The goal of technological advances

in health care has always been to improve delivery and outcomes for our patients. There is no denying that technology has changed the study and profession of audiology. While research takes years to make discoveries, it often takes exponentially longer for the findings to become a clinical standard of care. With computers, software developers can meet the demands of clinicians and consumers more quickly than ever, but there is often a long process for the approval of changes to medical devices. Is there evidence-based research to justify new technologies in practice, or are we relying on our own judgment when using new technology and when recommending it to our patients?

In 1995, the World Health Organization (WHO) recognized hearing loss as a major obstacle to communication and development and, in 2013, the organization estimated that 360 million people had debilitating hearing loss (WHO, 2013). In order to provide adequate hearing health care to the increasing number of patients with hearing loss and to prevent hearing loss from occurring at a progressive rate, new strategies need to be implemented (Clark and Swanepoel, 2014). The technological boom of the 2000s has included the hearing sector.

One rapidly expanding sector of technology includes mobile devices, specifically smartphones. As of February 2014, more than 163 million Americans owned smartphones (comScore, 2014). Theoretically, with the simple download of applications, or “apps,” audiologists and our patients now have the ability to transform the handheld device into an audiometer, sound-level meter, noise generator, aural re/habilitation program, personal amplifier, sign-language book, electronic medical record, or a slew of other tools that an audiologist might use or recommend within our scope of practice.

At a fraction of the cost of commercial equipment, the use of mobile apps has quickly gained popularity. Authors have been discussing apps for hearing health care in online forums, periodicals, and trade magazines since 2010 (Fligor, 2010; Healthy Hearing, 2011; Department of Defense Hearing Center of Excellence, 2013; Galster, 2013; Weber, 2013). Questions of accuracy were often raised, but until 2012, there was no literature published on the validity of these seemingly valuable tools. In 2012, the first peer-reviewed article on a hearing health-care smartphone app (for hearing testing) was published (Szudek et al, 2012).

With the disclaimer that this information will be out of date by the time it reaches press, let’s discuss what we now know.

The Basics

Platforms

iOS (Apple) and Android (Google) are the two dominant operating systems in the smartphone industry. Blackberry and Windows Phone are also mobile operating systems, but these two are no longer as widely used, and there was no research on audiology apps for either at the time of the writing of this article. App developers are independent of device manufacturers and must create different apps for each platform. Apps for Android are downloaded in Google Play; iOS apps are downloaded through the Apple App Store; and Windows apps are available in the Windows Store. The version of the operating system dictates which apps are able to run, so developers are constantly updating their apps to be compatible with the latest operating system. If you are having difficulty getting an app to run, try updating your operating system.
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**Devices**
Apple devices are the iPhone, iPad, and iPod. Android devices include multiple models from a variety of manufacturers including Samsung, HTC, Google, and Motorola. Windows is associated with the Nokia brand of phone.

**Apps**
To purchase apps, one must have an account with the appropriate store that corresponds with a specific type of mobile device. Searches in an app store can be overwhelming when looking for hearing loss, sound-level meter, or audiology.

In 2012, when the author was researching the accuracy of sound-level meter apps for the iPhone, there were more than 50 apps available. In 2014, when this article was written, an App Store search revealed 88 hits for hearing test, 87 hits for sound-level meter, 68 hits for hearing loss, 44 hits for audiology, and a whopping 586 results for hearing. There is overlap in these searches, but the sheer volume justifies discussion of the ever-popular question, “Which app is the best?”

**Literature Review**
An extensive search of PubMed, Google, and reference pages of previously published articles revealed a limited number of sources available on the subjects of hearing health care and mobile devices. The majority of material on the subject is from periodicals, blogs, or conference proceedings. However, peer-reviewed literature involving hearing health-care apps has been published on the validity of automated hearing-testing apps for consumers to use to evaluate their own hearing and on apps that measure sound levels.

