# Global Pediatric Hearing Health – In Search Of Novel Solutions to Current Challenges

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## Abstract

*Hearing loss is a pervasive chronic disability estimated to affect 32 million children around the world. Childhood hearing loss prevalence varies across world regions influenced in part by socio-economic conditions. Significant barriers, including limited professionals and equipment shortages, prevent children in underserved world regions to access secondary preventative ear and hearing health services. As a result, the majority of children who are deaf or have significant degrees of hearing loss do not receive schooling in underserved regions and those with ear disease are prone to complications. Screening and diagnosis for ear and hearing disorders are most commonly unavailable. In an effort to address barriers for children without access to ear and hearing health care services, including screening, diagnosis and intervention, novel solutions that capitalize on the advances in technology and connectivity are required. Two new technical developments to address these barriers in pediatric ear and hearing health care will be reviewed alongside existing evidence.*

This presentation is dedicated to Nelson Mandela who passed away only days before the Phonak 6th International Pediatric Audiology Conference began on December 8th, 2013.. It is dedicated in memory of his love for children, especially those with disabilities in South Africa and sub-Saharan Africa.

*"Our children are our greatest treasure. They are our future".*
*"Disabled children are equally entitled to an exciting and brilliant future".*

Nelson Mandela, (18 July 1918 – 5 December 2013)

Childhood hearing loss has been referred to as a silent disability (Swanepoel, 2010). No clinical examination of a child's physical status can alert parents or health care providers of a child's hearing loss in the first few weeks of life. As a result, the condition is not identified early if screening programs that employ electrophysiological test procedures (otoacoustic emissions or auditory brainstem responses) are unavailable. Despite parental suspicion in the first year of life, disabling hearing loss is only identified through initial consequences seen in behavior such as delayed or no speech production and poor responsiveness to sound. At this stage, critical developmental periods for language have already been missed that result in pervasive developmental delays in speech, language, cognitive and socio-emotional development, academic achievement and vocational outcomes (Busa, Harrison, Chappell, Yoshinaga-Itano, Grimes, Brookhouser, et al. 2007; Korver, Konings, Dekker, Beers, Wever, et al., 2010; Russ, Dougherty & Jagadish, 2010; Olusanya, Ruben & Parving, 2006).

Unfortunately for the majority of countries around the world, representing more than 90% of newborns, widespread newborn or infant hearing screening programs are unavailable (WHO, 2010). In a previous contribution to the Sound Foundation through Early Amplification Proceedings (Swanepoel, 2010) various approaches to improve primary and secondary prevention for newborns and infants was considered. The focus of this article is more focused on children as opposed to newborns and infants, with two specific strategies discussed to increase access to ear and hearing health care. The first relates to the issue of ear disease and early identification and treatment in underserved areas as a preventative measure and the second relates to identification of hearing loss in young children entering school systems.

## Global Challenges to Childhood Hearing Loss

**Prevalence of childhood hearing loss.** Permanent disabling hearing loss, characterized by a loss greater than 40 dB and 30 dB in the better ear for adults (≥ 15 years of age) and children (<15 years of age) respectively, is an increasingly prevalent global health care condition (WHO, 2013). In 1995 the World Health Organization estimated that 120 million people suffer from disabling hearing loss. This number more than doubled in 10 years to 278 million in 2005. In 2013 the number of persons with disabling hearing loss was estimated to be 360 million, which constitutes 5.3% of the global population. Of these 32 million children globally with disabling hearing loss the majority reside in South Asia and sub-Saharan Africa (Table 1). Prevalence of childhood hearing loss is exponentially related to economic development with higher prevalence for poorer world regions as illustrated in Figure 1 (WHO, 2013). Since the majority of these children are unable to access early detection and intervention services they are most likely assigned to a life of exclusion and limited outcomes in terms of literacy, academic achievement, vocational outcomes, economic contribution to society with poor quality of life (Olusanya, Ruben & Parving, 2006).

