancement, increasing accessibility of suitable devices, and the COVID-19 pandemic, online interviews and focus groups via videoconferencing have gradually gained traction (Santhosh et al., 2021). Conducting interviews and focus groups in person versus online may have different interactive dynamics, but in fact, both approaches have been reported to produce comparable levels of idea diversity (Richard et al., 2021). Aside from the number of participants involved in each discussion session, one notable difference between interviews and focus groups is the role of researchers. In interviews, since the interaction is one-to-one, researchers bear the role of "investigators" to take the lead in asking questions and being in charge of the discussion dynamics. On the contrary, as focus groups involve more than one participant, researchers should become "facilitators" or "moderators" and step back from steering the discussion. Rather, they should take up a more observational role, only moderate the discussion, and let the dynamics build organically among participants (O.Nyumba et al., 2018).

Considering the values qualitative approaches might bring to Study 2 and Study 5, open-ended questions about the parts of Oto with which participants felt satisfied and unsatisfied were included in Study 2, whereas focus groups were initially planned for Study 5 to gain in-depth insights. Focus groups were not conducted at the end unfortunately due to unsatisfactory recruitment, though all participants were informed before study commencement of the possibility of being invited to the focus groups. There are several plausible reasons: participants might be uninterested in attending focus groups, they might find Oto unhelpful in relieving tinnitus, or their motivation of spending time on extra research activity upon study completion had dwindled. Regardless of the actual reasons, the abortive attempt at organising focus groups had thwarted the collection of qualitative data reflective of Oto's user experience and satisfaction. In order to comprehensively evaluate the effectiveness and usability of Oto and other tinnitus smartphone apps, it is recommended that qualitative approaches, especially interviews or focus groups, should be included in future research to shed light on aspects which may not be readily investigated by quantitative approaches otherwise.

8.13.4 Cost-effectiveness analysis

Apart from simply measuring the effectiveness of an intervention in achieving certain health outcomes, the costs involved in the acquirement of the intervention, avoidance of seeking other medical treatments, and improvement in productivity can be included in the equation alongside effectiveness to perform cost-effectiveness analysis (U.S. Centers for Disease Control and Prevention, 2021). A cost-effectiveness ratio can be calculated if the net costs of an intervention prove to be positive, while a net cost saving can be calculated if the net costs are negative, and these outputs can be compared across different interventions or between an intervention and the status quo (no intervention) (U.S. Centers for Disease Control and Prevention, 2021).

Under the context of tinnitus interventions, existing cost-effectiveness studies are largely lacking. Some examples of those studies include the use of digital HAs (Haines et al., 2022), a range of current treatment pathways (Stockdale et al., 2017), various forms of CBT (individual, group, and Internet-based) (Patel et al., 2022), CBT-based specialised multidisciplinary care (Maes et al., 2014), and a physiotherapy program complemented by an exercise and counselling program delivered via a smartphone app (Demoen et al., 2022). No cost-effectiveness study has been reported on the use of smartphone apps targeting subjective idiopathic tinnitus (note that the study by Demoen et al. (2022) recruited individuals with somatic tinnitus which can be ameliorated by neck and jaw physiotherapy treatment). With the information extracted from the cost-effectiveness analyses of tinnitus smartphone apps as well as other tinnitus interventions, preferably using the same standardised outcome measures across studies (e.g., questionnaires assessing tinnitus severity and quality of life), tinnitus patients and clinicians will be able to make better-informed decisions on selecting effective interventions with the consideration of costs. In particular, given that some of the commercially available tinnitus smartphone apps are free of charge, they have substantial potential to become some of the most cost-effective tinnitus interventions after rigorous validation and cost-effectiveness analysis (Mehdi, Riha, et al., 2020).

With reference to the costs of tinnitus smartphone apps, some apps (e.g., Oto) provide paid in-app content and consumers may have a variety of attitudes and acceptance towards the costs. Surveying consumer perspectives can generate insights vital to the business and marketing decisions of the app developers, such as price setting and strategies to maintain customer loyalty. An exemplary study in this regard was conducted by Galvin et al. (2022), which discovered the acceptable price range for one-to-one telehealth appointments and online group training/information sessions was AUD$30-86 and AUD$47-103, respectively. Likewise, future research of tinnitus smartphone apps can consider probing into consumers' opinions on acceptable price range, which may aid app developers in determining and finetuning their service costs.

8.13.5 Integration of implementation science methodologies

In healthcare settings, sometimes even though an innovation has been shown by clinical trials to be effective in improving health outcomes, it may not be implemented into routine practice immediately and pervasively, or worse, not implemented at all. In fact, there is an average time lag of 17 years between the formulation of research evidence for clinical innovations and the actual application of such innovations in clinical practice (Morris et al., 2011). Moreover, more than half of the clinical innovations never reach the implementation stage, and over 80% of investment in medical research has not produced public health impact and gone to waste (Bauer & Kirchner, 2020; Chalmers & Glasziou, 2009).

This gap between a growing body of research evidence and lack of uptake of clinical innovations can be addressed by implementation science. Simply put, implementation science is “the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice to improve the quality and effectiveness of health services and care” (Eccles & Mittman, 2006). Along a research pipeline, efficacy studies usually constitute the early stage where the efficacy of a clinical innovation is tested in a highly controlled environment. After that comes effectiveness studies in which the applicability and generalisability of findings to populations beyond controlled conditions are prioritised and assessed. Implementation trials follow efficacy and effectiveness studies, with the aims of identifying uptake facilitators and barriers and developing implementation strategies (Bauer & Kirchner, 2020).

There are various categories of implementation science theories, models, and frameworks which can be employed in the context of tinnitus smartphone apps, e.g., determinant frameworks, implementation theories, and evaluation frameworks (Nilsen, 2015). Specifically, determinant frameworks such as the Theoretical Domains Framework (Cane et al., 2012) and implementation theories such as the COM-B model (Michie et al., 2011) can be used for the exploration and explanation of factors influencing implementation outcomes (i.e., facilitators and barriers). Although it is sensible to partially attribute the low uptake of tinnitus smartphone apps to the generally inadequate research evidence supporting their widespread and effective use, it is still beneficial to understand other potential factors which can have an impact on the apps’ uptake. With regard to evaluation frameworks such as the RE-AIM framework (Glasgow et al., 1999), they provide a structure under which different aspects of implementation (e.g., reach, effectiveness, maintenance, etc.) are evaluated to determine implementation success. In addition, implementation science often involves investigation on multiple levels and in multiple contexts and therefore, engagement of clinical innovation users, clinicians, clinics, organisations, and communities in implementation trials is commonly seen (Damschroder et al., 2009).

8.14 Summary of key findings and original contribution to knowledge of Study 4

Amongst the numerous options of smartphone-based and web-based apps designed to perform audiometric assessment, two smartphone-based apps – Hearing Test (Android version) and Mimi Hearing Test (iOS version) – and a web-based app, MDHearing Aid, were selected for Study 4. These apps’ performance (sensitivity, specificity, accuracy, and test-retest reliability), ecological validity, and usability in screening for mild and moderate hearing loss were assessed using conventional in-person PTA as gold standard for comparison. As such, the applicability of the three apps to clinical implementation was examined.

In relation to the three apps' performance, all of them showed fair to good sensitivity and specificity in identifying hearing impairment. The apps showed varying accuracy, with the web-based MDHearing Aid test showing the highest accuracy: MDHearing Aid test had moderate to good accuracy from 250 Hz to 8000 Hz; Hearing Test app had poor accuracy from 250 Hz to 500 Hz and moderate to good accuracy from 1000 Hz to 8000 Hz; and Mimi Hearing Test had poor accuracy from 250 Hz to 1000 Hz and moderate to good accuracy from 2000 Hz to 8000 Hz. The mean hearing thresholds obtained from the MDHearing Aid test differed from standard audiometric testing by 2-11 dB, Hearing Test app by 2-15 dB, and Mimi Hearing Test by 2-16 dB. All apps yielded fairly similar hearing thresholds to the first assessment when a second assessment was performed, as the Hearing Test app and Mimi Hearing Test showed good to excellent test-retest reliability at all tested frequencies, and the MDHearing Aid test showed moderate to excellent test-retest reliability at all tested frequencies.

As an evaluation of how accurately the apps would perform in real-life settings where ambient noise might be inevitable and calibrated headphones might not be readily available, participants repeated the app-based assessments at home using their own smartphones and headphones. Those assessments revealed poor ecological validity at 250 Hz and moderate ecological validity from 500 Hz to 8000 Hz of the Hearing Test app, poor ecological validity from 250 Hz to 500 Hz and moderate to excellent ecological validity from 1000 Hz to 8000 Hz of Mimi Hearing Test, and poor ecological validity from 250 Hz to 500 Hz and moderate to good ecological validity from 1000 Hz to 8000 Hz of the MDHearing Aid test. Regarding app usability, the Hearing Test app and the MDHearing Aid test were rated the highest at an MAUQ score of 5.9 out of 7, and Mimi Hearing Test scored 5.4 out of 7.

The idea of utilising smartphone-based and web-based apps for hearing assessment emerged over a decade ago (Almufarrij et al., 2022). It has been gradually drawing attention under research and clinical circumstances due to increasing smartphone ownership, global scarcity of hearing healthcare practitioners, and the apps' potentials in approaching wider populations (Almufarrij et al., 2022; Bright & Pallawela, 2016; Irace et al., 2021). In fact, a scoping review by Almufarrij et al.

(2022) identified 187 smartphone-based and web-based hearing assessment tools, in which only 22 were evaluated in peer-reviewed studies. Existing validation studies reported highly variable assessment results and app quality, underscoring the need for more high-quality research on validating available hearing assessment apps. Study 4 fit into this research gap by simultaneously examining three apps which had been evaluated to different extents – the Hearing Test app had been evaluated in seven validation studies with mixed results (e.g., Asghar et al., 2020; Durgut et al., 2020; Prithivi et al., 2019; Rianto et al., 2019), Mimi Hearing Test had been evaluated in one validation study (Yesantharao et al., 2022), and the MDHearing Aid test had never been evaluated. Furthermore, Study 4 was the first of its kind to examine app parameters such as test-retest reliability and ecological validity of all of those three apps. The addition of this research study will hopefully facilitate discussion and reflection upon adopting smartphone-based and web-based tools in conducting hearing assessment in Australia where such practice is uncommon.

8.15 General discussion of Studies 1-5

8.15.1 Study scopes within the hearing healthcare landscape

The series of five studies presented in this PhD is designed to correspond to different components of the hearing healthcare landscape. There are typically six stages along the client hearing care journey: awareness, assessment, information sharing, decision-making, intervention, and follow-up (Glista et al., 2023). Prior to seeking hearing care, potential clients have to first be aware of their need for a hearing test and identify hearing healthcare providers to which they can access. They will then go through assessment of their hearing status which provides results and information regarding their hearing needs and preferences to guide continuous care. Upon the discussion and mutually agreed decision on a well-informed treatment plan, personalised intervention options (e.g., hearing devices) can be offered to clients. Lastly, a follow-up care plan should be in place to troubleshoot technology, revisit client needs and goals, reevaluate hearing status, and provide additional support (Glista et al., 2023).

