TELEHEALTH FOR DIAGNOSIS OF HEARING LOSS

Christopher Brennan-Jones, Robert Eikelboom, DeWet Swanepoel

Telehealth offers unique opportunities for providing access to hearing healthcare services to underserved populations. The term *telehealth* refers to the utilisation of information and communication technology in healthcare [1]. Alternate terminology includes telemedicine, online health, m-health (*i.e.* mobile health) and e-health [2].

Telehealth can be employed in a synchronous, real-time manner *e.g.* an assessment via interactive videoconferencing, or in an asynchronous, store-and-forward manner *e.g.* digital picture emailed to health care provider, or a hybrid model encompassing synchronous and asynchronous aspects can be used. [3,4] The aim of telehealth is to improve healthcare access, quality of service delivery, effectiveness and efficiency of health care, and ameliorate the inequitable distribution of health professsionals globally. [5] Internet connectivity and technology provide a bridge between patients and health care providers who may otherwise be separated by distance, location, geographical and weather barriers, as well as economic barriers.

The high prevalence and burden of disease associated with hearing loss means providing audiology services to such a large number of people is a challenge.[6] Assessment of hearing and rehabilitation for hearing loss are important aspects of any audiology or ENT service. However, many people have poor access to audiologists and ENT specialists, or none at all [7]. The *World Health Organization (WHO)* has estimated that there may be as few as one audiologist per 6.5 million people in developing countries. [8] In contrast, the number of audiologists in developed countries is closer to one per 20,000 people (indicating a ratio density of audiologists in developping to developed countries of 300 to 1) [7].

Tele-audiology is a method for improving hearing health services for people in underserved areas who face long distances travelling to regional or city centres, as well as disruption to family and work when services are not available locally.[6] A number of telehealth applications in audiology and mobile health (mHealth) solutions have been developed to enable newborn hearing screening, screening audiometry services for children and adults, diagnostic hearing assessments, hearing aid fitting and rehabilitation and management for patients with hearing loss[9].

Audiometry

Audiometry is a key assessment for identification and management of hearing loss. Recent advances in audiometry have meant that real-time synchronous tele-audiometry is now possible. However, with the advent of automated audiometry and smartphone audiometry apps, there are now several options for asynchronous 'store-and-forward' tele-audiometry testing and opportunities for mHealth in addition to the traditional "live" remote audiometry. This chapter describes some of the options available, and the benefits and limitations. This is a rapidly expanding field and the list of devices here is not exhaustive, nor is it a recommendation. Individuals should weigh up the options and select the best device for their service.

mHealth: Screening audiometry (including mobile devices)

The cost of hearing screening can be prohibitive due to the expense of audiometric equipment and the requirement for trained personnel to conduct the screening. Whilst hearing screening cannot provide detailed diagnoses it can be useful to identify children and adults in need of interventions (whether medical, surgical or audiological) to enable them to participate fully in school, work and their community. There are numerous smartphone [10] and tablet [11] audiometry applications available for mobile devices (see *Figure 1* and the Mobile Phone and Cell Phone Audiometry chapter).