| Regions | Disabling hearing loss in children (<15 years of age) | |
|---|---|---|
| | **Millions** | **Prevalence %** |
| High-income | 0.8 | 0.5 |
| Sub-Saharan Africa | 6.8 | 1.9 |
| Middle East & North Africa | 1.2 | 0.9 |
| South Asia | 12.3 | 2.4 |
| Asia Pacific | 3.4 | 2.0 |
| Latin America & Caribbean | 2.6 | 1.6 |
| East Asia | 3.6 | 1.3 |
| World | 31.9 | 1.7 |

**Table 1.** Global estimated estimates prevalence of childhood hearing loss across world regions (WHO, 2013)

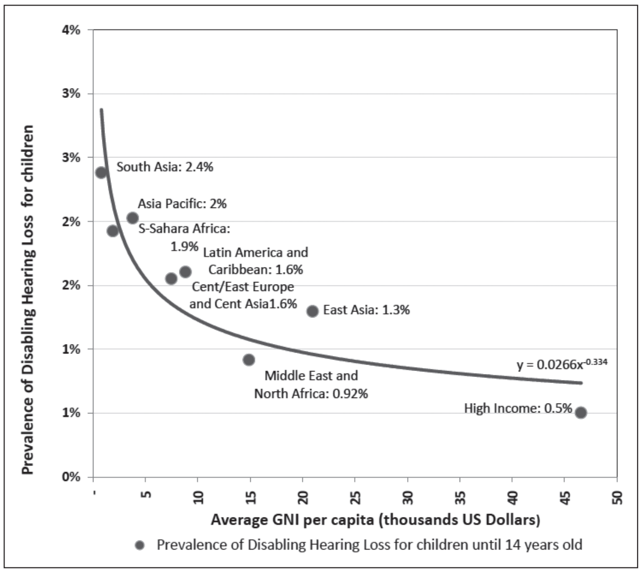


**Figure 1.** WHO (2013) estimated regional prevalence of disabling childhood hearing loss according to average gross national income (GNI) per capita.

Apart from permanent hearing losses in children there is also the significant burden of conductive ear diseases, including otitis media (OM), which may result in temporary hearing loss but potentially could also lead to permanent losses (Acuin, 2004; WHO, 2013). According to a recent systematic survey of global OM, an acute otitis media (AOM) incidence rate of 10.85% was reported, translating to 709 million annual cases of which 51% occur in children younger than 5 years (Monasta et al., 2012). Chronic suppurative otitis media (CSOM) incidence rate was reported as 4.8% with 22.6% of cases occurring in children younger than 5 years of age (Table 2). Complications related to OM as shown in Table 2 were estimated to include an OM-related hearing loss prevalence of 3.1 per 1000 and 21000 annual global deaths attributable to OM (Monasta, Ronfani, Marchetti, Montico, Vecchi-Brumatti, et al., 2012). The burden and population characteristics of OM differ greatly between world regions with India and sub-Saharan Africa accounting for the most deaths arising from OM related complications. The prevalence of CSOM in Africa has been classified as high amongst both children and adults, estimated to be between 3 to 6% (Acuin, 2004). The costs, direct and indirect, related to AOM, CSOM and resulting hearing loss is an important and significant burden on health systems and households globally, especially in underserved regions such as sub-Saharan Africa (Monasta et al., 2012) ology or otolaryngology services available. The dearth of ear and hearing health care professionals is primarily due to a reported lack of government funding, professional and public awareness, and, most significantly, available training programs (Goulios & Patuzzi, 2008). Only two African countries, for example, indicate having any training programs in audiology and many countries also indicate not having any otolaryngology training programs (Fagan & Jacobs, 2009).