Study 1 and Study 3 represent the awareness stage as these exploratory studies investigated the perspectives, motivation, and readiness of Australian-based hearing healthcare stakeholders on teleaudiology uptake in the past, present, and future. Findings from these studies revealed that awareness of teleaudiology services was not as prevalent among clients as in other stakeholder groups. These studies lay the foundation for a better understanding of the enabling and hindering factors influencing teleaudiology uptake, shed light on frequently overlooked stakeholder groups, and foster discussions about strategising improved uptake in the post-pandemic landscape.

Study 4 corresponds to the next stage in the client hearing care journey, i.e., assessment. The three smartphone-based and web-based hearing assessment apps examined in this study were shown to have reasonable performance, ecological validity, and usability, notwithstanding their restricted use for diagnostic purposes. One of these apps (Android-based app) is thought to be suitable for hearing screening in adults for the identification of hearing loss, yet further research is needed to fully unlock these apps' clinical potential. Apart from screening purposes, these apps may also be used for monitoring hearing sensitivity in individuals with or without hearing loss, thus addressing the needs in the follow-up stage of client hearing care journey. Furthermore, Study 4 contributes to the awareness stage, as hearing-impaired individuals as determined by those apps can increase their awareness of seeking further hearing care, and the apps can serve as tools for improving awareness of hearing health and relaying information about hearing loss prevention.

As for Study 2 and Study 5, they fall under the intervention stage of the client hearing care journey. The reasoning behind this categorisation is straightforward, since these studies evaluated the feasibility, effectiveness, and usability of a tinnitus smartphone app (Oto). Results from these studies show that Oto has the potential to alleviate tinnitus severity, though future research is required to more comprehensively evaluate its effectiveness in other tinnitus-related aspects, e.g., quality of life. Given the dearth of research evidence on safe and effective use of smartphone apps for tinnitus management, this intervention option may appear difficult to be incorporated in routine clinical practice in the near future. However, with collaborative research effort towards the establishment of smartphone apps as an effective means to deliver tinnitus care, particularly to underserved or remote populations, there is hope that these innovations will evolve into maturity suitable for clinical use.

Because teleaudiology is an extensive topic pertinent to almost the entirety of hearing healthcare landscape with numerous technological options for service delivery, it is impractical to encompass all stages of the hearing care journey, feasible clinical procedures via teleaudiology, and clinical innovations in the confined scope of this PhD. Although gradual advancement in teleaudiology innovations and applications has been observed, teleaudiology uptake is still in an immature and suboptimal state in which many dimensions of it are worth investigating. However, some of those dimensions have not been included in this PhD due to time and resource constraints. For instance, remote clinician-led and self-led HA fitting, programming, and follow-up is a popular research topic in the area of teleaudiology. A number of Australian-based studies have looked into this matter previously (Keidser & Convery, 2018; Keidser et al., 2019; Tao et al., 2021; Timmer et al., 2018). Another example is cochlear implant. Being an alternative rehabilitation option for people with more severe hearing loss, CI can also be fitted and mapped remotely (Eikelboom et al., 2014). With respect to hearing assessment, app-based pure tone and speech testing in children has been examined in Australian settings (Dillon et al., 2018; Mealings, Harkus, Flesher, et al., 2020; Mealings, Harkus, Hwang, et al., 2020). Regardless of the exclusion of the teleaudiology topics mentioned above, this PhD aims to showcase a variety of research scopes under the broad umbrella of teleaudiology or hearing care in general. Therefore, though the five studies presented here appear to have research questions and aims dispersed throughout the continuum of teleaudiology, they are all ultimately threaded together by a single theme revolving around the clinical uptake and application of teleaudiology.

8.16 Teleaudiology guidelines in different countries

Several guidelines specifically designed for remote hearing care are publicly available upon an Internet search. The identified teleaudiology guidelines from different countries are outlined below with a discussion of the relevance of the studies presented in this PhD to the guidelines.

8.16.1 Australia

As mentioned earlier in *Literature Review* (Chapter 2), Audiology Australia was funded by the Australian Department of Health to develop the first national teleaudiology guidelines in 2021 upon the foreseeable increase in teleaudiology uptake during and beyond the COVID-19 pandemic (Audiology Australia, 2022b). The guidelines consist of three sections: general considerations, practice operations guidance, and clinical guidance. General considerations provide some basic information regarding teleaudiology, including its scope, benefits, risks, opportunities for the involvement of third parties, and guiding principles for clinicians. The second section, practice operations guidance, describes the operational considerations prior to and during a teleaudiology appointment. These include maintaining service quality and safety, client- and family-centred care, preparation of client and clinician (e.g., time allocation and technology), and organisational considerations (e.g., workflow changes and staff communication skills development). Meanwhile, clinical guidance lists the range of audiological services which can or cannot be delivered through teleaudiology based on the current literature. The mode (i.e., synchronous or asynchronous, with or without trained assistant at client's location) and means (i.e., video call, online surveys, web-based tools, or apps) of service delivery are explained under each type of teleaudiology service.

The Australian Teleaudiology Guidelines appear to be somewhat generic as there is no suggestion of the actual tools which can be used to deliver teleaudiology services. The guidelines explicitly state that because of the abundant technology options, no specific equipment, device, platform, software, or app is recommended. This decision is a double-edged sword: it can give hearing healthcare providers plenty of freedom to design and implement teleaudiology so long as it adheres to the professional and ethical standards, but it can also render the guidelines less practical and helpful when setting up teleaudiology practice. Without proper suggestions, hearing healthcare providers will need to make greater effort and investment in researching for the most evidence-supported technology options best suited for their service delivery model, which may prompt them to maintain the status quo and become a barrier to teleaudiology uptake.

8.16.2 The UK

In the midst of the COVID-19 pandemic, delivery of essential in-person audiology services in the UK had to be swiftly adopted to the remote care model. In May 2020, the British Academy of Audiology Service Quality Committee and Manchester Centre for Audiology and Deafness developed a series of guides to remote working in audiology services during the pandemic and beyond (British Academy of Audiology, 2020). These guides are to be used in conjunction with the audiology and otology guidance jointly produced by the UK's audiology professional bodies (Association of Independent Hearing Healthcare Professionals et al., 2020) to aid patients and hearing healthcare professionals in the selection of remote care pathways.

The UK guides are separated into six parts: background and evidence, practical guidance remote care, checklists, adult hearing services, paediatric services, and vestibular services. A literature review is presented in the first part of the guides, detailing evidence supporting each type of remote care procedures, including adult and paediatric audiometric assessment, HA and CI programming and finetuning, tinnitus management, mobile health and other interventions, and remote risk assessment. Different from other identified teleaudiology guidelines, the UK guides also provide a summary of literature on patients' and clinicians' attitudes towards teleaudiology.

Compared with the Australian Teleaudiology Guidelines, the UK guides contain more information and resources regarding practical guidance. For example, they include suggestions for enhancing accessibility via captioning and sign language interpretation, as well as for those with visual impairment, lower digital proficiency, and English as a second language. Further, links to validated and useful resources such as web-based and app-based hearing screening tools, ear disease screening questionnaire, online rehabilitation tools, HA maintenance and support materials, and tinnitus support information are embedded within the guides. This has made the guides remarkably intuitive to use as having these plentiful resources from the get-go can streamline the process and shorten the time of locating remote care tools applicable to clinicians' own practice. In fact, findings from Study 3 showed that some clinicians found the Australian Teleaudiology Guidelines inadequately practical and concise. For clinicians and providers who are unfamiliar with teleaudiology but looking to implement it, they may not have the time and knowledge to undertake a thorough review of literature to identify a suitable implementation framework and tools. Having such resources developed by reputable organisations (e.g., hearWHOpro hearing test app by WHO, Sound Scouts hearing test app by NAL, etc.) suggested by professional bodies in the guides can provide a clear starting point for clinicians and providers to set up their remote care model.

Another convenient feature of the UK guides which is not found in other guidelines is the patient and clinician checklists. Almost like a step-by-step guide, these checklists enumerate a number of important considerations before and during a video appointment. These considerations are many-sided, encompassing the technical (e.g., use of fully charged device with a large screen and headset), environmental (e.g., sitting in a well-lit and quiet room), communicative (e.g., handling of signal delay and distortion), clinical (e.g., frequent check of patient's understanding and teach-back technique), and organisational (e.g., ensuring all staff are trained) aspects of an ideal video appointment.

8.16.3 France

A group of medical experts from the French Society of Audiology and the French Society of Otorhinolaryngology-Head and Neck Surgery drafted a set of practice recommendations in 2020 based on their clinical experience and a literature review of teleaudiology practice (Thai-Van et al., 2021). This guideline has a relatively smaller coverage of the definition, background, and scope of teleaudiology. It is primarily dedicated to the description of research evidence, practice recommendations, necessary equipment, and technology options of various procedures, including otoscopy, screening and diagnostic audiometry, brainstem auditory evoked potentials, and OAEs. Remote training of future practitioners is also discussed. Furthermore, considerations are suggested in the context of seeing children and elderly patients.

This French teleaudiology guideline differs from those in other countries in terms of its structure and target readers. First of all, despite this guideline being coined “best practice recommendations”, it only provides clinical guidance from the assessment perspective, omitting other aspects such as intervention and rehabilitation via teleaudiology. This is perhaps due to the fact that this guideline not only targets audiologists but also other medical practitioners (e.g., ENT specialists), to which audiological examination and hearing impairment identification are more relevant to their job nature. Second, possibly due to the same reason, clinical procedures which may be adopted by other practitioners but not regularly performed by audiologists, such as tuning fork testing, are included in this guideline. Third, use of technology for training audiology and medical students is mentioned in this guideline. Examples of remote training courses and patient simulation systems are listed as resources, and this feature is unique to this guideline comparing with others.

This guideline has its own strengths and limitations, just like other guidelines discussed here. It is worth noting that this guideline distinctly indicates that it presents the practice recommendations in the context of the French healthcare system. For instance, the French National Authority for Health defines that the technical part (performing the procedure) and intellectual part (interpreting the results) of otoscopy are indivisible, thus the facilitator who performs otoscopy must be a physician, while the practitioner who interprets the results remotely must be a specialist or subspecialist. This special characteristic of the local healthcare system restricts the role of facilitator which is otherwise not seen in other countries. Similar to the UK guides, the French guideline offers recommendations for technology options, e.g., products and software for teleaudiometry. However, what makes this guideline stand out is the detailed comparison of features and functions across all options. This information can narrow down the available options according to practitioners’ needs and preferences and guide them better in their search of the most suitable technology option. In regard to limitations, the most noticeable one is the guideline's rather confined scope. Practice recommendations are limited to audiological assessment and therefore, none is provided on the subsequent services which are equally important. For teleaudiology to be more widely implemented in the country, other elements in the patient care journey such as hearing device prescription and tinnitus management will need to be addressed by the guideline to inform practitioners of the best practice throughout the continuum of teleaudiology services.

8.16.4 The USA

The guideline for teleaudiology service delivery in the USA is part of the telepractice guideline developed by the ASHA (American Speech-Language-Hearing Association, n.d.-d). As the ASHA oversees the membership of audiologists and speech language pathologists nationally, this telepractice guideline is directed towards both groups of healthcare professionals. ASHA uses the term "telepractice" instead of "telehealth" or "telemedicine" to emphasise the extensive applications of telepractice services beyond healthcare settings. Similar to other teleaudiology guidelines, this guideline includes an overview of telepractice (e.g., definition and modes of service delivery), roles and responsibilities of clinicians, considerations when selecting clients and setting up the physical environment for virtual appointment, types of telepractice services, technological requirements, and privacy and security issues. Scientific evidence pertinent to the types of services deliverable via telepractice is presented as references and on a separate page (Telepractice Evidence Map) where expert opinions and client perspectives can also be found (American Speech-Language-Hearing Association, n.d.-e).

