

# Technology for Hearing Loss - as We Know It, and as We Dream It

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## ABSTRACT

Purpose: Worldwide demand for accessible hearing health technology continues to increase while the numbers of hearing health care specialists are grossly inadequate to meet this demand. Proliferation of innovative technology and the advent of greater access to global connectivity, are providing an opportunity to identify and harness new resources that may change current audiological service delivery methods to maximize access, efficiency and impact.

Methods: By searching through the most current literature and engaging in discussions with industry experts, it is possible to identify avenues that could increase services to those who have hearing loss with innovative health care technology. This article aims to review the current state as well as future trends of hearing health technology by addressing: Technology as We Know it; and Technology as We Dream it.

Results: Some of the newer technologies we have recently witnessed include: micro processors; personalized computing devices (e.g. smartphones); web based applications; an expanding clinical repertoire with integrated test equipment; and globalization of telecommunications that opens the door to telehealth; and self-fitting of hearing aids. Yet, innovation continues scaffolding on recent successes with innovations for hearing health care expected to increase into the future.

Conclusion: As technology and connectivity continue to evolve so should the practice of audiology adapt to the global needs by capitalizing on these advances to optimize service delivery access and sustainability.

**Implications for Rehabilitation**

- Capital investment in equipment will be dramatically reduced with smaller, lighter, less costly and more portable equipment.
- Individuals who live in remote regions with little or no hearing health care can undergo valid assessments by a professional via telehealth.
- Web based applications allow clinicians to expand their repertoire and reach of services.

**Keywords:**

Innovation  
Hearing Aids  
Cloud Computing  
Hearing Health Care  
telehealth  
telemedicine  
Self Fit Hearing Aids

**INTRODUCTION**

If the current available primary care medical workers remained the same in the United States, it would result in an alarming shortage of 20,400 practitioners by 2020. In fact, as the population in the United States grows, it has been calculated that physician services will need to increase by 22% by 2020 to meet the demands [1]. As an ever growing worldwide population challenges the current patient to general health care professional ratios, so too has the specialty of hearing health care felt the pressure to ensure accessible and relevant services. An estimated 5.3% of the world population is challenged by permanent disabling hearing loss [2]. The aging population accompanied by a growing diverse population, will account for much of the increased demand over the coming decade in hearing healthcare. Of the estimated 315 million total residents in the U.S., the greatest demands for hearing health care (specifically audiology) services across all ages will increase in elderly adults [3]. It is well accepted that 30% of adults age 65 – 84 years will acquire significant hearing loss, and more than half of those adults 85 years of age and older will acquire significant hearing loss [2]. Much like the supply of primary care physicians, qualified audiologists are precariously insufficient in developing as well as developed countries [3, 4, 5].

There are a number of possible avenues that may improve the accessibility of audiological and hearing health services to those in need. One solution would seemingly be to dramatically increase the number of trained professionals. However, the solution is unfeasible in the short term due to the expense and length in initiating training programs in poorly resourced areas for 2-4 years of graduate level didactic and practical training typical of entry-level audiological qualifications in many countries. Another less arduous, but equally lengthy process could increase available services by recruiting and training, a large number of assistants over 4 to 6 month periods to be front line clinical service providers. Finally, another feasible and perhaps more attainable option may be to deploy those innovations found within the “Brave New World” of technology to improve access to care.

When Thomas A. Edison unleashed the innovative yet practical electric lightbulb into the world, many end users could not imagine an invention of greater magnitude on “modern” life. One does not have to look far to find various facets of technology that have altered health care provision and which have become assimilated into clinical care, especially in front-line clinical practice. With the proliferation of innovative technology and advent of greater access to global connectivity, there is a growing opportunity to harness information and technology resources to move beyond the current reliance on expensive audiometric booths and equipment or labor intensive attention required from the limited number of professionals for diagnosis, remediation and monitoring. Not only have costs of computers enabled clinicians to easily access patients outside of the traditional office space and sound-isolating chambers, but open access to information technology experts, more powerful microchips, global telecommunication systems and “cloud” computing now only limit audiology practices by the clinician’s imagination. Without a doubt, the distance between communities and continents has begun to shrink irretrievably. This article aims to review the current state as well as future trends of hearing health technology by addressing: Technology as We Know it; and Technology as We Dream it.