It is not only developing countries that have a shortage of ear and hearing health care personnel however. The need for audiological services in a country like the USA is significantly greater than the current capacity of professionals providing these services. Margolis & Morgan (2008) compared the estimated number of audiograms required annually in the USA with the capacity of current professionals to provide these tests. According to their estimations there was an annual shortfall of 8 million audiograms in the year 2000 that was expected to increase to 15 million by 2050. A more recent study reported that the shortage in audiologists to meet the increasing demand for services in the US is expected to increase. It is estimated that in order to meet the demand, the number of persons to enter the field of audiology in the US should increase by 50% in 2013 and the attrition rate would need to be lowered to 20% (Windmill & Freeman, 2013).

| | AOM incidence (%) | CSOM incidence (%) | OM-related HL* per 1 000 people | OM-related deaths per million people |
|---|---|---|---|---|
| **Age** | | | | |
| < 1 year | 45.3 | 15.4 | .9 | 8.5 |
| 1–4 years | 61.0 | 10.1 | 2.3 | 9.0 |
| 5–9 years | 22.2 | 8.3 | 2.6 | 3.8 |
| 10–14 years | 18.5 | 3.9 | 2.7 | 3.2 |

**Table 2.** Global incidence of AOM, CSOM and prevalence of OM-related HL and deaths (Adapted from Monasta et al., 2012)

* OM-related hearing loss defined as > 25 dB permanent loss in best ear

## Access to Ear and Hearing Health Care Services

Global inequality is illustrated all too clearly in the area of ear and hearing health care with more than 80% of people with disabling hearing loss residing in underserved areas where services are either absent or very limited (WHO, 2006; Fagan & Jacobs, 2009). In developing countries the average ratio of audiologists to the general population varies between 1:500 000 to as few as one for every 6.25 million people. This is in contrast to a developed country like the UK where the average ratio for audiologists to people is one to every 20,000 persons (Goulios & Patuzzi, 2008; Fagan & Jacobs, 2009). In sub-Saharan Africa many countries do not have any audiology or otolaryngology services available.

## In Search Of Novel Solutions

The prevalence of ear and hearing disorders and the significant and lifelong consequence for young children if timely services are unavailable, as is typical with the global shortage in ear and hearing health services, make it imperative to investigate ways of improving sustainable access. No wonder that alternative strategies have been proposed towards increasing the capacity and reach of existing ear and hearing health care providers (Windmill & Freeman, 2013; Swanepoel, Clark, Koekemoer, Hall, et al., 2010; Margolis & Morgan, 2008). The utilization of advances in technology and the growth in global connectivity is opening doors to new modes and methods of service-delivery in ear and hearing health care. Two examples of this will be considered in the following section.

## Remote Diagnosis of Ear Disease

Early diagnosis and treatment of ear disease is not achievable for the majority of the global population, particularly in regions such as sub-Saharan Africa and India (WHO, 2013; Fagan & Jacobs, 2009). This predisposes to complications that may include temporary and permanent hearing loss and even death in some cases (Monasta et al., 2012). Capitalizing on the widespread availability of cellular phone networks and technology may provide a way to increase access to care through telehealth. One such method is the use of video-otoscopy for remote diagnosis of ear disease. By incorporating video-otoscopy at primary health care clinics or referral hospitals where specialist ear and hearing personnel are unavailable allows for images or recordings to be sent for remote interpretation by specialists in urban areas or even abroad (Biagio, Swanepoel, Adeyemo, Hall & Vinck, 2013; Swanepoel et al., 2010; Swanepoel & Hall, 2010). This may allow a way to effect timely diagnoses and treatment recommendations. Telehealth video-otoscopy has previously demonstrated that asynchronous video-otoscopy images are equivalent in quality to onsite otoscopy (Biagio, Swanepoel, Adeyemo, Hall & Vinck, 2013; Lundberg, Westman, Hellstrom & Sandstrom, 2008; Mbao, Eikelboom, Atlas & Gallop, 2003; Patricoski, Kokesh, Ferguson, Koller, Zwack, et al., 2003; Smith, Dowthwaite, Agnew & Wootton, 2008). Importantly, for the purpose of validating video-otoscopy within a hearing telehealth clinic, studies have demonstrated average to good diagnostic concordance between conventional otoscopy and asynchronous video-otoscopy images (Biagio et al., 2013; Lundberg, Westman, Hellstrom & Sandstrom, 2008; Mbao et al., 2003; Patricoski et al., 2003; Smith, Dowthwaite, Agnew, & Wootton, 2008).

