OPEN ACCESS GUIDE TO AUDIOLOGY AND HEARING AIDS FOR OTOLARYNGOLOGISTS

MOBILE PHONE AUDIOMETRY   **Faheema Mahomed-Asmail, De Wet Swanepoel**

Recent estimates by the *World Health Organization* (2013) indicate that 360 million persons, comprising 5.3% of the global population, suffer from permanent disabling hearing loss. The high prevalence of hearing loss has resulted in hearing loss becoming a significant global healthcare burden due its long-term consequences on affected individuals, communities and societies. Furthermore, the vast majority of individuals affected by a hearing loss may not have access to early detection services *(WHO, 2010, 2013).* However, with the widespread usage of mobile phones and penetration of cellular network reception globally, even in underserved regions such as sub-Saharan Africa *(Kelly & Minges, 2012),* the use of mobile health (mHealth) has emerged as a possible means of hearing assessment.

The trademark catch phrase, "There's an app for that" now has gained a place in hearing health care. Utilization of tele-health approaches for hearing assessment has steadily gained acceptance in recent years *(Swanepoel & Hall, 2010; Swanepoel et al, 2010).* A recent study by *Paglialongaa, Tognola and Pinciroli* (2015) indicated that, in hearing health care, there is a distribution of available apps in five major categories: i) education & information (23%), ii) hearing testing (18%), iii) rehabilitation (24%), iv) sound enhancement (28%), and v) assistive tools (7%) *(Paglialongaa, Tognola & Pinciroli, 2015).*

Mobile applications for screening have gained much interest of the past few years. However, as a field in its infancy much work remains to be done to develop and validate the technology available as a means of delivering services. The absence of hearing healthcare for the vast majority of people with hearing loss globally raises a moral obligation to pursue ways of penetrating underserved communities with audiological services. Tele-audiology holds the promise of bridging this gap by delivering services through an expanding reach of global connectivity**.**

This chapter reviews applications available for hearing screening that have published validation data. A summarized description of the current available applications is provided below according to the hardware and software utilized, the accuracy, advantages and limitations, as well as from where they can be downloaded.

uHear™

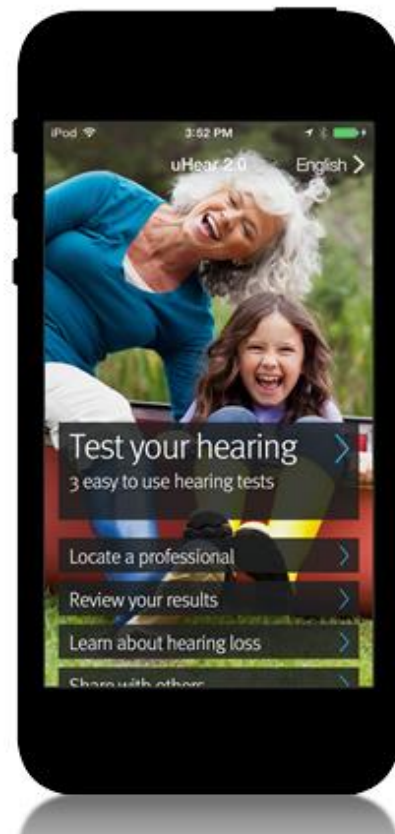Unitron developed uHear™ - a mobile application which uses a mobile iOS Apple operated device.

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 use of Apple-endorsed insert headphones (ear-buds) which are provided with the device. Any compatible headphones with built-in background noise eliminators can also be used. The application can be download for free from the *iTunes website*, or from *Apple App Store*.

Accuracy and evidence

Studies on uHear™ have indicated that it is sensitive only for high frequency hearing loss in a quiet room (p<0.05) with moderate sensitivity for detecting low frequency hearing loss. It has been recommended that uHear™ should be used to screen those at risk of developing or having a 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)

Although it has many advantages the following limitations exist

- It is inaccurate for low frequencies
- It must be performed in a quiet room or a soundproof room
- It does not distinguish between conductive and sensorineural hearing loss
- Because it uses ear buds it may not be suited to patients with otorrhoea
- Instructions are in English so non-English speakers need a translator to explain the steps of the test

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

EarTrumpet

EarTrumpet (Praxis Biosciences, Irvine, California) is a self-administered Apple iOS smartphone application downloaded from iTunes and can be installed on an iPhone and IPod Touch. It was originally created by Dr. Allen Foulad with the support of the Otolaryngology Department at the University of California, Irvine, USA.