**Audiometer Apps**
A wide variety of app-based tools has been developed in the last decade with the intention of automating hearing tests. These apps are designed to conduct hearing screenings for children, evaluate hearing air conduction thresholds for pure tones, and conduct speech audiometry and speech-in-noise tests. Some of these app-based hearing tests can be calibrated to monitor the output of the headphone. This process is not standardized, varies depending on the type of headphone or earbuds used, and involves the use of a coupler and the estimation of reference equivalent threshold sound pressure levels (RETSPLs) for the particular headphone.

Apps with peer-reviewed research for the iOS platform include uHear and EarTrumpet (Szudek et al, 2012; Kam et al, 2012; Foulad et al, 2013; Handzel et al, 2013; Na et al, 2014) and, for Android, are hearScreen and Smart Hearing (Swanepoel et al, 2014; Wenjin et al, 2014). Additionally, research has been published on apps not publicly available from the Apple and Google stores (Kam et al, 2012; Na et al, 2014). Reports of using tablets as automated hearing screeners have also been reported (Wenjin et al, 2014). A comprehensive review of data published regarding smartphone hearing tests is included in the introduction to a recent study looking at hearing screening with smartphones (Swanepoel et al, 2014).

Whether testing hearing with a smartphone or traditional audiometer, the presence of background noise in the testing environment can cause thresholds to be elevated, suggesting a hearing loss where one may not truly exist. This leads to the over-referral of patients and inefficiency in health care. With this in mind, Swanepoel et al (2014) published data on the hearScreen Android app for screening kindergarteners and first graders while monitoring environmental noise using the smartphone’s on-board microphone. This study suggested that the automated hearing screening app agreed with a traditional hearing screening at 25 dB HL 97.8 percent of the time. The study also suggested the automated screening app was faster, although not significantly so (six seconds). The results were similar to previous reports of high sensitivity and specificity for the iOS app uHear when it was calibrated prior to testing (Szudek et al, 2012; Handzel et al, 2013). However, results were not consistent with data reported by Khoza-Shangase and Kassner (2013), who found significantly elevated thresholds when using uHear compared to conventional audiometry.

Taking a new approach to the influence of background noise, Na et al (2014) published data on an unreleased app...
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developed for the Android platform that applies a correction factor to estimate hearing thresholds based on the amount of background noise. Their results suggest significant improvement in group mean threshold accuracy for 1000 and 2000 Hz with the correction factor applied. However, the app did not significantly improve accuracy for 500 and 4000 Hz, and the authors did not include subjects with hearing loss in their data analysis. Additionally, when the app was evaluated in real-world environments, corrected thresholds were overestimated when compared to sound-booth thresholds, sometimes by more than 15 dB. It was suggested that, in quiet environments, when compared to Internet- and PC-based automated hearing tests, the use of a mobile device or smartphone may yield better results because of the lack of fan noise produced by a PC or laptop (Masalski et al, 2014).

**Sound-Level Meter (SLM) Apps**

Initial forays into scientific research of smartphone-based sound measurement were written with the purpose of mapping urban noise environments (D’Hondt et al, 2012). Four articles each review a single sound-level measurement app (Kanjo, 2010; Maisonneuve and Stevens, 2010; Rana et al, 2010; Leao et al, 2014). Each of these apps was designed to engage users and share acoustic data from the user’s environment with the app developer in hopes of monitoring areas suspected of having high noise pollution. The NoiseTube app was studied in Antwerp using Nokia phones (Kanjo, 2010). The Ear-Phone used partially recorded sound measurements to predict sound levels for the given environment using Nokia phones (Rana et al, 2010). And, more recently, 2Loud? was used on iPhones to measure nighttime noise in homes near the highway in Boroondara, Australia (Leao et al, 2014). Background noise (e.g., people talking near the microphone, wind noise while riding a bicycle) was reported to cause difficulties with data analysis in all four studies.

