OPEN ACCESS GUIDE TO AUDIOLOGY AND HEARING AIDS FOR OTOLARYNGOLOGISTS

MOBILE PHONE AUDIOMETRY
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Over 60% of the global population uses mobile phones *(O'Dea 2020)*, with penetration rates steadily increasing as mobile technology becomes more affordable and accessible *(Cvrkel 2018)*. The widespread availability of mobile phones has led to the development of mobile health (mHealth) applications designed to improve access to and uptake of healthcare services *(Valenzuela et al. 2018; World Health Organization 2021; Rono et al. 2021)*. mHealth applications have been explored in various healthcare services, including hearing health.

Recent estimates by the World Health Organization (2021) indicate that more than 1.5 billion people globally, or one in four individuals, suffer from some degree of hearing loss. These prevalence rates are expected to increase to a staggering 2.5 billion persons by 2050 *(World Health Organization 2020)*. The high prevalence of hearing loss has made it a significant global healthcare burden due to its long-term consequences on affected individuals, communities, and societies. Furthermore, the vast majority of individuals with hearing loss do not have access to hearing healthcare services *(World Health Organization 2021; Mulwafu et al. 2017; World Health Organization 2013)*.

Mobile applications for hearing healthcare have gained significant interest over the past few years. A recent scoping review highlighted a dramatic increase in research publications on mHealth applications used for hearing healthcare, growing from one publication per year from 2006 to 2012 to seven in 2013 and then rising to 31 in 2020 *(Frisby et al., 2021)*. In total, 146 articles exploring mHealth applications were identified. The applications covered a diverse range of technologies developed and implemented across different ages, settings, and countries, spanning the entire hearing healthcare continuum. They ranged from applications for health promotion (2%), screening (39%), diagnosis (35%), and treatment (10%) to support (14%) *(Frisby et al., 2021)*.

The absence of hearing healthcare for the vast majority of people with hearing loss raises a moral obligation to pursue ways of providing underserved communities with audiological services. mHealth applications hold the promise of bridging this gap by delivering services through an expanding reach of global connectivity.

This chapter reviews applications available for hearing healthcare, spanning the entire hearing healthcare continuum, with a focus on screening and diagnosis applications. A summarized description of the currently available applications is provided, detailing the hardware and software utilized, the accuracy, advantages, and limitations, as well as their access and availability.

Health Promotion

The mHealth applications currently used in the realm of health promotion include monitoring music listening habits *(Paping et al. 2021; Paping et al. 2022)* and sound-level monitoring *(Knoetze et al. 2021)*. Such applications can evaluate users' listening habits and encourage safe listening habits.

Screening

uHear™

Unitron developed uHear™ - a mobile application that uses an iOS Apple-operated device. It was developed to facilitate early

detection of hearing issues. The app includes a questionnaire about common listening situations to provide a more holistic view of the user's hearing health. uHear™ also provides users with tips and resources on hearing loss prevention.

Figure 1. Initial screen view of uHear™

Hardware and software

uHear™ is suitable for the following Apple mobile devices: iPhone, iPod Touch, and iPad. The application requires Apple endorsed insert headphones (earbuds), which are provided with the device. Any compatible headphones with built-in background noise eliminators can also be used.

Accuracy and evidence

Studies on uHear™ have indicated that it is sensitive only to high-frequency hearing loss in a quiet room (p<0.05) with moderate sensitivity for detecting low-frequency hearing loss. Research has found that the uHear™ is most accurate when coupled to standard EarPod earbud earphones, which

are provided with the mobile device. It has been recommended that uHear™ should be used to screen those at risk of developing or having high-frequency sensorineural hearing loss, such as:

- Patients on ototoxic drugs, e.g., MDR-TB (Multi-Drug Resistant Tuberculosis) therapy, chemotherapy and HAART (Highly Active Anti-Retroviral) therapy.
- Patients with presbyacusis.
- Children to be screened in a classroom if no other audiology services are available.

Advantages and limitations

uHear™ has the following advantages:

- It can be self-administered as it is easy and simple to use.
- It takes only 6 minutes to administer the full test.
- Information is recorded on the mobile device and displayed immediately for assessment.
- It can be used on multiple Apple devices (iPhone, iPad, or iPod Touch)
- It is free of charge.
- The app assists in mapping out local hearing professionals based on the user's location.
- It is available in English, French, Spanish, and German.

Although it has many advantages, the following limitations exist:

- It is inaccurate for low frequencies.
- It must be performed in a quiet or soundproof room.
- It does not distinguish between conductive and sensorineural hearing loss.
- As it uses earbuds, it may not be suitable for patients with otorrhoea.

