

Advancing Equitable Hearing Care Through Innovations in Technology and Service-Delivery

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Abstract

Background: Hearing loss is a neglected global health priority affecting 1.5 billion persons. Global access to hearing care is severely limited with management options, like hearing aids, inaccessible to most. The cost and centralised nature of traditional service-delivery approaches in hearing care have undermined equitable access alongside poor awareness.

Summary: Recent innovations in digital and mHealth hearing technologies used by health workers through task-shifting are enabling novel community-based services across the continuum of care. This narrative review explores technology-enabled hearing care in communities. We provide examples focused on our work over the past decade to explore more equitable hearing care across primary, secondary and tertiary levels of prevention.

Key messages: Hearing health innovations have the potential to increase access to care, improve the quality of life for those affected by hearing loss and reduce global costs associated with untreated hearing loss. More equitable hearing care is a global health

priority that requires scalable service-delivery models enabled by innovative technologies within communities and integrated into public health initiatives including hearing health promotion.

Keywords

Teleaudiology; Telehealth; mHealth; Community hearing care; Equitable hearing care; Hearing loss; Hearing aids; Digits-in-noise; Hearing screening

Introduction

Hearing loss is a leading contributor to the global burden of disease, with an estimated 1.5 billion people affected [1]. Expected to increase to 2.5 billion by 2050, it has already risen to become the third leading cause of years lived with disability [1,2]. The impact of hearing loss is pervasive, affecting communication, social participation, education, employment, quality of life and health [1]. In terms of the growing public health concern of dementia, hearing loss has been identified as the leading population-based modifiable risk factor [3] and the use of hearing aids is associated with lower dementia prevalence [4].

Despite the high prevalence and associated costs of not treating hearing loss, the vast majority of affected persons globally are not able to access care. According to recent studies, access to care and utilisation of hearing aids remain alarmingly low in certain regions, with penetration rates as low as 2% in Africa for persons who can benefit from these assistive technologies [5,6]. As a result, the cost of untreated hearing loss on a societal level is estimated at a staggering \$980 billion annually [7]. Access to care, particularly in low and middle-income countries (LMICs) where access is typically unavailable, should therefore be prioritised on the global public health agenda [1]. The reasons for this limited access are multifaceted and include a scarcity of hearing healthcare professionals [8], lack of awareness and knowledge about hearing loss, societal stigma, and prohibitive costs of clinical technologies and associated service-delivery models. Addressing these barriers to access requires innovative approaches across technology, service delivery and health promotion.

Innovation in delivery of hearing care

Traditional service delivery models have been demonstrated to be unable to provide scalable hearing care, especially in LMICs, due to a combination of challenges, including the shortage of hearing care professionals and infrastructure and resources [9,10]. The centralised and highly specialised nature of traditional hearing care services is therefore

unable to support equitable access to hearing care at scale. Innovative service-delivery models that are accessible and affordable for the majority of persons with hearing loss require rethinking and, in established markets, likely also the disruption of traditional service-delivery models [9,10]. The recent over-the-counter hearing aid regulations in the US is one example of a move to improve cost and access barriers and is likely to also influence changes internationally [9].

From a global health perspective, the World Report on Hearing [1] recommends a reorientation of the hearing health care model that prioritises primary community-based care to improve access for the majority of affected persons. Efficient referral pathways to specialised care should be available for sub-groups of hearing loss, including for young children and adults with medical-related causes, but the vast majority could benefit from alternative community-based models of care [1,11]. Key principles supporting service-delivery innovation for scalable hearing care in this framework include task-shifting for community-based services and novel telehealth technologies integrated within a public health approach [1].

Community-based hearing services

Decentralised services provided in community-based settings by members of the community support access, preventative care, and cost-efficiency. Community-based hearing care (CBR) aligns with the WHO-recommended Community-Based Rehabilitation framework. A recent review [12] of Community-Based Hearing Rehabilitation (CBHR) reports on the value of this approach to improve access to hearing care. The majority of studies, however, are from high-income countries and focus on screening and assessment [13]. More research in LMICs where accessibility challenges are greatest is necessary across the hearing care journey to develop and support global action for improved access to care.