Hardware and software

EarTrumpet is an iOS-based hearing application suite that provides a user-administered hearing test and a customizable personal sound amplification tool. It is compatible with the iPhone, iPod Touch (2nd generation and later), and the iPad. A headset that has both an earpiece and a microphone is recommended. An Apple headset is required to provide the most accurate hearing test results. EarTrumpet also allows selection of a headphone transducer, with the application pre-calibrated for the accompanying Apple in-ear headphones *(Foulad et al, 2013)*.

The hearing suite consists of two modules: a hearing enhancer (*i.e.* sound amplifier) and hearing test. The self-administered hearing test module allows for three test types and has an option to select a headphone transducer *(Foulad et al, 2013)*. Test types include "Basic" (*i.e.* thresholds obtained at 500, 1000, 4000, 8000 Hz), "Comprehensive" (*i.e.* thresholds obtained at audiometric octave frequencies between 125 Hz and 8000 Hz), and "Custom" (*i.e.* thresholds to be selected for testing).

Before the test, the tester needs to couple the headphone transducer to the respective ear, then calibrate the volume level of the headphone's output to a predetermined level as depicted on the iPad screen by means of a sliding bar and a green check mark. Then the tester initiates the hearing test by pressing a button box labeled "start" which then defaults to the application running a 5-second analysis of the levels in the environment. Once the environment is considered satisfactory for testing, the application screen defaults to a new screen that displays a button box instructing the tester to press the button when they hear a series of three pulsed pure-tones. Thresholds at each frequency are determined in 5dB intervals and after the third ascending reversal *(Foulad et al, 2013)*.

Accuracy and evidence

The EarTrumpet and Apple iOS-based devices provide a platform for automated air conduction audiometry without requiring extra equipment and yield hearing test results that approach those of conventional audiometry *(Foulad et al, 2013)*. However it is indicated that EarTrumpet is intended for novelty purposes only and is not meant to replace clinical hearing tests. The information obtained from this application should not be used in the diagnosis of any medical condition, including but not limited to hearing loss.

Advantages and limitations

It has been reported that the EarTrumpet screening tool yields an increase in self-efficacy in individuals compared to individuals who experienced a traditional hearing screening model. This increase in self-efficacy improved the likelihood of impaired listeners seeking the services and technologies offered by hearing healthcare providers *(Amlani, 2014)*. Furthermore, it was found that EarTrumpet could be used as part of a hearing wellness program which would make healthcare available even with the limited supply of professionals entering the profession *(Swanepoel et al., 2010; Windmill & Freeman, 2013)*. A limitation of this device is that it cannot be used on Android applications and that the headphones cannot be calibrated according to current ISO standards.

EarTrumpet can be downloaded from iTunes at
https://itunes.apple.com/us/app/eartrumpet/id385494796

hearScreen™

hearScreen™ was developed for hearing screening with automated test sequences employing real-time monitoring of environmental noise and data management facilities. It is being 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 currently in a beta launch phase, and because the product has not been officially launched, its commercial availability is currently limited.

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 to allow for accurate hearing testing and screening. The screening version makes use of 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. There is also a threshold version (hearTest) that uses automated testing with a response button on the phone.
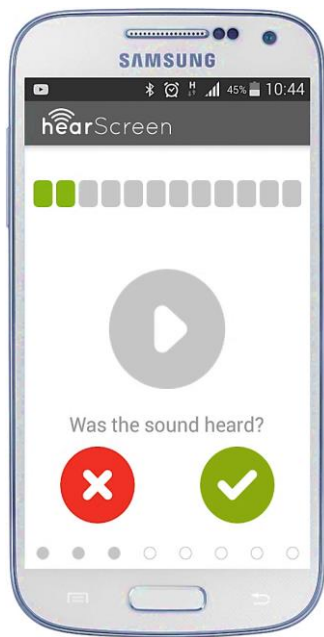

Figure 2. User-friendly force-choice paradigm with noise monitoring function

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 for screening outcomes using smartphone hearScreen™ and conventional audiometry was evident when tested on school-aged children *(Mahomed-Asmail et al., 2016)*. In addition, hearScreen™ has been validated in a primary health care setting *(Louw et al., in press)* and can be administered by a lay person *(Yousuf Hussein et al., in press)*.