- Limited languages are available. Users who are not fluent in the available languages will need a translator to explain the steps of the test.

uHear™ can be downloaded from iTunes at:
http://itunes.apple.com/us/app/uhear/id309811822?mt=8

hearScreen™

hearScreen™ was developed for hearing screening with automated test sequences employing real-time monitoring of environmental noise and data management facilities. It was developed at the University of Pretoria and is a mobile pure tone screening application that utilizes an inexpensive smartphone (Android OS) and headphone hearScreen™. It is commercially available through the hearX Group and is currently in use across 39 countries.

Hardware and software

The hearScreen™ application uses an Android SDK (software development kit) version 21.0.1 via the Eclipse IDE (integrated development environment) version 4.2.1 is developed for Android phones. The hearScreen™ software can link with a calibrated headphone for accurate hearing testing and screening. The screening version uses a force-choice paradigm that requires the test operator to present the test signal. Once the patient indicates the tone has been heard, the tester is required to indicate whether the patient has responded to the sound in a YES/NO response provided on the application *(Figure 2)*. Based on the response, the intensity and frequency change automatically according to the programmed test protocol. A threshold version (hearTest) uses automated testing with a response button on the phone.

Figure 2. User-friendly force-choice paradigm with noise monitoring function

Accuracy and evidence

hearScreen™ is calibrated according to current standards (ANSI/ASA S3.6-2010; ISO 389-1,1998) and has shown that valid monitoring of environmental noise can be achieved according to maximum permissible ambient noise levels (MPANLs).

No significant difference in screening outcomes using smartphone hearScreen™ and conventional audiometry was evident when tested on school-aged children *(Mahomed-Asmail et al., 2016)*. In addition, hear-Screen™ has been validated in a primary healthcare setting *(Louw et al. 2017)* and can be administered by a lay person *(Yousuf Hussein et al. 2018; Van Wyk, Mahomed-Asmail, and Swanepoel 2019)*.

Advantages and limitations

hearScreen™ has the following advantages:
- It is cost-effective.
- Clinically validated for screening both adults and children.

- It has a secure online database enabling digital data management.
- Environmental noise monitoring warns the user of noise concerns that could impact the screening.
- The screening is very quick and can be completed in under three minutes.
- It has adjustable screening protocols that can be customized based on the populations being screened.
- Minimally trained test facilitators can use it, and it has been used by community healthcare workers *(Van Wyk, Mahomed-Asmail, and Swanepoel 2019; Yousuf Hussein et al. 2018)*

The hearScreen™ has the following limitations:
- It is only compatible with Android OS software and requires calibrated headphones; however, this allows for validated and accurate results and monitoring of MPANLs while testing.
- The purchase price starts at $1050.
- Calibration and software license fees require yearly subscriptions, which increases the cost.
- It is only available in English, Spanish, and French.

hearScreen™ is available for purchase directly through the hearX Group. For more information, visit:
https://www.hearxgroup.com/hearscreen/

Diagnosis

hearTest™

The hearTest™ is the diagnostic extension of the hearScreen™ and was also developed by the University of Pretoria. It is available commercially through the hearX Group.

Hardware and software

The hearTest™ is a certified (IEC 60645-1) pure tone audiometer on a tablet or smartphone with calibrated headphones (ANSI/ASA S3.6-2010; ISO 389-1,1998). It can conduct pure tone testing from 125 – 8000 Hz and extended high-frequency testing up to 16 000 Hz. Similar to the hearScreen™, a force response is required by the user, and the protocol chosen will determine the intensity and frequency change automatically based on the user's response.

Accuracy and evidence

No significant differences between the hearTest™ and conventional audiometry were evident when testing the adult and children populations *(Van Tonder et al. 2017)*. It has also been used successfully by lay community healthcare workers to conduct hearing tests *(Bright et al. 2019; Van Wyk, Mahomed-Asmail, and Swanepoel 2019)*.

Advantages and limitations

The hearTest™ makes use of the same technology as the hearScreen™ and, therefore, has the same advantages.

Additional advantages include:
- Extended high-frequency testing.
- Pre-test conditioning to help faciliate user understanding of the test protocol.
- Narrowband masking.
- Downloadable hearing reports.
- Audiogram with pure tone average and degree of loss classification *(Figure 3)*.

The hearTest™ has the following additional limitations:
- It is not able to perform bone conduction testing and can, therefore, not distinguish between sensorineural and conductive hearing loss.
- It is only available in English, Spanish, and French.