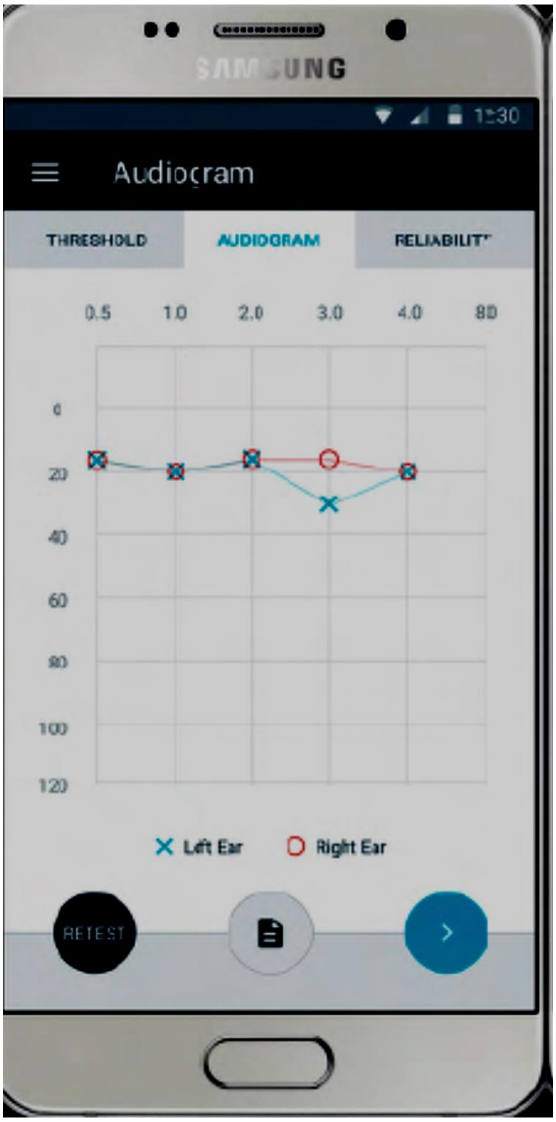

Figure 1: Applications such as HearTest enable mobile hearing assessments

The sensitivity and specificity of smartphone-based audiometry to detect hearing loss are comparable to manual screening (75% and 98.5%, respectively) [12]. The average time for smartphone hearing screening depends on the device used, but has been reported to be completed in less than a minute (mean: 54.5 sec ± 28.3 SD), comparable to conventional screening which takes just over a minute (mean: 62.2 sec ± 38.1 SD).[12] These devices therefore represent an accurate, cost-effective tool to assess hearing in children that can be incorporated into mHealth and telehealth programs.

Diagnostic tele-audiometry

Swanepoel and colleagues proved that distance was no barrier to audiometry with their intercontinental hearing assessment performed on 30 participants in Pretoria, South Africa by an audiologist located in Dallas, Texas.[13] PC-based audiometers, remote desktop and videoconferencing applications enables provision of remote tele-audiometry that can be performed with a number of different devices with accuracy comparable to face-to-face manual audiometry.[14] These remote audiometry assessments are efficient, typically taking 10 minutes to complete compared to the 8 minutes required for a comparable face-to-face assessment.[15] The barriers to implementation of remote audiometry assessments are a lack of suitable equipment to perform the test, a lack of human resource capacity to facilitate the test and a lack of connectivity to support an internet connection. However, these assessments are often well facilitated as part of an established telehealth program which already has trained facilitators or can be incorporated into well-resourced outreach clinical services to rural and remote areas where no local audiologist is available.

Test Environment

One of the key considerations for remote audiometry is the test environment. Pure-tone audiometry requires a quiet testing environment with low levels of background noise. Background noise can cause elevated thresholds, especially in the low frequencies. In some cases, there may be a suitable sound-treated room available to perform screening or diagnostic audiometry. Recommended ambient noise levels are dependent on the type of transducer, recommended by *American National Standards Institute (ANSI)* ambient noise levels and presented in *Table 1*. However, in many cases a sound-treated room is not available. In these instances devices such as the *KUDUwave*, that have been validated in non-sound-treated environments are preferred.[16] Other devices may have continual noise monitoring which will alert the tester if noise levels exceed the recommended standard.

Octave-band Frequency (Hz)	500	1000	2000	4000	8000
ANSI S3.1-1991	22	30	34	42	45

Table 1: Recommended Ambient Noise Levels for Pure-tone Audiometry based on ANSI S3.1-1991

Automated audiometry

Automated audiometry is an attractive option for diagnostic air and bone conduction audiometry in cases where audiology services are limited. These incorporate the standard Hughson-Westlake threshold seeking protocols and capture the thresholds. Several automated audiometers have been clinically validated, including the *AMTAS* [17,18] and *KUDUwave* [19] devices *(Figure 2)*. Studies have helped determine the effects of introducing background noise along with other variables on automated audiometry.[20] Recently, developments in smartphone applications have also enabled diagnostic audiometry to be performed as an examiner-conducted or a self-test using mobile devices as opposed to specialist audiometers.[21,22] The reduced cost of smartphones compared to automated audiometers may increase access to services for resource limited settings in the future.