This telepractice guideline has a few unique features. Under the section of client selection, an elaborate list of client characteristics which may affect telepractice success is included, e.g., sensory abilities, cognitive and behavioural characteristics, and access to additional support. Because of the complex and varying licensure and reimbursement requirements across different states in the USA, these topics are underlined with information and resources embedded in this guideline. This can act as a clear guidance to clinicians when navigating licensure to avoid pitfalls and ensure that clinicians practice in accordance with the regulations. Also, understanding the reimbursement system may enable timely payment to telepractice service providers and facilitate client and provider uptake. Moreover, there is a section dedicated to considerations for delivering telepractice services in school settings. Nevertheless, this guideline does not provide any example of telepractice tools (e.g., software and apps) unlike those in the UK and France.

8.16.5 India

The Indian Speech-Language and Hearing Association prepared the first national telepractice guideline in 2020 for use among audiologists and speech language pathologists (Indian Speech-Language and Hearing Association, 2020). This guideline, albeit seemingly more condensed, by and large resembles the teleaudiology guidelines in other countries. Information about the definition, scope, and operational considerations of telepractice are provided. Although examples of software for video call and synchronous clinical testing and apps for hearing screening, tinnitus management, assistive listening, hearing protection, and Indian sign language are provided in the appendices, the guideline emphasises that the list is only representative and inexhaustive, and it should by no means replace clinicians' critical review of scientific evidence.

What sets the Indian telepractice guideline apart from the rest of the identified teleaudiology guidelines is its focus on the administrative and ethical aspects of telepractice. Telepractice services do not merely entail the process of conducting clinical procedures. Same as in-person service delivery, the administrative process requires close attention so that the clinical practice is in line with professional and ethical standards. For example, this guideline specifies the provision of secure payment and invoices to clients. Besides, test results or session records from each telepractice encounter should be available to clients and stored securely. Furthermore, for the sake of identification, clinicians' names must be introduced in the first telepractice session, and their registration numbers must be shown in all invoices, records, reports, and electronic communication (e.g., email and text message). Having these protocols outlined in a black-and-white fashion can ensure all personnel are on the same page and leave minimal margin of administrative error. In terms of the ethical aspects of telepractice, this guideline elucidates the circumstances under which misconduct and malpractice are demonstrated. Examples of misconduct include insisting on telepractice regardless of client's preference for in-person services and misusing client data without consent. On the other hand, facilitators conducting tests or delivering telepractice services without the presence of a clinician represent some examples of malpractice. Such explanation of unacceptable and unethical behaviours is vital to the protection of client safety and upholding of professional and ethical standards.

8.16.6 Malaysia

Under the influence of the COVID-19 pandemic and release of the Malaysia Digital Economy Blueprint, which aimed to promote nationwide digitalisation including the healthcare sector, the Ministry of Health Malaysia published the Guidelines for Teleaudiology Services in 2021 (Ministry of Health Malaysia, 2021). The main purpose of these guidelines is to inform teleaudiology service delivery during the pandemic, but they are also applicable to circumstances beyond the pandemic if deemed appropriate. The Malaysian teleaudiology guidelines share some similarities with other identified guidelines in which topics such as the definition, mode of delivery, client eligibility criteria, technical requirements, data security, and medico-legal implications are covered.

A few distinct differences can be identified between the Malaysian guidelines and other guidelines. First, the Malaysian guidelines only provide guidance on teleaudiology use for intervention and rehabilitation purposes. In other words, performing hearing screening or diagnostic assessment via teleaudiology is not supported in the country. In fact, as indicated in the guidelines, these procedures are required to be conducted in person in an audiology clinic even during the pandemic. Second, a detailed list of the recommended work process for teleaudiology is provided. Clinicians can follow the list to make sure all necessary steps are covered in patient enrolment and before, during, and after the teleaudiology appointment. Third, flowcharts of suggested process for aural rehabilitation, HA service, tinnitus and hyperacusis service, and CI service delivered via teleaudiology are included. These flowcharts plainly illustrate the stages at which a decision to whether offer teleaudiology options or continue in-person care needs to be made, e.g., upon evaluation of eligibility and provision of consent. A recommended duration of 30 minutes to one hour for each teleaudiology appointment is stated in the flowcharts as well. Fourth, the appendices embedded in the Malaysian guidelines present as useful tools when organising teleaudiology appointments, including a form for determination of patient eligibility for teleaudiology and a sample of consent form. Further, as a recognition of the importance of quality and clinical outcome measurement, a sample of outcome measure questionnaire is provided. Patients are encouraged to complete this questionnaire under the supervision of clinicians as an evaluation of service quality and guide for improvement in the following teleaudiology appointment.

8.16.7 Relevance of Studies 1-5 to teleaudiology guidelines

All five studies presented in this PhD are highly relevant to the teleaudiology/telepractice guidelines identified and discussed above, as they contribute to the evidence base from which the guidelines are developed. Aside from being informed by the clinical experience of the experts who drafted the guidelines, recommendations for best teleaudiology practice in the guidelines are robustly grounded in the research evidence cumulated since teleaudiology became a viable option. This can ensure that hearing healthcare providers observe evidence-based practice and facilitate knowledge translation from research to clinical application.

Despite that only the UK guides include a section regarding patients' and clinicians' attitudes towards teleaudiology, addition of this information to other current or future guidelines is definitely worth considering. Without a comprehensive review of patients' attitudes, clinicians and providers may opt out of teleaudiology use according to their predetermined and perhaps even biased perceptions. It is probable that they assume elderly clients who are generally less digital literate are less accepting of teleaudiology, unbeknownst to them in some situations digital literacy may not be a good predictor of teleaudiology service acquisition (Ratanjee-Vanmali et al., 2020a). Study 1 and Study 3 produced invaluable insights into the perceptions of hearing healthcare stakeholders in Australia towards teleaudiology uptake, which can potentially be incorporated into teleaudiology guidelines to inform clinical practice and address barriers to teleaudiology uptake.

Examples of software and apps for video call, audiological assessment, and intervention can be found in some teleaudiology guidelines, e.g., in France and the UK. The guidelines have made it clear that those examples serve as suggestions only and final decisions should be made upon thorough review and professional judgment. In fact, two of the apps examined in Study 4 (Android version of Hearing Test app and iOS version of Mimi Hearing Test app) are mentioned in the French and Indian teleaudiology guidelines. This demonstrates that scientific evidence generated from teleaudiology app evaluation trials is crucial to the development of teleaudiology guidelines, which in return can assist clients and clinicians in the selection of tools during teleaudiology service delivery. With further validation of app effectiveness, other apps examined in Study 2, Study 4, and Study 5 may eventually make their appearance as suggested teleaudiology tools in the modified and upcoming guidelines in the future.

8.17 Teleaudiology suitability versus availability

It is evident that teleaudiology may not be suitable for all types of clients and clinical procedures. One consideration of offering teleaudiology services is undoubtedly client's access to the Internet and technological devices. Without these prerequisites, it is unfeasible to leverage technology to deliver any kind of audiology services. For clients with more severe sensory or cognitive impairment (e.g., vision impairment or dementia), it is conceivable that video consultations can become challenging, and even more so without the support of facilitators or clients' significant others (Kalicki et al., 2021). Indeed, clinicians have expressed differential willingness to perform various clinical procedures via teleaudiology based on their complexity and nature. For example, most of the clinicians are amenable to using teleaudiology for communication-based tasks such as answering questions about HAs, whereas technical tasks requiring high precision such as CI mapping and diagnostic assessment receive the most reluctance (Rashid et al., 2019; Singh et al., 2014). Findings from Study 3 in particular are in congruence with the above notions, in which clinicians questioned the accuracy of hearing assessment software and ability to check HA placement over a video call and hence, these tasks were considered unsuitable for teleaudiology. Possibly due to the varying practicality of using teleaudiology for each service type, though scientific evidence suggests almost all procedures can be conducted remotely, not every type of audiology services is included in the teleaudiology guidelines and reimbursement systems across the globe (e.g., Federal Register of Legislation, 2023; Ministry of Health Malaysia, 2021).

Selection of clients for teleaudiology services based on their eligibility is logical and in fact, recommended by all teleaudiology guidelines since offering such services to those for whom are unsuitable can jeopardise health outcomes and quality of care. That said, some clinicians may determine client suitability based on their own subjective assumptions rather than objective assessment of clients' ability, access to technology, preferences, etc. This biased or overly selective practice can have a detrimental effect on the benefits the clients would have enjoyed if teleaudiology was used accordingly. It can be seen from Study 3 that some clinicians would naturally presume clients were uninterested in teleaudiology without proper prompting beforehand and decide not to offer remote care options. Yet, it can come to clinicians as a surprise that when the choice of telehealth is made available to patients, sometimes those who are assumed incapable of or unkeen on using telehealth (e.g., elderly) can actually be even more technologically savvy than clinicians, and vice versa (i.e., younger patients do not necessarily prefer telehealth) (Cook et al., 2023). It is thus important to be mindful of prejudiced assumptions constructed solely upon a selection of client characteristics, and the significance of joint decision-making should never be overlooked. Availability of teleaudiology services should not be restricted by their assumed or generalised suitability for clients. Suitability of teleaudiology should be determined on a per encounter basis, taking all clinical and client factors into account (Cook et al., 2023; Thomas et al., 2024). It is only through this practice the usefulness of teleaudiology and client needs can be matched and client-centred care can be utterly attained.

Lastly, as indicated by findings from Study 3 concurring with the Australian Teleaudiology Guidelines, teleaudiology is not a replacement of in-person services but rather a complement or alternative to the traditional service delivery method (Audiology Australia, 2022b). Teleaudiology should be regarded as an addition tool to clinicians' repertoire which can be used to deliver hearing care to a wider population. Although the digital divide will persist as users' and providers' access to teleaudiology is dependent on their access to the Internet and devices as well as their digital literacy and acceptance (T. V. Le et al., 2023), making teleaudiology an option rather than the only option gives them the autonomy to determine its appropriateness. With the research findings presented in this PhD in conjunction with the literature, teleaudiology continues to prove a viable and effective means of delivering hearing care during the COVID-19 pandemic and in the post-pandemic landscape, while ongoing collaborative effort from all stakeholders is required to overcome the challenges of and barriers to teleaudiology uptake and realise the full potential of teleaudiology.

8.18 Overall strengths and limitations

The research studies presented in this thesis have a number of strengths. First of all, the scopes of the collection of five studies are appropriately extensive to encompass various stages of the hearing care journey with the use of teleaudiology: awareness, assessment, and intervention. This thesis attempts to address questions corresponding to each of the above stages in the hope of making suggestions and finding potential solutions for increasing teleaudiology uptake in Australia.

Second, the participation of multiple hearing healthcare stakeholder groups was emphasised, especially in Study 1 and Study 3 in which their experiences of and perceptions towards teleaudiology uptake were explored. Stakeholders who have frequently been overlooked by previous research, such as students, academics, and industry partners, were included in this thesis so as to enrich the diversity and depth of thoughts and opinions collected regarding teleaudiology uptake. In fact, Study 1 and Study 3 are one of the first studies to explore how teleaudiology education is implemented at university level and perceived by students and academics. Insights generated from these studies provide new avenues and directions for reviewing current curricula and facilitating incorporation of teleaudiology as a program topic.