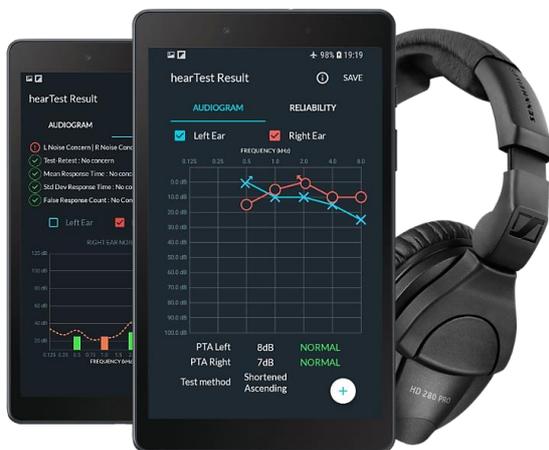- Calibration and software license fees require yearly subscriptions, which increases the cost.

Figure 3. Audiogram and hearing loss classification.

hearTest™ is available for purchase directly through the hearX Group. For more information, visit:
https://www.hearxgroup.com/heartest/

SHOEBOX® PureTest

The SHOEBOX® PureTest is an automated audiometer developed for testing outside a soundproof booth. It is being used in over 60 countries.

Hardware and software

The SHOEBOX® PureTest is tablet-based and coupled to calibrated headphones. It is compatible with iPads. It offers both automated and manual testing modes that enable use by both professionals and lay healthcare workers. This test uses the Modified Hughson-Westlake method to determine pure tone air conduction thresholds. The test is presented as a game where users must slide a blue disc to a green icon if they hear a sound or to a red icon if they do not hear a sound *(Figure 4).*
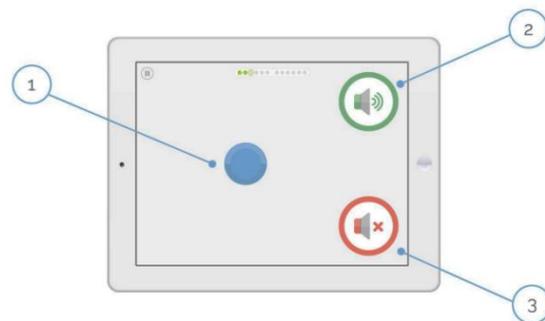

Figure 4: Testing screen with 1 indicating the disc that users slide to indicate if a sound was heard, 2 indicating the sound was heard, and 3 indicating the sound was not heard.

Accuracy and evidence

The SHOEBOX® has demonstrated a strong correlation with conventional audiometry when testing normal hearing and persons with hearing loss *(Adkins et al. 2024).* It has successfully been used to test adults and children in clinical and community-based settings *(Saliba et al. 2017; Vijaya-singam et al. 2020; Larsen-Reindorf et al. 2019).* However, it has been suggested that tablet-based audiometry may not be suitable for children under the age of six years as they might have difficulty understanding the test instructions *(Pereira et al. 2018).*

Advantages and limitations

Advantages are as follows:
- Extended high-frequency testing up to 16 000 Hz.
- Bone conduction testing.
- Environmental noise monitoring.
- Monitoring of unreliable patient responses.
- Digital data storage
- Includes a questionnaire to obtain a basic case history.

Limitations are:
- Add-on software requires yearly subscriptions, which increases the cost.

- Masked bone-conduction testing is not automated.
- Recalibration required yearly and is not offered outside the USA and Canada, and thus, devices would need to be sent for calibration.

The SHOEBOX® is available commercially through SHOEBOX Ltd. For more information, please visit: https://www.shoebox.md/

Treatment and Support

mHealth technologies used in the realm of treatment and support have been mainly focused on the adult population *(Frisby et al. 2021)*. mHealth for treatment includes applications to control hearing device gain, including the Hearing Aid Learning and Inference Controller (HALIC), and to improve speech recognition, including Smart-Hear and Petralex *(Frisby et al. 2021)*. In comparison, technologies aimed at supporting persons with hearing loss post-treatment include applications geared to educate, such as Train2hear and m2Hear, ecological momentary assessment, such as olMEGA, company-specific applications to control device settings, such as the Signia app and myPhonak app, and applications to assist with translation from text/sign to speech, such as Apollo SignSound and MobileASL *(Frisby et al. 2021)*.

Community-based applications

A recent scoping review on the applications of mHealth in hearing healthcare revealed the potential of mHealth applications being facilitated by lay non-professionals *(Frisby et al. 2021)*. It highlighted the use of mHealth in conjunction with task-shifting as an enabler to improve service delivery in low- and middle-income settings.

The following features are recommended when selecting mHealth technologies for community-based service delivery *(Frisby 2023)*:

- Low cost.
- User friendly design.
- Automated protocols.
- Cloudbased storage.
- Quality control monitoring.
- High quality, low cost, autofit hearing aids.

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