In 2014, two groups in the United States published peer-reviewed data reporting accuracy of smartphone apps when compared to a Type I sound-level meter (Kardous and Shaw, 2014; Nast et al, 2014). Both studies were conducted in laboratory settings and evaluated noise up to 95 dB HL. Kardous and Shaw tested 10 apps; Nast et al tested 5 apps. Common apps between the two studies were Advanced Decibel, SoundMeter, SPL Pro, and SPLnFFT; however, the version of these apps differed between the studies. The sound measured also differed between the two studies (broadband pink noise of 20 Hz to 20 kHz versus narrow-band noise at octave frequencies from 250 Hz to 8 kHz). Both research groups did not use calibration features available within the apps.

Results of the Kardous and Shaw study reported app measurements within ±2 dB of the reference sound-level meter (SLM) when using A-weighting for three apps: Noise Hunter, NoiSee, and SoundMeter, and when using an unweighted measurement for three apps: NoiSee, SoundMeter, and SPLnFFT. Nast et al reported only the SoundMeter app from Faber Acoustical was within 5 dB of their reference sound-level meter for both A- and C-weightings for all frequencies and intensities tested. Also of interest was the discussion of nonlinearity of measurements for high-intensity noise in three of the five apps. These apps did not show appropriate increases in measurements when the intensity of the noise was increased.

The conclusions of the authors were quite different: Kardous and Shaw concluded “that certain sound measurement apps for Apple smartphones and tablets may be considered accurate and reliable to be used to assess occupational noise exposures,” while Nast et al wrote, “Due to the inaccuracies of the apps as measured in this study, we do not recommend using even the best performing app, SoundMeter, without calibration and without complete understanding of the dynamic range over which the device can provide accurate measurements.”

As part of a recent study on the effectiveness of apps for measuring background noise during hearing screenings, Swanepol et al (2014) compared sound levels measured by the app hearScreen with those measured from a Type I sound-level meter. The results indicated the smartphone was able to measure within <1.5 dB of the reference SLM for 30-75 dB SPL at 1k, 2k, and 4k Hz with the exception of a <3 dB variation when measuring a 30 dB SPL noise at 4k Hz. Factors to consider when using or recommending mobile technology:

- Smartphone components are continually improving. However, these improvements may be optimized for phone reception rather than measuring environmental noise levels.
- The condition of your smartphone’s microphones may alter its ability to measure sound levels accurately. Along the same lines, using a case to protect your smartphone may also change the incoming signal.
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- Not all sound measurement apps are equal, and some are absolutely more accurate than others. Some apps perform better in soft environments, and some perform better in loud ones.

- The accuracy of app-based automated hearing tests is based on the ambient noise in the test environment, calibration of headphones prior to administration of the test, and amount of conditioning to testing prior to administration of the test.

- When conducting an automated hearing test on a mobile device, the most important factor for accuracy is background noise. Smartphones have an incorporated microphone that can be used for this purpose. However, ensuring the accuracy of your SLM app is crucial.

- The headphones used for automated testing matter. Both frequency response and sound attenuation of the headphones will play a part in the accuracy of the hearing test. The 3.5 cm headphone jack on smartphones has not provided any complications.

- With the exception of speech-in-noise tests, apps measuring hearing require calibration. Knowing the RETSPL of your headphones will allow you to calibrate accurately.

**Conclusion**

With the ever-changing landscape of mobile technology, how do we keep the research up to date? The phone manufacturers are constantly changing models, microphones, and digital signal-processing strategies to which app developers must conform. One of the apps tested by the author in 2012 has undergone 11 updates since that time! The Centers for Disease Control and Prevention now has a National Institute for Occupational Safety and Health (NIOSH) blog for the discussion of smartphone app accuracy (CDC, 2014). There are now numerous publications each year evaluating automated hearing tests on mobile devices. The bottom line is that we must be more informed than ever in this era of self-diagnosis and treatment.

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**References**