Third, the effectiveness and usability of a variety of smartphone-based and web-based apps for hearing assessment and tinnitus management were evaluated. Notably, the web-based MDHearing Aid test and Oto app examined in this thesis have never been investigated previously. Hence, findings from the app evaluation studies presented here constitute significant contribution to the largely insufficient scientific evidence on the performance of hearing assessment and tinnitus management apps at present. These findings also add to the foundation upon which possibilities of novel teleaudiology innovations can be explored and teleaudiology use in clinical practice can be expanded.

Fourth, this thesis adopted robust methods including close observation of standardised reporting guidelines and use of validated questionnaires. For the qualitative study (Study 3) and RCT (Study 5), the COREQ and CONSORT checklists were employed, respectively. In the app evaluation studies (Study 2, Study 4, and Study 5), validated questionnaires including the TFI and MAUQ were used to assess app effectiveness and usability, respectively. These practices can preserve the repeatability of experiment and facilitate meaningful comparisons of performance of the same app/between apps.

In spite of the strengths noted above, this PhD presents with several limitations which should be acknowledged. Although the aim of Study 1 and Study 3 was to involve as many hearing healthcare stakeholders as possible, recruitment was proved challenging with particularly low response rates among students, academics, and industry partners. The inadequate representation of these stakeholder groups dampens the generalisability of findings to the entirety of the corresponding groups, albeit such participants provided insightful comments on teleaudiology education and uptake.

As this PhD aimed to inform changes in the hearing healthcare model in Australia with the inclusion of teleaudiology, all participants were recruited within Australia. As discussed previously, there lies a great range of differences in the healthcare systems, reimbursement schemes, funding sources, infrastructure, and social and cultural characteristics across countries. Findings presented in this thesis may not be applicable or generalisable to other countries. Further research is required to investigate and depict the landscape of teleaudiology uptake in individual countries.

8.19 Overall future directions

Many future research directions have been generated from this PhD and discussed throughout this thesis. These directions are summarised in Figure 8.4 below.

Exploration of hearing healthcare stakeholders' **perceptions** towards teleaudiology uptake:
1. Increasing the sample size, especially for students, academics, and industry partners
2. Investment in research and initiation of campaigns to promote teleaudiology awareness
3. International-scale studies
4. Investigation on the roles and effects of teleaudiology consultation facilitators and training provided
5. Follow-up of changes in university curriculum and student willingness and confidence in using teleaudiology
6. Use of behavioural change models
7. Investigation of other underlying factors influencing teleaudiology uptake, e.g., personality traits

Evaluation of smartphone-based and web-based apps for **hearing assessment**:
1. Further inclusion of participants with more severe degrees of hearing loss
2. Use of insert earphones for threshold measurement and its comparison with the use of circumaural headphones
3. Further validation of hearing assessment apps which have barely or never been evaluated

Evaluation of smartphone apps for **tinnitus management**:
1. Increasing the variety of outcome measures
2. Investigation of predictors of treatment effectiveness
3. Use of EMA
4. Qualitative data collection through focus groups/interviews
5. Cost-effective analysis
6. Integration of implementation science methodologies
7. Investigation of alternative or improved control conditions for tinnitus clinical trials

Figure 8.4 Summary of future research directions.

8.20 Conclusion

The overarching aim of this thesis was to enhance teleaudiology service delivery in Australia through understanding hearing healthcare stakeholders' perceptions towards teleaudiology and evaluating web-based and smartphone-based interventions which can potentially be incorporated into routine clinical practice.

Combining the quantitative and qualitative responses regarding hearing healthcare stakeholders' past experiences with and current perceptions towards teleaudiology, it was revealed that clients shared less awareness and experience of teleaudiology services than other stakeholders including clinicians, students, academics, and industry partners. The benefits of teleaudiology were acknowledged by stakeholders, but major barriers were still present, deterring them from utilising teleaudiology further. Teleaudiology education at universities was deemed inadequate, despite students' and academics' willingness to increase its coverage in the curriculum. That said, development in improving teleaudiology uptake was reported recently in clinical and educational settings, especially since the COVID-19 pandemic, and stakeholders held positive attitudes towards post-pandemic teleaudiology use. This suggests a gradual shift in stakeholders' acceptance of teleaudiology and increasing endeavours in facilitating its uptake, though challenges of and barriers to accessing and providing teleaudiology services will need to be overcome before they can be fully implemented.

This PhD also demonstrated reasonable performance and usability of three smartphone-based and web-based hearing assessment apps, and the effectiveness of a smartphone app in reducing tinnitus severity and distress. These studies extend the knowledge from the attitudinal aspect to the clinical application aspect of teleaudiology. The apps examined in this thesis showed potentially promising use in delivering audiological services to populations who wish to receive care remotely and find in-person care inaccessible. The evidence presented here is, however, only the starting point upon which further research is required to more comprehensively investigate and unlock the apps' potential.

In the post-pandemic landscape, teleaudiology presents a wide range of avenues and opportunities for the enhancement of existing hearing healthcare paradigm. This thesis addressed multiple facets of teleaudiology with studies of varying nature and purposes. The work presented here bridges the gap in the continuum of teleaudiology and provides important contribution to the growing body of evidence on teleaudiology use.

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APPENDIX 1 – SIGNED CO-AUTHORSHIP APPROVAL FORM

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CO-AUTHORSHIP APPROVALS FOR HDR THESIS FOR EXAMINATIONS

In accordance with Clause 5, 7 and 8 in the HDR Thesis Rules, a student must sign a declaration that the thesis does not contain any material previously published or written by another person except where due reference is made in the text or footnotes. There can be no exception to this rule.

a. Publications or significant sections of publications (whether accepted, submitted or in manuscript form) arising out of work conducted during candidature may be included in the body of the thesis, or submitted as additional evidence as an appendix, on the following conditions:
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   II. they are formatted in the same way as the other chapters (i.e. not presented as reprints unless as an appendix), whether included as separate chapters or integrated into chapters
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   II. there is a clear statement in prose for each publication at the front of each chapter, recording the percentage contribution of each author to the paper, from conceptualisation to realisation and documentation.
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STUDENT DETAILS

Student Name	Lok Sum (Boaz) Mui
Student ID	2232563
College	College of Education, Psychology & Social Work
Degree	Doctor of Philosophy
Title of Thesis	Human Centred Design and Teleaudiology: Transforming the Future

PUBLICATION 1

This section is to be completed by the student and co-authors. If there are more than four co-authors (student plus 3 others), only the three co-authors with the most significant contributions are required to sign below.

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Section of thesis where publication is referred to	Chapter 2 (Study 1)

Student's contribution to the publication	80	%	Research design
	95	%	Data collection and analysis
	80	%	Writing and editing

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Significant contribution to study design conceptualisation, ethics modification, participant recruitment, data collection and analysis, and writing (original draft and editing during review process).

APPROVALS

By signing the section below, you confirm that the details above are an accurate record of the students contribution to the work.

Name of Co-Author 1	Jameel Muzaffar	Signed	[redacted]	Date	22/10/2024
Name of Co-Author 2	Niranjan Bidargaddi	Signed		Date	24/10/2024
Name of Co-Author 3	Giriraj Singh Shekhav	Signed		Date	22/10/2024

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Full Publication Details	Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Digital therapeutics in tinnitus care: A feasibility study of the Oto smartphone application.
Section of thesis where publication is referred to	Chapter 3 (Study 2)

Student's contribution to the publication	70	%	Research design
	90	%	Data collection and analysis
	80	%	Writing and editing

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Significant contribution to study design conceptualisation, ethics application, participant recruitment, data collection and analysis, and writing (original draft and editing during review process).

APPROVALS

By signing the section below, you confirm that the details above are an accurate record of the students contribution to the work.

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PUBLICATION 3

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Section of thesis where publication is referred to	Chapter 4 (Study 3)

Student's contribution to the publication

80	%	Research design
80	%	Data collection and analysis
80	%	Writing and editing

Outline your (the student's) contribution to the publication:

Significant contribution to study design conceptualisation, ethics modification, participant recruitment, data collection and analysis, and writing (original draft and editing during review process).

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Student's contribution to the publication

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80	%	Writing and editing

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Name of Co-Author 2	Vinaya Manchaiah	Signed		Date	23-10-2024
Name of Co-Author 3	Giriraj Singh Shekhav	Signed		Date	22/10/2024

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Full Publication Details	Mui, B., Muzaffar, J., Chen, J., Bidargaddi, N., & Shekhawat, G. S. (2024). Towards digital solutions for tinnitus: A randomised controlled trial of the Oto smartphone application.
Section of thesis where publication is referred to	Chapter 6 (Study 5)

Student's contribution to the publication	70	%	Research design
	90	%	Data collection and analysis
	80	%	Writing and editing

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Significant contribution to study design conceptualisation, ethics application, participant recruitment, data collection and analysis, and writing (original draft and editing during review process).

APPROVALS

By signing the section below, you confirm that the details above are an accurate record of the students contribution to the work.

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APPENDIX 2 – SURVEY FOR CLIENTS (STUDY 1)

Introduction

Introduction

Teleaudiology is defined as "the use of telecommunications and digital technology to provide access to audiological services for clients who are not in the same location as the clinician" (Audiology Australia, 2020). It includes the delivery of all kinds of

audiological services via digital means such as phone calls, video calls, internet/smartphone applications (apps), emails, text messages, online instant messaging, and websites.

Demographics

What is your age? (Years)

[ ]

What is your gender?

- ○ Male
- ○ Female
- ○ Other - please specify [ ]

Which country are you currently living in?

[⌄]

Which state or territory are you currently living in?

- NSW
- VIC
- QLD
- SA
- WA
- TAS
- NT
- ACT

Do you have hearing loss?

- Yes
- No

Do you experience tinnitus (ringing/buzzing/other sounds in the ears without any external sound)?

- Yes
- No

How long have you been having hearing loss? (Years)

Tinnitus characteristics (adapted from TSCHQ)

How long have you been experiencing tinnitus? (Years)

Where do you hear your tinnitus?

- ○ Right ear
- ○ Left ear
- ○ Both ears, worse in right
- ○ Both ears, worse in left
- ○ Both ears, equally
- ○ Inside the head
- ○ Elsewhere - please specify

Would you describe your tinnitus as:

- ○ Intermittent - it comes and goes from time to time
- ○ Constant - it is there all the time

How would you describe the pitch of your tinnitus?

Very low pitch (e.g., thunder) — Very high pitch (e.g., whistle)

0○ 1○ 2○ 3○ 4○ 5○ 6○ 7○ 8○ 9○ 10○

Chronic pain

Do you experience chronic pain condition?

- ○ Yes
- ○ No

How long have you been experiencing chronic pain condition? (Years)

What is the cause of your chronic pain condition? (Select all that apply)

- ☐ Neuropathy/nerve damage related condition
- ☐ Osteoarthritis/bone damage related condition
- ☐ Rheumatoid arthritis/autoimmune related condition
- ☐ Non-specific pain/multi-regional pain/fibromyalgia related condition (pain without an underlying observable cause)
- ☐ Migraine related condition

How would you describe your pain when you are NOT EXPERIENCING tinnitus?

No pain — Painful as bad as it could possibly be

0○ 1○ 2○ 3○ 4○ 5○ 6○ 7○ 8○ 9○ 10○

How would you describe your pain when you are EXPERIENCING tinnitus?