The World Report on Hearing [1] recommends the implementation of task-sharing as a broader workforce strategy to improve access and quality of hearing services across the life course while reducing healthcare disparities and inefficiencies [1,11]. Task-sharing refers to a redistribution of clinical tasks or some of their components between different cadres of health workers [1]. Tasks that in traditional models may have been facilitated by specialist health workers can now be facilitated by community health workers (CHWs), nurses or technicians [11,12,14]. The WRH [1] proposes, for example, that CHWs and nurses could potentially facilitate hearing screening, hearing loss assessment in adults with red flags for specialised care, hearing aid fittings in adults without red flags, auditory training and counselling for adults. The contexts for community-based hearing care provide a degree of

flexibility to increase access by using settings that include homes, schools, community centres and primary health care clinics [12,15]. This, however, requires equipment that is suited to community services and which is mobile, cost-effective and supports a decentralised model of care.

Digital technology-enabled hearing care

Digital technologies are rapidly disrupting health care delivery, including hearing health, which has longstanding challenges of inaccessibility and prohibitive costs [9]. Even in high-income countries, this disruption is evidenced by changes like the recent over-the-counter hearing aid regulations in the US with self-fitting digital hearing aids typically accompanied by smartphone applications [9]. Similar technology-enabled developments are promising access to hearing care in LMICs that are scalable and cost-effective [10,16]. Community-based hearing care can be delivered using innovative digital technologies that support minimally trained persons to facilitate services through task-sharing [1,10,11]. Rapidly increasing global access to connectivity and digital technologies [17] are scaffolding the roll-out of tech-enabled hearing health care delivery. For example, smartphone penetration is estimated to increase from 75% to 84% from 2021 to 2025 [17]. Despite the rapid smartphone penetration, access to devices and cost of data remain important barriers towards more equitable digital health solutions. If available these devices can facilitate a range of hearing health care services, from screening through to interventions delivered by community health workers [15,18].

The World Report on Hearing [1] encourages governments to employ innovations in hearing technologies for screening, diagnosis and management based on rigorous testing that demonstrates safety and compliance with international standards. A recent review demonstrated the potential role of mHealth technologies in improving access, penetration, quality and convenience of hearing health services on a more affordable and scalable level [18]. This review identified 146 articles, more than 50% published in the last five years, that investigated hearing care supported or facilitated by mHealth technologies. The studies covered the continuum of hearing care from health promotion (2%), screening (39%), diagnosis (35%), treatment (10%) and support (14%).

Rapid innovation in digital hearing health technologies is enabling novel service-delivery models and approaches to care across all levels of prevention [9,10,19]. This narrative review explores examples of community-based hearing services that are enabled by innovative technologies and facilitated by minimally trained health workers like CHWs (Table 1). Most of these examples are from community-based implementation projects based in

Africa and in partnership with communities and local organizations. The scope of our hearing care examples is not comprehensive and excludes aspects like tinnitus, auditory processing disorders and hearing aid fitting in young children.

Table 1. Examples of technology-enabled innovations in community-based hearing health prevention

Primary Prevention	Secondary Prevention	Tertiary Prevention
mHealth support for maternal and child health	Smartphone pure tone audiometry screening for children and adults. Also facilitated by CHW's ([Mahomed-Asmail 2016 [1]; Wasmann 2022 [25]; WHO 2021 [27]; van Wyk [31]; Yousuf Hussein 2015 [32]; Yousuf-Hussein 2018 [33])	mHealth-enabled model to deliver hearing aids (Frisby 2022 [15])
mHealth ear and hearing health training in early childhood development (du Plessis 2022 [23])	Combined smartphone hearing and vision screening by CHWs for preschool and school children (Eksteen 2019 [35]; Manus 2021 [36])	A mHealth hearing aid acclimatisation and support program was facilitated by the CHWs (Frisby 2023 [53])
	Online or app-based digits-in-noise hearing screening for adults, e.g., hearWHO app (De Sousa 2018 [38]; Schönborn 2020 [39]; De Sousa 2022 [40])	Community-based hearing aid fittings by CHWs to treat sensorineural hearing loss (Borg 2018 [13]; Gupta 2020 [51]; Nieman 2022 [52])
	Point-of-care automated pure tone audiometry (Frisby 2022 [15]; De Sousa 2022 [16])	
	Novel hearing loss triage approaches i.e., AI-supported video-otoscopy, mHealth tympanometry and algorithms using air-conduction tests (Jayawardena 2020 [47]; Vekstein 2022 [48]; De Sousa 2020 [49])	