The proliferation of innovative technology is easily witnessed as a mainstream standard in many domains. Some of the innovations that appear in abundance on the clinical audiology landscape include: clinical diagnostic software residing within the continually miniaturized computers; web based applications; an expanding clinical repertoire with unique testing equipment; and

globalization of telecommunications that opens the door to telehealth and patient self-fitting of hearing aids.

## **COMPUTING**

Once the size of an average sized house and requiring extensive and advanced user knowledge to operate, computers today have significantly more computing power than what can now be stored in a small satchel with a weight as light as 2 pounds and are operated by young children. Thanks to micro processors and miniaturization of electronic components, computer sizes have continued to shrink while power and memory capacity have been increasing exponentially. As a consequence, clinically based software is now readily available commercially with a plethora of friendly applications unique to Audiology which are downloadable at anytime from anywhere in the world.

### Technology As We Know It

Some of the computing applications utilize video conferencing through the miniaturized microphone and video camera integrated into most laptops and desktop computers. Other computing applications are aimed at bundling images, sounds, and/or test results and then transporting to a central location through “cloud” computing. In essence, “cloud” computing is any number of remote servers hosted commercially on the internet with the express purpose of storing, managing and processing data rather than utilizing a local server or personal computer. The benefits of such “cloud” computing lie in the ease of accessing stable computing resources and information by anyone, anywhere, at any time in the world.

### Technology As We Dream It

The computing revolution is not yet over. In fact it is changing faster and diversifying more than ever before. “Personal” computing is taking on new dimensions with programs residing in mobile devices such as smartphones, tablets and phablets and cloud-based computing. An estimated 1.6 billion personal computers were in use around the world in 2011 compared to 1.8 billion mobile handsets sold in 2011 alone [6]. Smartphone sales are rising sharply with a 59% rise in 2011 to more than 470 million units, which translates to 1 in every four mobile phones [6]. Reflecting the staggering pace of smartphone penetration the number of sold units is

estimated to have risen by 200% from 2011 to 2013 with 1.4 billion units by the end of 2013 [7]. At this pace personal computing devices such as smartphones will soon be universally available. These personal devices integrate a host of internal sensors (e.g. sensors in cameras, gyroscopes, accelerometers and Global Positioning Systems (GPS)) that can readily interface with other external sensors which open up a whole new world of personalized health monitoring, assessment and even intervention [8]. Since these devices are connected to the Internet, information can be shared, compared using online databases, interpreted or used for computer-assisted diagnoses, to mention only a few possibilities. This personalization of computing technology has initiated an era of personalized health care screenings, monitoring and even assessments and interventions that will continue to impact and change hearing health care.

## **TEST EQUIPMENT**

Another domain reaping the benefits of miniaturization and microchips is clinical audiometric equipment. Though not as large as the early computers, until recently diagnostic audiometric systems have historically been costly and cumbersome, and the analogue versions were especially prone to lose calibration precision when physically moved. The stationary nature of diagnostic hearing assessment has traditionally been reinforced because of the need for a costly sound isolating booth for valid testing.

### Technology As We KNOW It

When the possibility of smaller, and hardier handheld portable and battery operated testing equipment became a commercial reality in 2001 [9], deploying automated and/or screening test equipment for large scale use began. Much like the manual mode, automated audiological threshold testing depends upon carrying out a sequence of steps according to specific rules of protocol that were established decades ago [10, 11]. With the advent of internal microprocessors embedded in the automated equipment, it is possible to have software driven decisions initiate and complete the hearing test in its entirety. Some automated systems provide simple screening tests, which will provide only one intensity presentation for each of four frequencies important for speech understanding; the results yielded would be either “pass” or “fail”/“refer”. Other systems have the option of automatically completing a full diagnostic test protocol utilizing the