No pain — Painful as bad as it could possibly be

0○ 1○ 2○ 3○ 4○ 5○ 6○ 7○ 8○ 9○ 10○

Do you use any medication to treat your chronic pain condition?

- ○ Yes - please specify
- ○ No

Knowledge & general telehealth experience

Do you know what teleaudiology is?

- ◯ Yes
- ◯ No

Please describe what teleaudiology means to you:

Have you ever used any telehealth services APART FROM teleaudiology services, e.g., with general practitioners (GPs) and other health professionals OTHER THAN hearing healthcare professionals?

- ◯ Yes
- ◯ No - I have been offered telehealth services, but I didn't take it
- ◯ No - I haven't been offered any

When did you use telehealth services?

- ◯ Only before 2020 (before COVID-19 outbreak)
- ◯ Only since 2020 (since COVID-19 outbreak)
- ◯ Both before and since 2020

How positive was your previous experience with telehealth services?

- ◯ Very negative
- ◯ Somewhat negative
- ◯ Neutral
- ◯ Somewhat positive
- ◯ Very positive

Would your previous experience with telehealth services affect how you think about and make decision to use teleaudiology services?
Why/why not?

- ◯ Yes - please explain why ________
- ◯ No - please explain why not ________

Why didn't you use telehealth services? (Select all that apply)

- ☐ Prefer in-person appointments
- ☐ Lack of suitable devices (smartphone/tablet/computer)
- ☐ Insufficient internet connectivity
- ☐ My unfamiliarity with technology
- ☐ Clinician's unfamiliarity with technology
- ☐ Appointment not reimbursable
- ☐ Personal data security concern
- ☐ There is no need any more as lockdown has ended/social restrictions have been eased
- ☐ Services I need cannot be delivered online - please describe type of services ________
- ☐ Other - please specify ________

Would your hesitation in using telehealth services affect how you think about and make decision to use teleaudiology services?
Why/why not?

- ◯ Yes - please explain why ______
- ◯ No - please explain why not ______

Teleaudiology appointments

Have you ever attended any teleaudiology appointments?

- ◯ Yes
- ◯ No

When did you attend those teleaudiology appointments?

- ◯ Only before 2020 (before COVID-19 outbreak)
- ◯ Only since 2020 (since COVID-19 outbreak)
- ◯ Both before and since 2020

What were the appointments about? (Select all that apply)

- ☐ Hearing assessment
- ☐ Discussion on hearing aid/cochlear implant/other hearing device options
- ☐ Hearing aid initial fitting
- ☐ Hearing aid review and finetuning
- ☐ Cochlear implant initial fitting
- ☐ Cochlear implant review and finetuning
- ☐ Other hearing devices fitting
- ☐ Other hearing devices review and finetuning
- ☐ Counselling on everyday communication strategies/Auditory training programs
- ☐ Tinnitus management
- ☐ Other - please specify ____________

How were the appointments delivered? (Select all that apply)

- ☐ Phone call
- ☐ Video call
- ☐ App-based (internet/smartphone)
- ☐ Email
- ☐ Text message
- ☐ Online instant messaging
- ☐ Other - please specify ____________

Other than you and the clinician, who also attended the appointments? (Select all that apply)

- [ ] A facilitator who assisted the clinician in conducting the tests and communication
- [ ] A significant other (e.g., spouse, family member, carer, friend)
- [ ] A clinician in another discipline (e.g., general practitioner (GP), Ear, Nose and Throat (ENT) specialist)
- [ ] Other clients (e.g., in a group hearing rehabilitation program)
- [ ] None of the above

How did the third party affect your experience during the teleaudiology appointments?

- ○ They improved the experience - please explain ______
- ○ They worsened the experience - please explain ______
- ○ They didn't affect the experience

What do you like about the appointments?

______

What do you not like about the appointments?

______

What factors do you think make an ideal teleaudiology appointment?

How likely will you continue having teleaudiology appointments?

- Very unlikely
- Somewhat unlikely
- Neutral
- Somewhat likely
- Very likely

Compared to face-to-face appointments, how have teleaudiology appointments affected service quality?

- Significantly worsened
- Slightly worsened
- No change
- Slightly improved
- Significantly improved

Why would service quality be worsened by having teleaudiology appointments instead of face-to-face ones?

Why would service quality be improved by having teleaudiology appointments instead of face-to-face ones?

Compared to face-to-face appointments, how have teleaudiology appointments affected your relationship/interaction with the clinician?

- Significantly worsened
- Slightly worsened
- No change
- Slightly improved
- Significantly improved

Have you been offered a teleaudiology appointment and did you take it?

- Yes - I have been offered one, but I didn’t take it
- No - I haven't been offered any

If you were offered a teleaudiology appointment, would you take it?

- Yes
- No

What hinders you from having teleaudiology appointments? (Select all that apply)

- ☐ Prefer in-person appointments
- ☐ Lack of suitable devices (smartphone/tablet/computer)
- ☐ Insufficient internet connectivity
- ☐ My unfamiliarity with technology
- ☐ Clinician's unfamiliarity with technology
- ☐ My hearing difficulty stops me from communicating well over the phone/online
- ☐ Appointment not reimbursable
- ☐ Unable to find service providers
- ☐ Personal data security concern
- ☐ There is no need any more as lockdown has ended/social restrictions have been eased
- ☐ Services I need cannot be delivered online - please describe type of services ______
- ☐ Other - please specify ______

Teleaudiology apps

Have you ever used any smartphone/computer apps that are made specifically to provide audiological services including hearing test, hearing aid finetuning, tinnitus management, noise level monitor, etc. (i.e., not the generic apps for making video calls such as Skype, Zoom, Microsoft Teams, etc.)?

- ○ Yes
- ○ No

How did you discover those apps? (Select all that apply)

- [ ] Search in app store/internet
- [ ] Clinician's suggestion
- [ ] Family/friend's suggestion
- [ ] From an advertisement
- [ ] Other - please specify ______

When did you use those apps?

- ○ Only before 2020 (before COVID-19 outbreak)
- ○ Only since 2020 (since COVID-19 outbreak)
- ○ Both before and since 2020

Which type of device did you use the apps on? (Select all that apply)

- [ ] Smartphone
- [ ] Tablet
- [ ] Computer

What kind of services do the apps provide? (Select all that apply)

- ☐ Otoscopy (taking pictures/videos of your ear canal and eardrum for examination)
- ☐ Hearing screening (test results are shown as pass/fail only)
- ☐ Hearing diagnostic test (test results determine type and degree of hearing loss)
- ☐ Hearing aid finetuning
- ☐ Cochlear implant finetuning
- ☐ Other hearing devices finetuning
- ☐ Tinnitus management e.g., sound generator, counselling, relaxation
- ☐ Auditory training programs
- ☐ Hearing loss prevention e.g., noise level monitor, hearing protection educational information
- ☐ Other - please specify ________

What are the names of the apps?

____

What do you like about the apps?

____

What do you not like about the apps?

____

What factors do you think make an ideal teleaudiology app?

How likely will you continue using teleaudiology apps?

- Very unlikely
- Somewhat unlikely
- Neutral
- Somewhat likely
- Very likely

Why wouldn't you continue using teleaudiology apps?

Why would you continue using teleaudiology apps?

What hinders you from using those teleaudiology apps?

- ☐ Unaware of any
- ☐ Lack of suitable devices (smartphone/tablet/computer)
- ☐ Insufficient internet connectivity
- ☐ My unfamiliarity with technology
- ☐ Clinician's unfamiliarity with technology
- ☐ Insufficient research evidence to support their effectiveness
- ☐ Personal data security concern
- ☐ Other - please specify ____________

Satisfaction

To what extent do you agree with this statement: I think teleaudiology services/apps should be promoted and used more often.

- ○ Strongly disagree
- ○ Slightly disagree
- ○ Neutral
- ○ Slightly agree
- ○ Strongly agree

Why do you think teleaudiology services/apps shouldn't be promoted and used more often?

____

Why do you think teleaudiology services/apps should be promoted and used more often?

Anything else

Is there anything else you would like to share regarding teleaudiology?

- ○ Yes - please explain
- ○ No

Further contact

Would you be interested to further discuss your views and comments on teleaudiology with a member of the research team in a short one-on-one online chat?

- ○ Yes
- ○ No

Please provide an email address for us to contact you. (By answering this question, you consent to being contacted via email by the research team listed in the participant information sheet.)

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APPENDIX 3 – SURVEY FOR CLINICIANS (STUDY 1)

Demographics

What is your age? (Years)

What is your gender?

- ○ Male
- ○ Female
- ○ Other - please specify

Which country are you currently living in?

Which state or territory are you currently working in?

- NSW
- VIC
- QLD
- SA
- WA
- TAS
- NT
- ACT

What position are you working in?

- Audiologist
- Audiometrist
- Other - please specify

Which type of clients do you work with?

- Adult
- Paediatrics
- Both adult and paediatrics

How long have you been working as a clinician? (Years)

Which type of clinic do you primarily work in?

- ○ Large chain clinic (>20 clinics)
- ○ Small chain clinic (≤20 clinics)
- ○ Single independent clinic
- ○ Government hospital/clinic
- ○ Private hospital
- ○ University clinic
- ○ Other - please specify [ ]

Knowledge

Do you know what teleaudiology is?

- ○ Yes
- ○ No

Please describe what teleaudiology means to you:

[ ]

Teleaudiology appointments

Have you ever conducted any teleaudiology appointments?

- ○ Yes
- ○ No

When did you conduct those appointments?

- ○ Only before 2020 (before COVID-19 outbreak)
- ○ Only since 2020 (since COVID-19 outbreak)
- ○ Both before and since 2020

How many times have you conducted teleaudiology appointments BEFORE 2020?

- ○ <10
- ○ 11-20
- ○ 21-30
- ○ 31-40
- ○ 41-50
- ○ >50

How many times have you conducted teleaudiology appointments SINCE 2020?

- ○ <10
- ○ 11-20
- ○ 21-30
- ○ 31-40
- ○ 41-50
- ○ >50

Which types of appointments have you provided via teleaudiology? (Select all that apply)

- ☐ Hearing assessment
- ☐ Discussion on hearing aid/cochlear implant/other hearing device options
- ☐ Hearing aid initial fitting
- ☐ Hearing aid review and finetuning
- ☐ Cochlear implant initial fitting
- ☐ Cochlear implant review and finetuning
- ☐ Other hearing devices fitting
- ☐ Other hearing devices review and finetuning
- ☐ Counselling on everyday communication strategies/Auditory training programs
- ☐ Tinnitus management
- ☐ Other - please specify ____________

How were the appointments delivered? (Select all that apply)

- ☐ Phone call
- ☐ Video call
- ☐ App-based (internet/smartphone)
- ☐ Email
- ☐ Text message
- ☐ Online instant messaging
- ☐ Other - please specify ____________

Other than you and the client, who also attended the appointments? (Select all that apply)

- ☐ A facilitator who assisted you in conducting the tests and communication
- ☐ A significant other (e.g., spouse, family member, carer, friend)
- ☐ A clinician in another discipline (e.g., general practitioner (GP), Ear, Nose and Throat (ENT) specialist)
- ☐ Other clients (e.g., in a group hearing rehabilitation program)
- ☐ None of the above

How did the third party affect your experience during the teleaudiology appointments?

- ○ They improved the experience - please explain ________
- ○ They worsened the experience - please explain ________
- ○ They didn't affect the experience

What do you like about the appointments?