Advantages and limitations

hearScreen™ is a unique, patented solution for school-based hearing screening, which utilizes a commercial smartphone and headphones with a software module allowing for calibration of signals according to current standards (SANS 10154-1:2004). It makes use of recommended screening protocols preprogrammed for consistent, reliable and user-friendly screening and has integrated noise monitoring which provides real-time feedback on compliance of environmental noise to prescribed Maximum Permissible Ambient Noise Levels (MPANLs).

It is intended for use by minimally trained test facilitators and has been used by community health workers *(Yousuf Hussein et al., in press)*. It also has an electronic data capturing feature, hearData, which allows for data sharing with cellular or Wi-Fi networks, ensuring data management which permits monitoring outcomes and efficacy of screening programs. A limitation of the screening application is that 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.

hearScreen™ is currently in a beta launch phase. For more information visit https://www.hearscreen.com

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hearZA™

hearZA™, South Africa's National Hearing Test, is a self-test which serves as a speech-in-noise screening tool that was recently developed by a group of researchers at the University of Pretoria. Currently it is only available for download in South Africa and offers 3 free hearing screenings. The screening results are provided immediately and are reported to the user on the smartphone.

Hardware and software

hearZA™, is a smartphone application that was designed using Android studio (version 0.6.0, created by Google) written in Java (Java development kit version 8.0, created by Oracle). The smartphone application was designed to be used on any Android smartphone with any headphone or earphone and results can be obtained within a few minutes. A list of triplets is stored in the Android application containing 120 unique digit triplets *(Smits, Goverts & Festern, 2013).* Sound-files of the digits 0 to 9 were stored separately in OGG format on the application. When the test starts a digit triplet is randomly selected from the list of 120 different digit triplets. After the triplet has been identified, the program assembles the triplet by selecting and presenting the appropriate digits with silent intervals of 500ms in between. The test operates with a fixed noise level and a varying speech level when triplets with negative SNRs are presented. When triplets with positive SNRs are presented the speech level becomes fixed and the noise level varies. This procedure ensures a constant overall level of the stimulus (i.e., triplet and noise).

When the application is opened a tutorial screen appears to instruct the subject how to use the application. The next screen instructs the user to enter their biographic details and then moves on to an instruction screen which prompts the user to put on the smartphone headset and listen to digits being repeated. The user uses a scrollbar to adjust the intensity of the digits to a comfortable listening intensity. A "Start Test" button allows the subject to begin testing. When the test starts digits are presented diotically. A popup keypad appears after the subject listened to the digits to allow the subject to enter the response.

Accuracy and evidence

HearZa has been successfully developed and validated as a self-test on a smartphone via a smartphone application using any available headphone type *(Potgieter et al., 2016).* The mean SRT and speech recognition functions for the smartphone-based hearing test corresponds well to previous developed telephone-based digits-in-noise tests (Smits et al, 2004; Jansen et al, 2010). The application can be used on any Android smartphone and with any headphone type.

Advantages and limitations

The South African smartphone digits-in-noise hearing test could increase access to hearing services if made available via online App-stores. The issue of English additional language speakers' performance needs to be investigated in the context of the multilingualism *(Potgieter et al., 2016).* Furthermore, currently hearZa is only available for download in South Africa and provides 3 free hearing screenings.

More information on hearZa:
http://www.hearza.co.za

Current recommended clinical applications of mobile phone audiometry

Based on ***current*** data about reliability of the above mobile phone audiometry apps,

the authors recommend the following clinical applications:

Settings where no formal audiology is available

- Screening
- Ototoxicity monitoring (calibrated headphones)
- Occupational monitoring (calibrated headphones)
- Evaluation for hearing aid fitting

Settings where there is limited access to formal audiology

- Screening
- Ototoxicity monitoring (calibrated headphones)
- Occupational monitoring (calibrated headphones)

Settings where there is full access to formal audiology

- Screening
- Onsite monitoring programmes

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