The person acquiring the actual video-otoscopic image in reports vary from nurses, general practitioners and otolaryngologists, which may influence the quality of the telehealth video-otoscopy images (Lundberg et al., 2008; Mbao et al., 2003; Patricoski et al., 2003; Smith et al., 2008). Since general practitioners and specialists are usually unavailable at primary health care clinics in underserved areas, the validity of a remote telehealth service depends largely on using non-specialist personnel such as nursing staff or laypersons. A recent study investigated using a telehealth clinic facilitator, with no formal health care training or tertiary education, to capture images from the ear canal of adult patients attending a primary health care clinic (Biagio et al., 2013). The otolaryngologist who conducted the onsite assessment remotely interpreted the images a few weeks later. Diagnostic concordance was moderate and the study findings indicated that a trained telehealth facilitator could acquire adequate quality video-otoscopic images for asynchronous diagnosis of ear disease using video-otoscopy in underserved populations. The fact that the study was conducted on adults was a limitation however, since the primary group affected by middle-ear disorders like OM is young children. Furthermore it was noted that video-otoscopic images lack depth perception, which may be a limitation in accurate diagnosis (Biagio et al., 2013).

In a follow-up study (Biagio, Swanepoel, Laurent & Lundberg, submitted 2014), we sampled a population of 140 children between 2 and 15 years of age attending a primary health care clinic for onsite otomicroscopy by an otologist serving as the gold standard diagnosis of ear canal and tympanic membrane status. Video-otoscopy was conducted by the same telehealth facilitator used in the study by Biagio et al. (2013) using a different video-otoscope. However, instead of images, brief video clips were taken of the ear canal and tympanic membrane (<30 seconds). Onsite training was provided to the facilitator over a two-day period by the otologist on how to conduct video-otoscopy recordings. Training included aspects related to positioning, visual inspection of external ear, appropriate hand position, manipulation of direction of speculum, focus adjustment, recording capture, video-otoscope software use, and equipment cleansing. Video recordings were uploaded to a Dropbox folder and the otologist interpreted these remotely at 4 and 8 weeks subsequent to the onsite examination.

The findings of this follow-up study indicated that an unskilled telehealth facilitator could be trained to acquire good quality video-otoscopy recordings for a pediatric sample. Concordance of diagnoses for video-otoscopy recordings interpreted remotely compared to onsite otomicroscopy was better than previous research concordance with video-otoscopy images. Asynchronous video-otoscopy recordings also demonstrated high intrarater reliability. These findings support the possibility of delivering remote specialist diagnoses for ear disease in pediatric populations living in underserved areas through telehealth. Video-otoscopy is a powerful tool that can be used by unskilled, but trained, personnel to acquire adequate recordings (video clips as opposed to static images) for sharing through cellular networks for remote interpretations and diagnoses. This may ensure timely and accurate treatments to minimize complications related to ear disease. High quality recordings can be assessed within a minute or two for diagnostic purposes and may be time and cost-efficient.

## School-based Hearing Screening and Diagnosis

Benefits of early detection for hearing loss through newborn hearing screening (NHS) programs is widely established and accepted (Busa et al. 2007). Nonetheless a significant number of permanent hearing losses are only identified around the time of school entry (Bamford et al., 2007; AAA, 2011). A number of reasons may lead to this and include the fact that screen technologies target hearing losses of 30 to 40 dB and miss low-frequency hearing losses. Furthermore some infants referred from newborn hearing screening services do not receive diagnostic services and then there are also cases of of late-onset, acquired or progressive losses (AAA, 2011; Bamford, Fortnum, Bristow, Smith, Vamvakas & Davies, 2007). For underserved regions like sub-Sahara Africa where newborn screening programs for hearing loss are unavailable, school screening may provide the first opportunity to detect a hearing loss (Olusanya, Swanepoel, Castillo, Chapchap, Habib, Mukari, et al., 2007).