standard psychometric method of limits used in audiology. There is a growing body of evidence that automated test results obtained for hearing screening or diagnostic assessment are as accurate and valid as those of an audiologist providing a manually conducted test [9, 12]. A recent systematic review and meta-analysis of automated audiometry concluded that it generally provides an accurate measure of hearing acuity [13]. It was however indicated that more validated data is necessary using bone conduction audiometry and testing in children and difficult-to-test populations in addition to more varied types and degrees of hearing loss [13]. There are some concerns expressed by audiologists that automated testing equipment could potentially place future job stability at risk. However, it has likewise been argued that automated testing will allow the audiologist to spend more time integrating information and working on more complex tasks such as counseling, hearing aid fitting and rapid intervention, potentially allowing more patients to be seen due to greater efficiencies in service delivery [9]. There will always remain those cases requiring the hands-on assessment expertise of an audiologist's clinical expertise, such as children and other difficult-to-test patients including those with functional hearing loss or secondary disabilities. To date, however, clinical adoption of automated audiometry has remained limited [13].

Having the ability to maintain accuracy with portable equipment, an audiologist or assistant can provide testing services at a patient bedside or at a home or work place location. A screening and/or automated platform also negates the resource intense use of audiologists by introducing a simpler protocol easily carried out by assistants or volunteers. Some of the automated clinical procedures that have been commonly used include: newborn hearing screening that may take place as early as 12 hours to three months after birth; regular adult occupational hearing screening for the purposes of monitoring hearing status; hearing screenings for school aged children; and hearing screenings in a primary care provider's offices as part of a general health screening.

### Technology As We DREAM It

As personal computing devices become increasingly ubiquitous their use as operating systems for audiological procedures such as audiometry and auditory evoked response recording, and even intervention such as hearing aid programming and rehabilitation programs for hearing loss or tinnitus, is inevitable. The advantages of this approach include portability, cost-effectiveness,

and integrated connectivity for onsite data capturing, sharing and management. Connections between the devices and hardware used for assessments may also be wireless (e.g., Bluetooth or Wi-Fi) to keep cables to a minimum whilst improving portability. In terms of the hardware connected to these computing devices (e.g., tablets and smartphones), integrated systems with multiple functionalities incorporated in the probe inserted into the ear, will facilitate efficient assessment of various auditory functions. Middle-ear status may, for example, be gauged with wideband reflectance or immittance measures followed by a check of outer hair cell integrity with otoacoustic emissions prior to pure tone audiometry, all using the same probe.

Other areas of development in the mainstay of the audiological assessment of hearing—pure tone audiometry—should increase the precision of testing. Current calibration standards are based on an average outer ear cavity for humans of 2cc. In reality, however, there are significant differences in the outer ear cavity across individuals—especially between men and women, and children and adults. These differences mean that the average intensity of air conduction pure tone signals calibrated using a 2-cc coupler may be substantially different when they reach the tympanic membrane in different persons [14]. In-ear calibration of pure tone signals using a microphone inserted into the ear canal during testing could allow for individualized calibration. Audiometry equipment to conduct this as an integrated feature is an important future priority and will improve accurate hearing threshold characterization.

One area where threshold accuracy may be improved is in the actual threshold seeking step-size or resolution. The typically used Hughson-Westlake procedure tests in 5 dB increments and this has remained the clinical norm [10, 11]. Smaller step-sizes using this method increase accuracy but also increase test time and the extra time required comes with associated confounding influences such as fatigue. There are, however, other audiometric procedures that allow for greater precision but without compromising time requirements. Bekesy audiometry, which is an automated audiometry threshold procedure dating back more than 60 years [15], utilizes a tone that sweeps in intensity based on the response button controlled by the patient. These sweeps may be within a single frequency (fixed frequency Bekesy) or across frequencies (Sweep frequency Bekesy) and can search for a hearing threshold in intensity increments of 1 or 2 dB in a clinically feasible timeframe [13, 16]. The sweep frequency Bekesy also allows for greater definition in thresholds since the signal sweeps across the frequency range for 1/3 octave frequencies as well as the octave frequency points used in conventional audiometry. Part of the

reason this procedure is not employed in clinical audiometry is because bone conduction audiometry cannot be completed with earlier Bekesy audiometry equipment. Bone conduction testing requires contralateral narrowband masking noise that should theoretically track with changes in test frequency and intensity [16]. New technologies, however, can more effectively include Bekesy-type bone conduction audiometry or utilize conventional bone conduction audiometry as related to the air conduction Bekesy audiometric thresholds. These methods should be considered for future applications towards more accurate audiometric results that can more accurately inform digital hearing aid fitting in greater intensity and frequency definition compared to existing audiometry.