____

What do you not like about the appointments?

____

What factors do you think make an ideal teleaudiology appointment?

How likely will you continue conducting teleaudiology appointments?

- Very unlikely
- Somewhat unlikely
- Neutral
- Somewhat likely
- Very likely

Compared to face-to-face appointments, how have teleaudiology appointments affected service quality?

- Significantly worsened
- Slightly worsened
- No change
- Slightly improved
- Significantly improved

Why would service quality be worsened by providing teleaudiology appointments instead of face-to-face ones?

Why would service quality be improved by providing teleaudiology appointments instead of face-to-face ones?

Compared to face-to-face appointments, how have teleaudiology appointments affected your relationship/interaction with clients?

- ○ Significantly worsened
- ○ Slightly worsened
- ○ No change
- ○ Slightly improved
- ○ Significantly improved

What hinders you from providing teleaudiology appointments? (Select all that apply)

- ☐ Prefer in-person appointments
- ☐ Lack of suitable devices (smartphone/tablet/computer)
- ☐ Insufficient internet connectivity
- ☐ My unfamiliarity with technology
- ☐ Client's unfamiliarity with technology
- ☐ No/limited training available
- ☐ Appointment not reimbursable
- ☐ Personal data security concern
- ☐ There is no need any more as lockdown has ended/social restrictions have been eased
- ☐ Services I provide cannot be delivered online - please describe type of services
- ☐ Other - please specify

Teleaudiology apps

Have you used any teleaudiology apps such as those made specifically for hearing assessment, hearing aid finetuning, tinnitus treatment, noise monitor, etc. as part of your service delivery (i.e., not the generic apps for making video calls such as Skype, Zoom, Microsoft Teams, etc.)?

- ◯ Yes
- ◯ No

When did you use those apps?

- ◯ Only before 2020 (before COVID-19 outbreak)
- ◯ Only since 2020 (since COVID-19 outbreak)
- ◯ Both before and since 2020

Which type of device did you use the apps on? (Select all that apply)

- ☐ Smartphone
- ☐ Tablet
- ☐ Computer

What kind of services do the apps provide? (Select all that apply)

- ☐ Otoscopy/video-otoscopy
- ☐ Hearing screening (test results are shown as pass/fail only)
- ☐ Hearing diagnostic test (test results determine type and degree of hearing loss)
- ☐ Hearing aid finetuning
- ☐ Cochlear implant finetuning
- ☐ Other hearing devices finetuning
- ☐ Tinnitus management e.g., sound generator, counselling, relaxation
- ☐ Auditory training programs
- ☐ Hearing loss prevention e.g., noise level monitor, hearing protection educational information
- ☐ Other - please specify ______

What are the names of the apps?

______

What do you like about the apps?

______

What do you not like about the apps?

______

What factors do you think make an ideal teleaudiology app?

How likely will you continue using teleaudiology apps in your service delivery?

- Very unlikely
- Somewhat unlikely
- Neutral
- Somewhat likely
- Very likely

Why wouldn't you continue using teleaudiology apps in your service delivery?

Why would you continue using teleaudiology apps in your service delivery?

How likely will you continue recommending those apps to your clients?

- ○ Very unlikely
- ○ Somewhat unlikely
- ○ Neutral
- ○ Somewhat likely
- ○ Very likely

What hinders you from using teleaudiology apps as part of your service delivery?

- ☐ Unaware of any
- ☐ Lack of suitable devices (smartphone/tablet/computer)
- ☐ Insufficient internet connectivity
- ☐ My unfamiliarity with technology
- ☐ Client's unfamiliarity with technology
- ☐ Insufficient research evidence to support their effectiveness
- ☐ Personal data security concern
- ☐ Other - please specify

Support/satisfaction

How confident are you in providing quality teleaudiology services?

- ○ Very unconfident
- ○ Slightly unconfident
- ○ Neutral
- ○ Slightly confident
- ○ Very confident

How much training does your clinic/company provide to support your teleaudiology service delivery?

- ◯ None at all
- ◯ Limited amount
- ◯ Fair amount
- ◯ Quite a lot
- ◯ A lot

How much support do you receive from companies/product specialists that provide teleaudiology products?

- ◯ None at all
- ◯ Limited amount
- ◯ Fair amount
- ◯ Quite a lot
- ◯ A lot

How do you perceive your clients' acceptance towards teleaudiology services?

- ◯ Very reluctant
- ◯ Slightly reluctant
- ◯ Neutral
- ◯ Slightly accepting
- ◯ Very accepting

What factors would have affected their acceptance?

To what extent do you agree with this statement: I think teleaudiology services/apps should be promoted and used more often.

- ◯ Strongly disagree
- ◯ Slightly disagree
- ◯ Neutral
- ◯ Slightly agree
- ◯ Strongly agree

Why do you think teleaudiology services/apps shouldn't be promoted and used more often?

Why do you think teleaudiology services/apps should be promoted and used more often?

Anything else

Is there anything else you would like to share regarding teleaudiology?

- ○ Yes - please explain ______
- ○ No

Further contact

Would you be interested to further discuss your views and comments on teleaudiology with a member of the research team in a short one-on-one online chat?

- ○ Yes
- ○ No

Please provide an email address for us to contact you. (By answering this question, you consent to being contacted via email by the research team listed in the participant information sheet.)

______

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APPENDIX 4 – SURVEY FOR STUDENTS (STUDY 1)

Demographics

What is your age? (Years)

What is your gender?

- Male
- Female
- Other - please specify

Which country are you currently living in?

Which institution are you currently studying in?

- ○ The University of Queensland
- ○ The University of Western Australia
- ○ Flinders University
- ○ Macquarie University
- ○ The University of Melbourne
- ○ La Trobe University
- ○ Charles Darwin University
- ○ TAFE
- ○ Other - please specify ______

Which year of study are you currently in?

- ○ Master - first year
- ○ Master - second year
- ○ Higher Degree by Research
- ○ Diploma - first year
- ○ Diploma - second year
- ○ Other - please specify ______

Knowledge

Do you know what teleaudiology is?

- ○ Yes
- ○ No

Please describe what teleaudiology means to you:

What types of audiological services do you know can be delivered by teleaudiology (e.g., things that can be done during a face-to-face appointment)?

Where did you learn/observe the use of teleaudiology? (Please specify which aspect of teleaudiology you learned/observed from each selected option) (Select all that apply)

- ☐ Lectures - please specify aspect
- ☐ Tutorials - please specify aspect
- ☐ Clinical/practical sessions - please specify aspect
- ☐ Placements - please specify aspect
- ☐ Self-study, e.g., reading literature/attending seminars or conferences at your own time - please specify aspect
- ☐ Other - please specify where and aspect
- ☐ I did not learn anything about teleaudiology

How has learning/observing the use of teleaudiology influenced your perception of teleaudiology?

- ○ Positively influenced
- ○ Negatively influenced
- ○ No change

Why would learning/observing the use of teleaudiology positively influence your perception of teleaudiology?

Why would learning/observing the use of teleaudiology negatively influence your perception of teleaudiology?

Perception

How important is it to learn about teleaudiology during your study?

- ○ Very unimportant
- ○ Slightly unimportant
- ○ Neutral
- ○ Slightly important
- ○ Very important

How much teaching/training about teleaudiology was provided during your study?

- ○ None at all
- ○ Limited amount
- ○ Fair amount
- ○ Quite a lot
- ○ A lot

How interested are you in learning about teleaudiology?

- ○ Very uninterested
- ○ Slightly uninterested
- ○ Neutral
- ○ Slightly interested
- ○ Very interested

How competent are you in teleaudiology?

- ○ Very incompetent
- ○ Slightly incompetent
- ○ Neutral
- ○ Slightly competent
- ○ Very competent

What are the barriers that hinder you from being more competent in teleaudiology? (Select all that apply)

- ☐ It is not included in the curriculum
- ☐ It is taught but to a very limited extent
- ☐ No/limited placement opportunities
- ☐ Placement clinics are not using teleaudiology
- ☐ I don't know where to find resources/learning materials of teleaudiology
- ☐ I am not interested in teleaudiology
- ☐ Other - please specify

What would motivate you to learn more about teleaudiology during your study? (Select all that apply)

- ☐ It is taught more often in class
- ☐ Teleaudiology competency becomes a requirement for program completion
- ☐ Increase competitiveness for employment
- ☐ Increase future client satisfaction
- ☐ Be better prepared to meet the National Competency Standards for Audiologists during internship
- ☐ Personal expansion of knowledge
- ☐ Other - please specify

Anything else

Is there anything else you would like to share regarding teleaudiology?

- ○ Yes - please explain ________
- ○ No

Further contact

Would you be interested to further discuss your views and comments on teleaudiology with a member of the research team in a short one-on-one online chat?

- ○ Yes
- ○ No

Please provide an email address for us to contact you. (By answering this question, you consent to being contacted via email by the research team listed in the participant information sheet.)

____

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APPENDIX 5 – SURVEY FOR ACADEMICS (STUDY 1)

Demographics

What is your age? (Years)

What is your gender?

- Male
- Female
- Other - please specify

Which country are you currently living in?

Which institution are you currently working in?

- ◯ The University of Queensland
- ◯ The University of Western Australia
- ◯ Flinders University
- ◯ Macquarie University
- ◯ The University of Melbourne
- ◯ La Trobe University
- ◯ Charles Darwin University
- ◯ TAFE
- ◯ Other - please specify

How long have you been working as an academic? (Years)

Knowledge

Do you know what teleaudiology is?

- ◯ Yes
- ◯ No

Please describe what teleaudiology means to you:

Curriculum

Is teleaudiology part of your institution's current curriculum?

- ○ Yes
- ○ No

Where does your institution incorporate teleaudiology in the curriculum? (Please specify which aspect of teleaudiology is incorporated in each selected option) (Select all that apply)

- ☐ Lectures - please specify aspect ________
- ☐ Tutorials - please specify aspect ________
- ☐ Clinical/practical sessions - please specify aspect ________
- ☐ Placements - please specify aspect ________
- ☐ Other - please specify where and aspect ________

Has your team invited any companies or product specialists to provide teaching/training on teleaudiology for the students?

- ○ Yes, and they accepted the invitation - please specify company names ________
- ○ Yes, and they rejected the invitation - please specify company names ________
- ○ No

Which aspects of teleaudiology did they teach/train the students?

____

Are teleaudiology competencies assessed upon course completion?

- ◯ Yes
- ◯ No

Why is teleaudiology not included in the curriculum? (Select all that apply)

- ☐ Our team has never discussed/considered the inclusion of it
- ☐ It is less important in clinical settings compared to other topics
- ☐ All staff are busy with other work duties
- ☐ Lack of staff with adequate knowledge in this area
- ☐ Inadequate funding
- ☐ Inadequate teaching materials available
- ☐ Unaware of companies/product specialists who can provide teaching/training in this area
- ☐ Teleaudiology companies/product specialists rejected invitation to teach/train students
- ☐ Lack of national standards for practice so it is impractical to teach students only one/few ways of conducting teleaudiology
- ☐ Other - please specify ______

Perception

How important is it to include teleaudiology in the curriculum?

- ◯ Very unimportant
- ◯ Slightly unimportant
- ◯ Neutral
- ◯ Slightly important
- ◯ Very important

How much teaching/training about teleaudiology is provided for students?