Figure 2: KUDUwave automated audiometer

A meta-analysis of automated audiometry conducted by Mohamed et al.[23] showed comparability of automated audiometry to manual audiometry. However, there was a lack of studies examining the accuracy of bone-conduction audiometry, and studies with children. There is no consensus about the superior accuracy of one device over one another and variation in accuracy is largely dependent on the target population, the placement of transducers and the test environment.[16] However, different devices may be suitable in different clinical contexts. The *KUDUwave*, for example, uses double-attenuation with insert earphones and supra-aural ear cups, together with continuous noise-monitoring that pauses the test if ambient noise levels rise above the maximum permissible ambient noise levels (MPANLs) while testing. This allows testing in environments that are not sound-treated. In contrast, the *AMTAS* uses supra-aural headphones only. Whilst this device will not be expected to perform as accurately outside of a sound-treated booth, it may be better tolerated by more patients as it is lighter and does not use insert earphones.

Automated audiometry can facilitate diagnostic hearing assessments in resource-limited settings. However, whilst pre-defined diagnostic criteria can be applied to automated testing to provide guidance to local health workers [2], it is preferable for the results of diagnostic audiometry assessment to be available for interpretation by an audiologist or otolaryngologist to determine the next step in the clinical pathway.

Automation and service delivery

Synchronous or "live" tele-audiology assessment, where the clinician administers and interprets the hearing assessment simultaneously, may not be possible due to connectivity issues in many rural and remote areas or due to limited clinician time.[13] Alternative service delivery methods include remote diagnosis and interpretation of the results in an asynchronous telehealth model (see *Figure 3* for example of workflow).[24] Combining automated testing with the ability to asynchronously review results on a cloud-platform provide improved efficiency in terms of time and personnel resource requirements using these technologies. Whilst limited studies are available, the remote interpretation of automated audiograms appears to be an acceptable approach for diagnosing hearing loss and identifying appropriate interventions.[24] An asynchronous tele-audiology model where audiograms and other test results are forwarded for interpretation by audiologists or ENT specialists could facilitate much wider coverage of ear and hearing services, streamlining both metropolitan specialist services and reducing the need for specialists to travel to rural and remote regions to administer services.

Advances in tele-audiology assessment and rehabilitation

Remote Auditory Brainstem Response

Telehealth-enabled auditory brainstem response (ABR) testing has been possible for

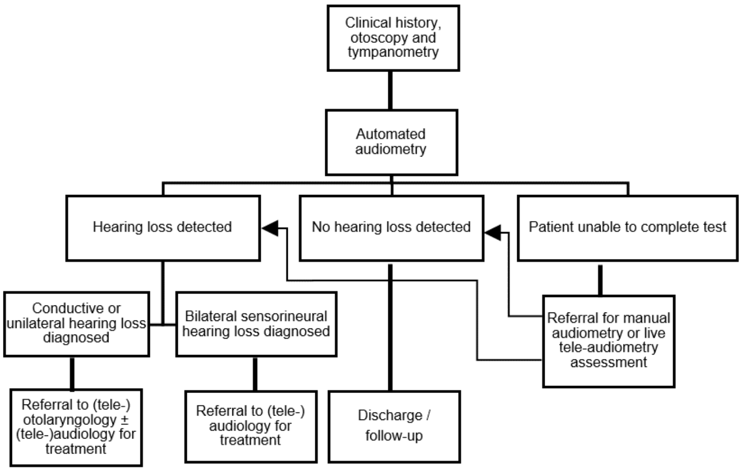

Figure 3. Flowchart of the potential patient journey through a service incurporating pre-defined diagnostic criteria applied to automated audiometry [2]

over a decade, but its implementation is still limited.[9] This application of tele-medicine in audiology is an important tool for assessing children referred through newborn hearing screening programs, who due to their distance from a tertiary audiology or ENT department, may be lost to follow-up. Many children will have failed their newborn hearing screening due to a conductive loss caused by a middle ear effusion, rather than a permanent sensorineural hearing loss, and a follow-up diagnostic ABR assessment with bone-conduction is important to establish a correct diagnosis.