Major challenges that hinder the successful implementation of school-based screening programs include challenges related to the expense of screening audiometry equipment, poor training of screening personnel, ambient noise leading to over-referrals, and in many underserved regions the lack of electricity necessitating battery-operated systems. Furthermore the lack of data capturing facilities integrated into systems allowing for data surveillance and monitoring is another important limitation to the majority of current audiometers.

In an attempt to address these challenges we have developed a smartphone-based screening audiometry application (Android OS) calibrated with a supra-aural headset (University of Pretoria Patent, trademarked as hearScreen™). Although other hearing screening smartphone applications have been reported on (Foulad, Bui & Djalilian, 2013; Handzel et al., 2013; Khoza-Shangase & Kassner, 2013; Szudek et al., 2012) these have revealed mixed findings and have all been developed for the more expensive Apple OS products. This product has been developed on the Android operating system to function on budget smartphones typically used in developing countries.

The *hearScreen*™ application (Figure 2) follows an automated protocol whereby the screener presents the sound and then indicates whether the child heard the sound or not. The response initiates the next step in the protocol, which means the screener does not have to make in protocol decisions. As a result, very little training in audiometric principles is required and it ensures that the screening protocols across screeners can be enforced in a standardized fashion. Additionally, the application is the first to employ a noise-monitoring feature using the integrated microphone of the smartphone to monitor environmental noise levels. This monitoring feature is calibrated for the selected model of phone (UP Patent). In addition to these features, the application also allows for data capturing on the phone with a sharing function for emailing the database or uploading it to a secure online server. In this way, data can be geo-tagged and uploaded from school sites for surveillance purposes. The initial laboratory and clinical results (Swanepoel, Myburgh, Howe, Mohamed & Eikelboom, submitted 2014) from this development have demonstrated real promise as a mobile hearing screening solution that is cost-effective, requires minimal training, monitors ambient noise level for compliance to maximum permissible ambient noise levels, is battery-operated for a full-day of testing and allows for data capturing and sharing for monitoring program efficacy.

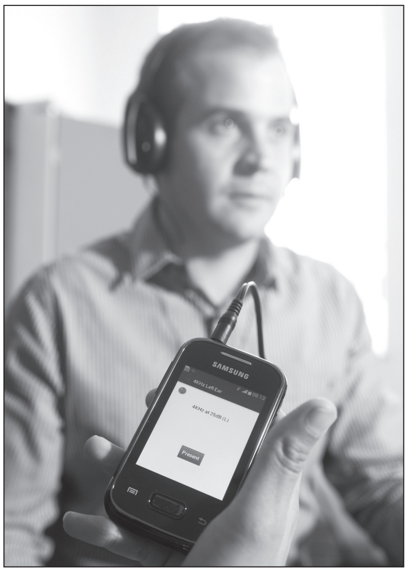


**Figure 2.** The hearScreen™ application being used to screen an adult.

## Conclusion

There is an overwhelming shortage of ear and hearing health care providers to adequately serve the number of children with hearing loss and ear disease. Advances in technology and connectivity offer a way to improve the efficiency and accessibility of current service-delivery models towards improving outcomes. We considered two examples of novel technologies that in combination with the growing global connectivity offer ways to make ear and hearing health care services more accessible and sustainable. A non-specialist person with hands-on training can acquire video-otoscopy recordings of the ear canal and tympanic membrane and those video clips can be used for reliable remote diagnoses in children. Furthermore cost-effective mobile screening audiometry can be done using smartphone applications designed for calibration of the stimuli. Quality control can also be ensured by integrating noise monitoring using the smartphone microphone during testing and including data capturing and sharing facilities.

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