- ◯ None at all
- ◯ Limited amount
- ◯ Fair amount
- ◯ Quite a lot
- ◯ A lot

How interested are you in teaching teleaudiology?

- ◯ Very uninterested
- ◯ Slightly uninterested
- ◯ Neutral
- ◯ Slightly interested
- ◯ Very interested

How confident are you in teaching teleaudiology?

- Very unconfident
- Slightly unconfident
- Neutral
- Slightly confident
- Very confident

What can be done to help incorporate teleaudiology better in the curriculum?

What can be done to motivate students to learn more about teleaudiology?

Anything else

Is there anything else you would like to share regarding teleaudiology?

- Yes - please explain
- No

Further contact

Would you be interested to further discuss your views and comments on teleaudiology with a member of the research team in a short one-on-one online chat?

- ○ Yes
- ○ No

Please provide an email address for us to contact you. (By answering this question, you consent to being contacted via email by the research team listed in the participant information sheet.)

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APPENDIX 6 – SURVEY FOR INDUSTRY PARTNERS (STUDY 1)

Demographics

What is your age? (Years)

[ ]

What is your gender?

- ○ Male
- ○ Female
- ○ Other - please specify [ ]

Which country are you currently living in?

[▾]

Which company are you working in?

[ ]

What position are you working in?

- ○ Manager
- ○ Product specialist
- ○ Other - please specify [ ]

How long have you been working in this position? (Years)

Knowledge

Do you know what teleaudiology is?

- ○ Yes
- ○ No

Please describe what teleaudiology means to you:

Products & services

What teleaudiology products does your company provide? (Select all that apply)

- ☐ Equipment for otoscopy/video-otoscopy
- ☐ Smartphone/computer apps for otoscopy/video-otoscopy
- ☐ Equipment for hearing screening
- ☐ Smartphone/computer apps for hearing screening
- ☐ Equipment for diagnostic hearing assessments (pure-tone audiometry and speech testing)
- ☐ Smartphone/computer apps for diagnostic hearing assessments (pure-tone audiometry and speech testing)
- ☐ Equipment for tympanometry and acoustic immittance testing
- ☐ Equipment for otoacoustic emission testing
- ☐ Hearing aids that can be fitted and finetuned remotely
- ☐ Smartphone/computer apps for hearing aid fitting and finetuning
- ☐ Cochlear implants that can be fitted and finetuned remotely
- ☐ Smartphone/computer apps for cochlear implant fitting and finetuning
- ☐ Assistive listening devices that can be fitted and finetuned remotely
- ☐ Smartphone/computer apps for assistive listening device fitting and finetuning
- ☐ Smartphone/computer apps for tinnitus management
- ☐ Smartphone/computer apps for auditory training program
- ☐ Teleaudiology appointment platforms
- ☐ Other - please specify ________
- ☐ None of the above

How frequently do you provide support to clinicians regarding your company's teleaudiology products?

- ◯ Never
- ◯ Seldom
- ◯ Sometimes
- ◯ Often
- ◯ Always

How positive is the clinicians' feedback on your company's teleaudiology products?

- ◯ Very negative
- ◯ Slightly negative
- ◯ Neutral
- ◯ Slightly positive
- ◯ Very positive

Which teleaudiology products received most positive feedback and what was the feedback?

Which teleaudiology products received most negative feedback and what was the feedback?

How confident are you in training clinicians to use teleaudiology products?

- ◯ Very unconfident
- ◯ Slightly unconfident
- ◯ Neutral
- ◯ Slightly confident
- ◯ Very confident

If your company provides teleaudiology products, how confident will you be in training clinicians to use those products?

- ◯ Very unconfident
- ◯ Slightly unconfident
- ◯ Neutral
- ◯ Slightly confident
- ◯ Very confident

What can be done to improve teleaudiology product promotion and clinical uptake?

To what extent do you agree with this statement: I think teleaudiology products should be promoted and used more often.

- Strongly disagree
- Slightly disagree
- Neutral
- Slightly agree
- Strongly agree

Why do you think teleaudiology products shouldn't be promoted and used more often?

Why do you think teleaudiology products should be promoted and used more often?

Teaching

Have you been invited to teach/train students on teleaudiology?

- Yes, and I accepted the invitation - please specify institution names
- Yes, and I rejected the invitation - please specify institution names
- No

Which aspects of teleaudiology did you teach/train the students?

Why did you reject the invitation?

How interested will you be if you are invited to teach/train students on teleaudiology?

- Very uninterested
- Slightly uninterested
- Neutral
- Slightly interested
- Very interested

Why are you uninterested in teaching/training students on teleaudiology?

How confident are you in teaching/training students on teleaudiology?

- ○ Very unconfident
- ○ Slightly unconfident
- ○ Neutral
- ○ Slightly confident
- ○ Very confident

Anything else

Is there anything else you would like to share regarding teleaudiology?

- ○ Yes - please explain [ ]
- ○ No

Further contact

Would you be interested to further discuss your views and comments on teleaudiology with a member of the research team in a short one-on-one online chat?

- ○ Yes
- ○ No

Please provide an email address for us to contact you. (By answering this question, you consent to being contacted via email by the research team listed in the participant information sheet.)

[ ]

APPENDIX 7 – TINNITUS FUNCTIONAL INDEX (TFI)

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APPENDIX 8 – COMPLETED COREQ CHECKLIST (STUDY 3)

Consolidated criteria for reporting qualitative studies (COREQ): 32-item checklist

Item No	Guide Questions/Description	Reported on Page #
Domain 1: Research team and reflexivity		
Personal Characteristics		
1. Interviewer/ facilitator	Which author/s conducted the interview or focus group?	5
2. Credentials	What were the researcher's credentials? E.g., PhD, MD	N/A
3. Occupation	What was their occupation at the time of the study?	N/A
4. Gender	Was the researcher male or female?	N/A
5. Experience and training	What experience or training did the researcher have?	5
Relationship with participants		
6. Relationship established	Was a relationship established prior to study commencement?	5-6
7. Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research?	5-6
8. Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic	5-6
Domain 2: study design		
Theoretical framework		
9. Methodological orientation and Theory	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	6
Participant selection		
10. Sampling	How were participants selected? e.g., purposive, convenience, consecutive, snowball	7
11. Method of approach	How were participants approached? e.g., face-to-face, telephone, mail, email	7
12. Sample size	How many participants were in the study?	7
13. Non-participation Setting	How many people refused to participate or dropped out? Reasons?	7
14. Setting of data collection	Where was the data collected? e.g., home, clinic, workplace	7

Item No	Guide Questions/Description	Reported on Page #
15. Presence of nonparticipants	Was anyone else present besides the participants and researchers?	7
16. Description of sample	What are the important characteristics of the sample? e.g. demographic data, date	8
Data collection		
17. Interview guide	Were questions, prompts, and guides provided by the authors? Was it pilot tested?	7
18. Repeat interviews	Were repeat interviews carried out? If yes, how many?	N/A
19. Audio/visual recording	Did the research use audio or visual recording to collect the data?	7
20. Field notes	Were field notes made during and/or after the interview or focus group?	7
21. Duration	What was the duration of the interviews or focus group?	8
22. Data saturation	Was data saturation discussed?	22
23. Transcripts returned	Were transcripts returned to participants for comment and/or correction?	8
Domain 3: analysis and findings		
Data analysis		
24. Number of data coders	How many data coders coded the data?	8
25. Description of the coding tree	Did the authors provide a description of the coding tree?	8
26. Derivation of themes	Were themes identified in advance or derived from the data?	8
27. Software	What software, if applicable, was used to manage the data?	8
28. Participant checking	Did participants provide feedback on the findings?	N/A
Reporting		
29. Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g., participant number	8
30. Data and findings consistent	Was there consistency between the data presented and the findings?	8
31. Clarity of major themes	Were major themes clearly presented in the findings?	9-18

Item No	Guide Questions/Description	Reported on Page #
32. Clarity of minor themes	Is there a description of diverse cases or a discussion of minor themes?	N/A

APPENDIX 9 – INTERVIEW GUIDE FOR CLIENTS (STUDY 3)

Semi-structured interview guide (client)

Thank you for taking your time to participate in this interview. Today we have invited you here to discuss your thoughts on teleaudiology. In this interview, we will focus on teleaudiology services delivered in real time, such as by phone calls or video calls, as well as the use of teleaudiology apps.

- Before we start, I would like to remind you that I will not judge any of your answers or feelings. There is no right or wrong answer to these questions.
- Your decision to participate in this interview and study is completely voluntary. There will be no requirement for an explanation if you decide not to participate at any time before or during the interview.
- The interview should take approximately 45 minutes depending on how much information you would like to share.
- With your permission, I would like to video-record the interview because I don't want to miss any of your comments.
- Your interview responses will be de-identified and kept confidential. This means that your responses will only be shared with research team members and that any personal information that we include in any disseminated reports or publications will not identify you as a participant.
- You may decline to answer any question or stop the interview at any time and for any reason.
- Do you have any questions about what I have just explained?

Topic	**Question**
Teleaudiology appointment	**For those who HAVE had teleaudiology appointments:* In the online survey, you mentioned that you have had teleaudiology appointments. • Can you tell me about your experience with teleaudiology appointments? • If you were seeing a clinician via teleaudiology and had not met them face-to-face before, how would you feel? • Are there any aspects of hearing care you would prefer to have face-to-face rather than via teleaudiology?

1

	• What concerns do you have regarding teleaudiology appointments? **For those who HAVEN'T had teleaudiology appointments:* In the online survey, you mentioned that you have never had teleaudiology appointments. Has that changed since you completed the survey last year? • **If yes:* Ask the questions above for those who HAVE had teleaudiology appointments. • **If no:* Ask the questions below. • Were you offered any teleaudiology appointments? • **If yes:* Why did you decline it? • **If no:* Would you accept it if it was offered? Why/why not?
Teleaudiology apps	**For those who HAVE used teleaudiology apps:* You mentioned that you have used apps which are made specifically to provide audiology services such as hearing test, hearing aid adjustment, and tinnitus management. • Can you tell me about your experience using teleaudiology apps? • What concerns do you have regarding teleaudiology apps? **For those who HAVEN'T used teleaudiology apps:* You mentioned that you have never used apps which are made specifically to provide audiology services such as hearing test, hearing aid adjustment, and tinnitus management. Has that changed since you completed the survey last year? • **If yes:* Ask the questions above for those who HAVE used teleaudiology apps. • **If no:* Ask the questions below. • Were you aware of these apps? • **If yes:* Why didn't you try these apps? • **If no:* Would you be interested in trying them? Why/why not?

Environmental context and resources	• What factors influence whether or not you use teleaudiology services? (e.g., information, technology, cost/funding, etc.)
Social influences	• Do you feel supported by clinicians to use teleaudiology services? • Is there anyone you would want to receive support from when using teleaudiology services?
Willingness	• How has your willingness to use teleaudiology services changed over time?
Post-pandemic use	• Do you think teleaudiology will be useful even after the COVID pandemic?
Conclusion	• That brings me to the end of my questions. Is there anything else you would like to add about teleaudiology? • Thank you very much for your time and the information you have shared today.

APPENDIX 10 – INTERVIEW GUIDE FOR CLINICIANS (STUDY 3)

Semi-structured interview guide (clinician)

Thank you for taking your time to participate in this interview. Today we have invited you here to discuss your thoughts on teleaudiology. In this interview, we will focus on teleaudiology services delivered in real time, such as by phone calls or video calls, as well as the use of teleaudiology apps.