Community hearing care innovation

Primary prevention

mHealth initiatives in public health have generally been focused on prevention due to the simple, low-cost and scalable nature of sending text messages to patients on a range of services, including reminders to take medication and prenatal education [20]. From a public health perspective, mHealth initiatives can support maternal and early childhood health, including promoting immunisation to prevent childhood hearing loss [21,22]. More specifically in hearing care, however, there has been limited adoption of mHealth initiatives for primary prevention [15]. Recently a mHealth-supported hearing health training program for early childhood development (ECD) practitioners was developed and evaluated in low-

income South African communities [23]. Using WhatsApp messages constituting simple infographics and a voice note allowed for training ECD practitioners to improve knowledge and perceptions of hearing health in young children. This study included a large sample of more than 1000 practitioners that demonstrated significant improvements in knowledge and perceptions post-training that was maintained six months later [23]. Using low-cost mHealth technologies and widely used communication platforms like text messaging and WhatsApp can facilitate hearing health education and training to promote early detection, appropriate referral and even support strategies for affected children. These approaches are usually inexpensive and can easily be scaled to target populations.

Secondary prevention

The majority of hearing losses cannot be prevented and, therefore, systematic implementation of secondary prevention strategies is essential to promote optimal outcomes for affected individuals and reduce societal costs associated with late identified hearing loss [1,19]. The World Report on Hearing prioritises early detection through screening programs across the life course with an emphasis on innovative technologies to make this possible [1]. There has been a tremendous increase in digital and mHealth technologies to allow for early detection of hearing loss over the past decade [15,24,25,26]. The majority of published mHealth applications in hearing care have centred on screening performed in LMICs and on young children [18].

Pure tone audiometry screening

Pure tone audiometry screening using digital devices, including smartphones and tablets, has become increasingly available using downloadable applications or as preloaded with calibrated headphones [25,27]. Downloadable pure tone audiometry applications do not offer audiometry with calibrated headphones that adhere to international standards (i.e., ISO or ANSI) and typically present with poorer quality results [25,26]. The hardware consistency and earphone consistency of Apple devices have shown better quality screening results compared to other manufacturers, but they still do not offer a certified audiometry application. Several mHealth solutions with preloaded applications and calibrated headphones are now registered audiometry solutions with calibrated headphones that have been widely validated and also recommended by the World Health Organization [1,25,26,28].

In LMICs, the use of mHealth audiometry screening technologies by minimally trained screeners, including CHWs and nurses, has proven effective in community-based services [19,29-33]. The inclusion of stringent quality control features in these solutions, like real-time

monitoring of environmental noise, tracking response times and even doing surveillance of the facilitator's screening quality, is essential for decentralised screening [30,33,34]. Linked to cloud-based data management facilities allow for surveillance of program outcomes and asynchronous models of telehealth provision by program managers [10,30]. Recent studies have demonstrated large-scale school-based screening for hearing and vision loss by CHWs using a mobile device [35,36]. These studies demonstrate the scalability and cost-effectiveness of pure tone audiometry screening for hearing loss using primary health workers operating innovative technologies that are automated and easy to operate. The intuitive nature of mHealth technologies designed to be digitally inclusive means that minimally trained persons can facilitate hearing health screenings. One of these technologies for example (hearScreen by hearX Group, South Africa), was selected as an international case study by UNESCO in community health support through the use of inclusive digital solutions by persons with even basic literacy and digital skills [37].

Digits-in-noise screening

Apart from more traditional hearing screening using pure tone audiometry, there has been much work done on self-screening solutions using speech-in-noise testing, in particular, the digits-in-noise (DIN) test. This test requires listening to randomly presented digit triplets in background noise that must be identified on a keypad. The benefit of the DIN test is that it does not require calibrated headphones, it is quick and efficient and can be offered on digital platforms, including websites and smartphone applications [26]. The first smartphone version launched as a national hearing screening test is called hearZA (hearX group, South Africa), with widespread uptake in South Africa [38,39]. Subsequently, the World Health Organization launched a version in 2019 supporting multiple languages called hearWHO [40]. Available on iOS and Android app stores, the hearWHO test was conducted by almost 250 000 persons in nearly every country (92%) in just over two years. Also available as a free hearWHO Pro version for use by CHWs, this mHealth screening tool demonstrates the power of digital technologies as a secondary prevention strategy that can be scaled rapidly at minimal cost [40].