In 2005, Towers et al.[25] conducted a study on fifteen subjects comparing traditional face-to-face ABR assessment and remote telehealth assessment between two sites in the United States without any clinical difference between methods. In 2013, Ramkumar et al.[26] used a satellite link to connect with a mobile van containing ABR equipment and trained health workers to prepare patients and place electrodes. A total of 24 newborns aged 8-30 days underwent ABR in face-to-face and telehealth mode. They found ABR recordings in newborn babies made by telehealth was feasible and there was no significant difference between ABR peak V latency measured by telehealth compared to face-to-face assessment.

Whilst there is a growing number of studies examining tele-ABR the implementation of this telehealth application is low. There are significant challenges to its implementation, namely the additional training required for telehealth facilitators to be competent and confident to place electrodes on newborn babies and the cost of ABR equipment required for these assessments. However, there is significant potential for future research and innovation in this field to improve the uptake and coverage of tele-ABR services.

Conclusions

Recent advances in telehealth have enabled introduction of remote tele-audiometry, automated diagnostic audiometry and hearing screening using mobile apps. These advances have significantly increased our ability to provide hearing services to rural, remote and resource limited settings. Audiology telehealth programs are being established and expanded widely. Whilst all these approaches and the service delivery models that support them continue to be developed and refined, many of these methods could be utilised by clinicians today.

A recent international survey of audiologists showed positive attitudes toward telehealth and associated technology.[27] However, less than 25% had used tele-audiology. This low number of audiologists willing to apply these new devices and techniques will continue to limit clinical implementation despite the potential benefits to patients. Audiologists and otolaryngologists are ideally suited to implement these technologies.

References

1. WHO. 2010. *Telemedicine: Opportunities and Developments in Member States*. Geneva: World Health Organization
2. Brennan-Jones CG, Eikelboom RH, Swanepoel DW. 2016. Diagnosis of hearing loss using automated audiometry in an asynchronous telehealth model: A pilot accuracy study. *J Telemedicine and Telecare,* 23:256-62
3. Krumm M. 2007. Audiology telemedicine. *Journal of Telemedicine and Telecare,* 13:224-9
4. Eikelboom RH, Swanepoel, D. 2016 Remote diagnostic hearing assessment. In: Houston TK, Rushbrook, E, ed. *Telepractice in Audiology*. San Diego: Plural Publishing
5. Wootton R. 2009. The future use of telehealth in the developing world. In: Wootton R, Patil, N.G., Scott, R.E., Ho, K, ed. *Telehealth in the Developing World*. London: Royal Society of Medicine Press, 299-308
6. Swanepoel DW, Clark JL, Koekemoer D, et al. 2010. Telehealth in audiology: The need and potential to reach underserved communities. *Int J Audiol,* 49:195-202
7. Goulios H, Patuzzi RB. 2008. Audiology education and practice from an international perspective. *Int J Audiol,* 47:647-64
8. WHO. 1998. *Hearing Aids Services - Needs and technology assessment for developing countries. Report of a WHO/CBM Workshop*. Geneva: World Health Organization
9. Swanepoel D, Hall JW, 3rd. 2010. A systematic review of telehealth applications in audiology. *Telemedicine and e-Health,* 16:181-200
10. Louw C, Swanepoel D, Eikelboom RH, Myburgh H. 2017. Smartphone-based hearing screening at primary health