An important barrier to widespread audiometry penetration in underserved areas is the requirement for annual calibration using expensive equipment, which is most often unavailable in regions such as sub-Saharan Africa [17]. Digital audiometers are less prone to lose calibration compared to their analogue counterparts for which current calibration standards were initially developed. Future developments that provide ways of merely monitoring calibration to identify if and when any shifts in intensity have taken place would be valuable. This may offer a service-delivery requirement for calibration only when such calibration enabled instruments show a significant deviation in output. In underserved regions this type of development will significantly improve availability and sustainability of hearing assessments.

Quality control monitoring during testing is another future area of interest. Recently developed audiometry equipment has reported the use of integrated microphones to monitor environmental noise in real-time during testing [18, 19, 20]. This feature allows for diagnostic testing outside of conventional sound isolating booths that are typically very expensive to install and often prohibitive in resource-constrained localities. Even in conventional audiometric booth settings such equipment may improve quality control since there is always a risk of transient noise that may exceed maximum permissible ambient noise levels. Personal computing devices with their integrated microphones are uniquely suited to this same purpose.

Hearing assessments performed using personal computing devices from home are another important advance for patients who may require regular monitoring, such as those on ototoxic drug regimens. Automated features make this possible and may save significant health care



costs, whilst promoting earlier detection due to regular testing and information sharing through Wi-Fi [21, 22] or cellular networks.

## **TELEHEALTH**

Of course the earliest form of telehealth/telemedicine occurred in the 1950s when a patient was able to telephone their family physician or physician's nurse to discuss symptoms and possible pathways toward better health. By the late 1970s a physician or their office personnel could TeleFax patient health information to another professional participating in a patient's clinical healthcare. The 'next big step for "human"-kind' was the use of telehealth to monitor astronauts in space [23].

### Technology As We KNOW It

Once overcoming the hurdle of monitoring astronauts in space, innovative technology has proliferated in the clinical realm with the ease of accessible rechargeable batteries, hand-held portable devices such as smart phones, tablets, and small laptops—all with 5 to 24 hours of battery life. Simply defined, telehealth is considered the use of electronic information and telecommunications technologies that provide professional oversight for clinical patient healthcare. As technology and telecommunication networks have significantly advanced, it is currently viable for multi-functioning audiological systems to be integrated into one laptop computer placed at the patient side, but controlled from a remote site by an Audiologist. Typically, a trained assistant would be stationed on the patient side to facilitate the testing procedures. Of course the onus is on the clinicians to ensure that the level and quality of services they and their assistants are providing via telehealth are equivalent to that provided face-to-face. In addition to being competent in the licensed scope of audiological practice, there are additional skills professionals and assistants need to attain competency in telehealth [21, 24].

There is ample evidence that telehealth has been successfully deployed over the past number of years for counseling in the clinical psychology and speech-language pathology domains [25]. More recently, screening and diagnostic hearing testing as well as monitoring patient status have become well accepted telehealth practices in audiology, especially for those less populated regions where health services are either not available or severely limited (such as Appalachia, Rocky Mountains, deserts of Arizona or New Mexico, etc). Until recently, the uptake of telehealth in audiology within the U.S. has been remarkably slow due to third party

reimbursement limitations and lack of standard definition for telehealth across the various state Audiology Licensing Boards [26].

### Technology As We DREAM It

It is estimated that telehealth will experience an exponential growth over the next 5 years. Some have predicted that the telehealth market within the U.S. will grow from the current \$240 million to \$1.9 billion by 2018 [27]. A large part of the growth is attributed to the increasing number of third party reimbursements for telehealth services within the United States. A prediction of such growth is tenable given the recent actions undertaken in late 2013 through the introduction of two legislative bipartisan bills that are designed to advance telehealth services [27]. Though, only two legislative bipartisan bills seem insignificant, they show evidence of the growing telehealth applications with every expectation that this trend will only increase well into the future.