- Before we start, I would like to remind you that I will not judge any of your answers or feelings. There is no right or wrong answer to these questions.
- Your decision to participate in this interview and study is completely voluntary. There will be no requirement for an explanation if you decide not to participate at any time before or during the interview.
- The interview should take approximately 45 minutes depending on how much information you would like to share.
- With your permission, I would like to video-record the interview because I don't want to miss any of your comments.
- Your interview responses will be de-identified and kept confidential. This means that your responses will only be shared with research team members and that any personal information that we include in any disseminated reports or publications will not identify you as a participant.
- You may decline to answer any question or stop the interview at any time and for any reason.
- Do you have any questions about what I have just explained?

Topic	Question
Demographics	• How long have you been working as an audiologist/audiometrist? • Are your clients adults only, paediatrics only, or both? • What kind of audiological services do you provide? • Do you provide services other than audiological services? (e.g., speech pathology or psychology)
Teleaudiology appointment	**For those who HAVE conducted teleaudiology appointments:* In the online survey, you mentioned that you have conducted teleaudiology appointments.

1

	• Can you tell me about your experience with teleaudiology appointments? • If you were seeing a client via teleaudiology and had not met them face-to-face before, how would you feel? • Are there any aspects of hearing care you would prefer to deliver face-to-face rather than via teleaudiology? • What concerns do you have regarding teleaudiology appointments? ***For those who HAVEN'T conducted teleaudiology appointments:*** In the online survey, you mentioned that you have never conducted teleaudiology appointments. Has that changed since you completed the survey last year? • **If yes:* Ask the questions above for those who HAVE conducted teleaudiology appointments. • **If no:* Ask the question below. • What stops you from providing teleaudiology appointments?
Teleaudiology apps	***For those who HAVE used teleaudiology apps in their service delivery:*** You also mentioned that you have used apps which are made specifically to provide audiology services such as hearing test, hearing aid adjustment, and tinnitus management in your service delivery. • Can you tell me about your experience using teleaudiology apps? • What concerns do you have regarding teleaudiology apps? ***For those who HAVEN'T used teleaudiology apps in their service delivery:*** You also mentioned that you have never used apps which are made specifically to provide audiology services such as hearing test, hearing aid adjustment, and tinnitus management in your service delivery. Has that changed since you completed the survey last year? • **If yes:* Ask the questions above for those who HAVE used teleaudiology apps. • **If no:* Ask the questions below. • Were you aware of these apps?

	• **If yes:* Why didn't you use these apps? • **If no:* Would you be interested in using them? Why/why not?
Australian Teleaudiology Guidelines	Audiology Australia launched the Australian Teleaudiology Guidelines in June 2022 which aim to support the delivery of audiology services safely and effectively through teleaudiology. • Have you read the Guidelines? • **If yes:* How useful are the Guidelines in facilitating teleaudiology implementation in your clinic? • **If no:* Is there any reason why you haven't read them? Aside from the Guidelines, Audiology Australia also launched clinician and client resources. • Have you used those resources/directed your clients to them? • **If yes:* How useful are the resources?
Environmental context and resources	• What factors influence whether or not you provide teleaudiology services? (e.g., information, technology, support, cost/funding, etc.)
Social influences	• Do you feel supported by your colleagues/clinic to implement teleaudiology? • Is there anyone you would want to receive support from when implementing teleaudiology?
Willingness	• How has your willingness to provide teleaudiology services changed over time?
Post-pandemic use	• Do you think teleaudiology will be useful even after the COVID pandemic?
Conclusion	• That brings me to the end of my questions. Is there anything else you would like to add about teleaudiology? • Thank you very much for your time and the information you have shared today.

APPENDIX 11 – INTERVIEW GUIDE FOR STUDENTS (STUDY 3)

Semi-structured interview guide (student)

Thank you for taking your time to participate in this interview. Today we have invited you here to discuss your thoughts on teleaudiology. In this interview, we will focus on teleaudiology services delivered in real time, such as by phone calls or video calls, as well as the use of teleaudiology apps.

- Before we start, I would like to remind you that I will not judge any of your answers or feelings. There is no right or wrong answer to these questions.
- Your decision to participate in this interview and study is completely voluntary. There will be no requirement for an explanation if you decide not to participate at any time before or during the interview.
- The interview should take approximately 45 minutes depending on how much information you would like to share.
- With your permission, I would like to video-record the interview because I don't want to miss any of your comments.
- Your interview responses will be de-identified and kept confidential. This means that your responses will only be shared with research team members and that any personal information that we include in any disseminated reports or publications will not identify you as a participant.
- You may decline to answer any question or stop the interview at any time and for any reason.
- Do you have any questions about what I have just explained?

Topic	**Question**
Learning experience	• Can you tell me about your experience learning about teleaudiology at the university? • Can you tell me about your experience learning about teleaudiology at the placement clinics?
Future career	• How would having/not having teleaudiology in the curriculum affect your future job prospect? • If you were seeing a client via teleaudiology and had not met them face-to-face before, how would you feel?

	• How would you ensure trust and rapport with your clients is maintained when using teleaudiology? • How would you want to implement and use teleaudiology in your future career as audiologist?
Environmental context and resources	• What factors influence whether or not you learn about teleaudiology? (e.g., information, training, employment prospect, client satisfaction, etc.)
Social influences	• Do you feel supported by academics at your university/clinicians at placement clinics to learn about teleaudiology? • Is there anyone you would want to receive support from when learning about teleaudiology?
Willingness	• How has your willingness to learn about teleaudiology changed over time?
Post-pandemic use	• Do you think teleaudiology will be useful even after the COVID pandemic?
Conclusion	• That brings me to the end of my questions. Is there anything else you would like to add about teleaudiology? • Thank you very much for your time and the information you have shared today.

APPENDIX 12 – INTERVIEW GUIDE FOR ACADEMICS (STUDY 3)

Semi-structured interview guide (academic)

Thank you for taking your time to participate in this interview. Today we have invited you here to discuss your thoughts on teleaudiology. In this interview, we will focus on teleaudiology services delivered in real time, such as by phone calls or video calls, as well as the use of teleaudiology apps.

- Before we start, I would like to remind you that I will not judge any of your answers or feelings. There is no right or wrong answer to these questions.
- Your decision to participate in this interview and study is completely voluntary. There will be no requirement for an explanation if you decide not to participate at any time before or during the interview.
- The interview should take approximately 45 minutes depending on how much information you would like to share.
- With your permission, I would like to video-record the interview because I don't want to miss any of your comments.
- Your interview responses will be de-identified and kept confidential. This means that your responses will only be shared with research team members and that any personal information that we include in any disseminated reports or publications will not identify you as a participant.
- You may decline to answer any question or stop the interview at any time and for any reason.
- Do you have any questions about what I have just explained?

Topic	**Question**
Demographics	• Are you working at (university name)? • How long have you been working as an academic?
Teaching experience	• Is teleaudiology part of the curriculum at the university? **If yes:* • How is teleaudiology taught within your university's curriculum? • Can you tell me about your experience teaching teleaudiology at the university? • How would having teleaudiology in the curriculum affect your students' future job prospect?

	**If no:* • Is there any reason why it is not included in the curriculum? • How would not having teleaudiology in the curriculum affect your students' future job prospect?
Environmental context and resources	• What factors influence whether or not you teach teleaudiology? (e.g., information, technology, cost/funding, staffing, students' employment prospect, etc.)
Social influences	• Do you feel supported by your colleagues/university to teach teleaudiology? • Is there anyone you would want to receive support from when teaching teleaudiology?
Willingness	• How has your willingness to teach teleaudiology changed over time?
Post-pandemic use	• Do you think teleaudiology will be useful even after the COVID pandemic?
Conclusion	• That brings me to the end of my questions. Is there anything else you would like to add about teleaudiology? • Thank you very much for your time and the information you have shared today.

APPENDIX 13 – INTERVIEW GUIDE FOR INDUSTRY PARTNERS (STUDY 3)

Semi-structured interview guide (industry partner)

Thank you for taking your time to participate in this interview. Today we have invited you here to discuss your thoughts on teleaudiology. In this interview, we will focus on teleaudiology services delivered in real time, such as by phone calls or video calls, as well as the use of teleaudiology apps.

- Before we start, I would like to remind you that I will not judge any of your answers or feelings. There is no right or wrong answer to these questions.
- Your decision to participate in this interview and study is completely voluntary. There will be no requirement for an explanation if you decide not to participate at any time before or during the interview.
- The interview should take approximately 45 minutes depending on how much information you would like to share.
- With your permission, I would like to video-record the interview because I don't want to miss any of your comments.
- Your interview responses will be de-identified and kept confidential. This means that your responses will only be shared with research team members and that any personal information that we include in any disseminated reports or publications will not identify you as a participant.
- You may decline to answer any question or stop the interview at any time and for any reason.
- Do you have any questions about what I have just explained?

Topic	**Question**
Demographics	• Are you working at (company name)? • What position are you working in? • How long have you worked there?
Teleaudiology products	• How is teleaudiology related to your job? • Can you tell me about your experience providing teleaudiology products? • Do you provide training/support for end users to use your products? If so, how often?

1

Teaching experience	• Have you been invited to give a talk/product demo for university students? **If yes:* • Can you tell me about your experience teaching teleaudiology? **If no:* • If you were to teach students about teleaudiology, what topics/aspects would you talk about?
Teleaudiology implementation	• What factors influence teleaudiology implementation in clinics? • How do the clinics that successfully implemented teleaudiology differ from those that did not?
Environmental context and resources	• What factors influence whether or not you do teleaudiology-related work? (e.g., information, technology, support, cost/funding, etc.)
Social influences	• Do you feel supported by your colleagues/company to do teleaudiology-related work? • Is there anyone you would want to receive support from when doing teleaudiology-related work?
Willingness	• How has your willingness to do teleaudiology-related work changed over time?
Post-pandemic use	• Do you think teleaudiology will be useful even after the COVID pandemic?
Conclusion	• That brings me to the end of my questions. Is there anything else you would like to add about teleaudiology? • Thank you very much for your time and the information you have shared today.

APPENDIX 14 – MHEALTH APPS USABILITY QUESTIONNAIRE (MAUQ)

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APPENDIX 15 – COMPLETED CONSORT CHECKLIST (STUDY 5)

CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	2
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	3-4
	2b	Specific objectives or hypotheses	4
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	5-6
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	13
Participants	4a	Eligibility criteria for participants	8
	4b	Settings and locations where the data were collected	5-6
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	9-12
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	7
	6b	Any changes to trial outcomes after the trial commenced, with reasons	N/A
Sample size	7a	How sample size was determined	8
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	9
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	9
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	9
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	9

Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	9
	11b	If relevant, description of the similarity of interventions	N/A
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	12-13
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	N/A
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	Figure 3
	13b	For each group, losses and exclusions after randomisation, together with reasons	Figure 3
Recruitment	14a	Dates defining the periods of recruitment and follow-up	8
	14b	Why the trial ended or was stopped	N/A
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Table 1
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	Figure 3
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	14-16
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	N/A
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	N/A
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	16
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	22
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	22
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	17-21
Other information			
Registration	23	Registration number and name of trial registry	5
Protocol	24	Where the full trial protocol can be accessed, if available	N/A
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	23

Citation: Schulz KF, Altman DG, Moher D, for the CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. BMC Medicine. 2010;8:18.
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*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.