care clinics. *Ear and Hearing*, 38:e93-e100

11. Yeung JC, Heley S, Beauregard Y, Champagne S, Bromwich MA. 2015. Self-administered hearing loss screening using an interactive, tablet play audiometer with ear bud headphones. *Int J Ped Otorhinolaryngol*, 79:1248-52
12. Mahomed-Asmail F, Swanepoel D, Eikelboom RH, Myburgh H, Hall J, 3rd. 2016. Clinical Validity of hearScreen Smartphone Hearing Screening for School Children. *Ear and Hearing*, 37:e11-7
13. Swanepoel D, Koekemoer D, Clark J. 2010. Intercontinental hearing assessment - a study in tele-audiology. *J Telemedicine and Telecare*, 16:248-52
14. Choi JM, Lee HB, Park CS, Oh SH, Park KS. 2007. PC-based tele-audiometry. *Telemedicine and e-Health*, 13:501-8
15. Swanepoel D, Biagio L. 2011. Validity of diagnostic computer-based air and forehead bone conduction audiometry. *J Occupational and Environmental Hygiene*, 8:210-4
16. Brennan-Jones CG, Eikelboom RH, Swanepoel DW, Friedland PL, Atlas MD. 2016. Clinical validation of automated audiometry with continuous noise-monitoring in a clinically heterogeneous population outside a sound-treated environment. *Int J Audiol*, 55: 507-13
17. Eikelboom RH, Swanepoel D, Motakef S, Upson GS. 2013. Clinical validation of the AMTAS automated audiometer. *Int J Audiol*, 52:342-9
18. Margolis RH, Glasberg BR, Creeke S, Moore BC. 2010. AMTAS: automated method for testing auditory sensitivity: validation studies. *Int J Audiol*, 49:185-94
19. Swanepoel D, Mngemane S, Molemong S, Mkwanazi H, Tutshini S. 2010. Hearing assessment-reliability, accuracy, and efficiency of automated audiometry. *Telemedicine and e-Health*, 16:557-63.
20. Storey KK, Munoz K, Nelson L, Larsen J, White K. 2014. Ambient noise impact on accuracy of automated hearing assessment. *Int J Audiol*, 53: 730-6
21. van Tonder J, Swanepoel W, Mahomed-Asmail F, Myburgh H, Eikelboom RH. 2017. Automated Smartphone Threshold Audiometry: Validity and Time Efficiency. *J Am Acad Audiol*, 28:200-8
22. Sandström J, Swanepoel D, Myburgh H, Laurent C. 2016. Smartphone threshold audiometry in underserved primary healthcare contexts. *Int J Audiol*, 55:232-8
23. Mahomed F, Swanepoel D, Eikelboom RH, Soer M. 2013. Validity of automated threshold audiometry: a systematic review and meta-analysis. *Ear and Hearing*, 34:745-52
24. Brennan-Jones CG, Eikelboom RH, Bennett RJ, Tao KFM, Swanepoel DW. 2018. Asynchronous interpretation of manual and automated audiometry: Agreement and reliability. *J Telemedicine and Telecare*, 24(1):37-43
25. Towers AD PJ, Froelich TM, Krumm M. 2005. The reliability of click-evoked and frequency-specific auditory brainstem response testing using telehealth technology. *Seminars in Hearing*, 26:26-34
26. Ramkumar V, Hall JW, Nagarajan R, Shankarnarayan VC, Kumaravelu S. 2013. Tele-ABR using a satellite connection in a mobile van for newborn hearing testing. *J Telemedicine and Telecare*, 19:233-7
27. Eikelboom RH, Swanepoel D. 2016. International survey of audiologists' attitudes toward telehealth. *Am J Audiol*, 25:295-8

Author

Christopher G. Brennan-Jones
Telethon Kids Institute, The University of Western Australia
Department of Audiology
Perth Children's Hospital, Nedlands
Western Australia
chris.brennan-jones@telethonkids.org.au

Robert H. Eikelboom
Ear Science Institute Australia, Subiaco, Western Australia
Ear Sciences Centre, The University of Western Australia
Department Speech-Language Pathology and Audiology, University of Pretoria, South Africa
rob.eikelboom@earscience.org.au

Author and Editor

De Wet Swanepoel PhD
Professor
Department of Communication Pathology
University of Pretoria
Pretoria, South Africa
dewet.swanepoel@up.ac.za

Editors

Claude Laurent MD, PhD
Professor in ENT
ENT Unit
Department of Clinical Science
University of Umeå
Umeå, Sweden
claude.laurent@ent.umu.se

Johan Fagan MBChB, FCS(ORL), MMed
Professor and Chairman
Division of Otolaryngology
University of Cape Town
Cape Town, South Africa
johannes.fagan@uct.ac.za

OPEN ACCESS GUIDE TO AUDIOLOGY & HEARING AIDS FOR OTOLARYNGOLOGISTS
www.entdev.uct.ac.za