One of the areas in telehealth that is expected to play an increasingly important role into the future is the field of mobile health (mHealth). It is considered a subset of telehealth that utilizes mobile devices using technologies to promote, provide and monitor health care services [8]. The widespread penetration of mobile phones make this a particularly promising development to improve the cost-effectiveness of health care services whilst improving access to care and overall impact on the burden of disease and disability. A recent review reported that in 2013 there were already more than 15 000 health care applications available for mobile devices [28]. At present the evidence supporting the use of these applications in clinical practice is still largely unavailable but mobile (m)Health initiatives are increasingly being employed by governments [8].

In audiology, numerous smartphone applications are now readily available to conduct a variety of audiological services such as hearing assessments (e.g., pure tone audiometry, speech audiometry), viewing the external ear canal, ambient noise level measurements, programming hearing aids and/or even functioning as a hearing aid (e.g. Jacoti ListenApp on iTunes). Although significant challenges arise when equipment calibration is not controlled, these personal computing technologies have considerable potential. In some instances, they are already utilized to provide an access point for services that include information/education, screening, and possibly diagnosis and interventions [29,30, 31]. Future developments in telehealth for audiology

will look to capitalize on the widespread penetration of smartphones and on their increasingly advanced capabilities alongside the rapidly expanding global reach of connectivity.

### **PATIENT SELF-FIT (“DO-IT-YOURSELF”) HEARING AIDS**

Clearly the shortage of qualified Audiologists continues to contribute to the scarcity of hearing health services worldwide. One specific service offered by Audiologists, audiological rehabilitation, is considered as important as dispensing personal amplification systems (i.e. hearing aids and personal sound amplification systems) for remediating hearing loss. Some would argue that the consumer perceived need for hearing aids is far less than predicted due to the evidence of very low uptake of hearing aids by those who easily have access and resources [32]. Regardless of whether access or costs or inconvenience are creating needless barriers to rehabilitation for hearing loss, the demand is clearly present. Though the concept of self-fitting hearing aids was patented in 1984 [33], some hearing aid manufacturers are introducing a soft-launch of patient self-fit (“do-it-yourself”) amplification/hearing aids as an alternative delivery model to reach more hearing impaired individuals.

### Technology As We KNOW It

Hearing aids are one of the preferred methods of rehabilitation for hearing loss and are defined by the U.S. Food and Drug Administration (FDA) as ‘any wearable sound amplifying device that is intended to compensate for impaired hearing’ [34]. Consequently, hearing aid rehabilitation is wholly dependent upon accurate hearing thresholds so that the hearing aid can be programmed to the prescribed amplification appropriate for the wearer. Unlike hearing aids that require accurate measure of an individual’s hearing status, personal sound amplification products (PSAP) have been commercially available for a number of years and touted as being over-the-counter ‘reading glasses for the ears’. These affordable devices defined by the U.S. FDA as ‘amplifiers for *non-hearing impaired* consumers to accentuate sounds in specific listening environments’ and are ‘not to compensate for hearing impairment’ [34] do not depend upon the measure of hearing status. However, the more prevalent advertising seen for PSAPs indicates the advantages of the devices for those who have hearing problems. Clearly, blurred lines for application of each of the two categories have not only confused consumers, but in the regulatory arena as well as practitioners seeking to understand professional qualifications required for fitting each category of device.

Though the FDA does not allow manufacturers or retailers to sell hearing aids on the internet, an internet search would reveal that consumers are easily able to purchase from other consumers online: hearing aids, cables, software, programming interface devices with instructions on how to program a hearing aid. There are also manufacturers that sell all the necessary supplies and instructions for programming hearing aids, but not the hearing aids through their websites.

As discussed previously, the appropriate programming is based on the wearer's hearing thresholds. If the hearing aids are not programmed appropriately either the hearing aid/s will under amplify (i.e., provide less than optimal amplification) or over amplify (i.e., provide more than optimal amplification which can potentially create additional hearing loss for the wearer). Though currently only dispensed through Audiologists or Hearing Aid Dispensers, there are hearing aid manufacturers who, in the past few years, produced behind the ear hearing aids with on-board programming buttons that negate the need for computer software or programming cables, and possibly bypass the need for professional fine tuning of the instrument.