Point-of-care diagnostics

Digital and mHealth technologies for diagnosis in hearing care have been widely studied in recent years [18]. To support decentralised screening models in communities, novel point-of-care diagnostic tools facilitated by CHWs are making onsite confirmation and differentiation of hearing loss possible [10,41]. Sound-attenuating strategies, including passive attenuation with headphones or using earmuffs covering insert earphones or hearing aids employed for

in situ audiometry, enable testing in non-clinical environments like homes, schools and community centres [15,36,42,43]. Adults with sensorineural hearing loss can also be tested with air conduction audiometry with less susceptibility to environmental noise since their hearing thresholds are already elevated.

Sound booths are expensive, stationary and, apart from tertiary health care or advanced private health facilities, are typically unavailable in the LMICs [44]. Required for bone conduction and freefield audiometry sound booths are not essential to provide hearing care to the majority of persons with hearing loss. In adults, more than 95% of hearing loss is sensorineural loss, with an estimated 2 to 5% having conductive, mixed or retrocochlear losses [45,46]. In cases of hearing loss due to ear disease, more clinical test environments, i.e., sound booths, are typically required for diagnostic purposes. Triage using innovative technologies and algorithms can support the differentiation of persons who are suited to community-based management from those requiring more advanced medical diagnostics and treatment. Community-based screening programs also benefit from point-of-care diagnostics to effectively triage patients that can benefit from onsite management and those requiring referral for follow-up care. Innovative mHealth technologies, including AI-supported video-otoscopy [47], mHealth tympanometry [48] and novel algorithms combining common test results [49] are increasingly emerging to support diagnostic access and effective triage of patients in communities.

Tertiary prevention

Once hearing loss has been confirmed, management options to mitigate the negative consequences must be prioritised [19]. Community-based hearing care has been demonstrated to be effective in providing primary ear and hearing services [50] and treating sensorineural hearing loss using hearing aids for adults [13,51,52]. A recent community-based hearing intervention study demonstrated that a community health worker-delivered personal sound amplification device significantly improved self-perceived communication function compared with a wait-list control group [13].

In another recent study, we employed an mHealth-enabled model to deliver hearing aids programmed for the unique hearing loss of patients in low-income communities [15]. In this study, older adults with self-reported hearing loss were provided with in situ audiometry facilitated from a mobile phone. Once completed, the hearing aids were programmed immediately via Bluetooth according to a clinical hearing aid fitting algorithm (NAL/NL2) to allow users a demonstration of amplification. The demonstration in a real-life setting, in this instance in a person's home, was a powerful motivator to take up hearing aids [15]. In

instances where community members acquired hearing aids, community health workers were the first point of contact for support queries via text messaging or WhatsApp. These could be escalated to the audiologist serving as the program manager. A mHealth hearing aid acclimatisation and support program was facilitated by the CHWs and consisted of 20 messages delivered over a 45-day period that contained a voice note and graphical illustration sent via WhatsApp [53]. This hearing aid fitting and support program was found to be feasible, successfully facilitated by CHWs, supportive of sustained hearing aid use, and had high rates of satisfaction [15,53].

In contrast to growing evidence and demonstrated potential for the community-based provision of hearing interventions for adults, there is very limited evidence in children, especially young children with hearing loss [54]. While children with hearing loss are a much smaller group compared to adults, providing timely, cost-effective interventions in communities can significantly improve families' outcomes and reduce disability-adjusted life years [1]. Innovations directed at children with hearing loss must therefore be prioritised, especially for those in LMICs unable to access care.

Conclusion

Innovations in technology, service delivery models, and community-based interventions are crucial in reaching the unreached with hearing care. These innovations have the potential to increase access to hearing care, improve the quality of life for those affected by hearing loss and reduce global costs associated with untreated hearing loss. However, it is important that these innovations be coupled with increased public health awareness and education on hearing loss and its impact on quality of life to support more equitable access to hearing care.

Conflict of Interest Statement

The relationship between author DS and the hearX Group includes equity, consulting, and potential royalties.

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Author contributions

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