#### Technology As We DREAM It

Self-fitting hearing aids, hardly a far-fetched concept, have been proposed to be housed within a behind the-ear hearing aid so that they may be fit entirely by the wearer with no intervention by an Audiologist/hearing health care provider, no computer support needed, and no telephone access required. Ultimately, the goal with any self-fitting hearing aids is for an equivalent outcome to that accomplished by an Audiologist. Yet, there remains the hurdle of obtaining accurate hearing thresholds without the oversight of an audiologist, so that the hearing aid might calculate and program itself to the prescribed amplification. Efforts to utilize the hearing aid itself to determine hearing thresholds are only in the early stages and limited success hinders current progress [35]. Whilst the concept seems feasible and some promising results have been reported [36] there are important challenges that still need to be addressed. These challenges include: a) instructions to manage insertion of the hearing aid [37] and subsequent hearing threshold measurements, b) control of ambient noise levels and, c) issue of contraindications such as asymmetrical hearing loss, conductive hearing loss or other pathology requiring medical intervention [38].

Contraindications to immediate hearing aid rehabilitation, such as conductive hearing loss, are well known to hearing health practitioners, but not to the typical wearer. For instance, the most

common (and most remediable) cause of hearing loss is due to pathology or conditions of the outer and/or middle ear that can be easily identified through thorough diagnostic testing [38]. There are also life-threatening conditions which, when identified by a hearing health practitioner, may require immediate pharmacological or surgical intervention. Again, these conditions are well known by hearing health professionals, but not by the typical hearing aid wearer. A recent study has demonstrated the promise of an air-conduction measure called the tone-in-noise detection task, which may be used in self-fitting hearing aids to differentiate conductive hearing losses from sensorineural losses [36].

The area of self-fitting hearing aids is bound to see increasing interest but at present there is limited evidence on the outcomes in patients, leaving much work to be done. In developed economy contexts, where there are sufficient numbers of professionals to fit hearing aids appropriately, these technologies are likely to find resistance. In underserved areas of the world, representing the majority of those with disabling hearing loss [37], these types of devices may offer real solutions in light of the severe shortage of hearing health care personnel.

In high-income contexts in particular self-fitting hearing aids may play an important role to introduce those with hearing loss to the benefits of amplification. A new variant of this is in the form of a smartphone used with an accompanying headset to function as a hearing aid programmed according to the individual's hearing loss. In this way individuals can use their current smartphone with a downloaded application to personally evaluate their perceived benefit, albeit more crudely, of amplification. Several such applications have recently been released on smartphone app stores. One specific application (ListenApp by Jacoti, Apple App Store) also allows for an audiologist to remotely upload the audiogram and make hearing aid adjustments, which are then programmed to the user's iPhone.

## **CONCLUSION**

It is estimated that only one out of five Americans who could benefit from hearing aids are able to access and purchase hearing aids. On a worldwide scale, approximately 328 million adults and 32 million children experience disabling hearing loss that could be assessed and ultimately they could benefit from hearing aid rehabilitation [38]. There is abundant and undeniable evidence that the need for accessible hearing healthcare has historically created barriers for many individuals who have hearing loss. Some barriers to ameliorate hearing loss, such as extreme

poverty, perception of the existence of disabling hearing loss, culturally driven help seeking behaviors, etc., may remain insurmountable for now.

However, as technology and connectivity continue to reach deeper into the hearing health arena, the ability to advance and optimize accessibility and sustainability of service provision for many more individuals has evolved. As shown within this article, microprocessors and miniaturization of electronic components have resulted in a smaller capital investment as well as the size of audiometric equipment without sacrificing quality or validity of test. When coupling affordable and portable equipment with opportunities to harness information and communication technology, service provision has expanded far beyond the typical care provider-to-patient dyad of occupying the same room simultaneously. The distance between the service provider and patient is now largely limited by speed of global connectivity. Thus, testing and service provision can be offered in remote regions via telehealth or mHealth. Research to validate novel technologies and procedures must however be prioritized to ensure adoption of clinically valid and reliable technologies. The rapid rate of new developments compared to the timeframe required for systematic validation result in an unavoidable gap between what technologies can offer today and what current practice prescribes. Despite the challenges however the future remains promising for the expansion of hearing health care services and technology transfer in under resourced regions, especially Low- and Middle-Income Countries.

#### Declaration of Interest

The authors report no declarations of interest

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