Expanding the Capacity of Otolaryngologists in Kenya through Mobile Technology

Asitha D. L. Jayawardena, MD, MPH1, Charissa N. Kahue, MD1, Samantha M. Cummins2, and James L. Netterville, MD1

Abstract

Objective. To determine if reliable, objective audiologic data can be obtained by nonotolaryngology and nonaudiology practitioners using novel mobile technology in an effort to expand the capacity for early identification and treatment of disabling hearing loss in the developing world.

Study Design. Cross-sectional, proof-of-concept pilot study.

Setting. Screenings took place during an annual 2-week otolaryngology surgical mission in October 2016 in semirural Malindi, Kenya.

Subject and Methods. Eighty-seven patients (174 total ears) were included from 2 deaf schools (n = 12 and 9), a nondeaf school (n = 9), a tuberculosis ward (n = 8), and a walk-in otology clinic at a local hospital (n = 49). An automated, tablet-based, language-independent, clinically validated, play audiometry system and wireless otoscopic endoscopy via an iPhone or laptop platform was administered by Kenyan community health workers (CHWs) and nursing staff.

Results. Various degrees of hearing loss and otologic pathology were identified, including 1 child presumed to be deaf who was found to have unilaterally normal hearing. Other pathology included 2 active perforations, 2 healed perforations, 2 middle ear effusions, and 1 cholesteatoma. CHWs and nursing staff demonstrated proficiency performing audiograms and endoscopy. Patients screened in a deaf school were more likely to complete an unreliable audiogram than patients screened in other settings (P < .01).

Conclusion. This study demonstrates the feasibility of a non–otolaryngology-based hearing screening program. This may become an important tool in reducing the impact of hearing loss and otologic pathology in areas bereft of otolaryngologists and audiologists by allowing CHWs to gather important patient data prior to otolaryngologic evaluation.

Keywords
global health, public health, low- and middle-income countries, endoscopic otoscopy, mobile technology, iPad audiometry, hearing screening, community health workers

Received January 9, 2018; revised February 5, 2018; accepted March 5, 2018.

The vast majority (80%) of disabling hearing loss is found in low- and middle-income countries (LMICs). Unfortunately, the countries with the highest burden of hearing loss are often those least able to help patients accommodate to their disability. In these regions, early identification and treatment are of the utmost importance, as deafness can cause significant functional impairment in the ability of these individuals to contribute productively to society. Sub-Saharan Africa, unfortunately, has very limited otolaryngology and audiology capacity. In Kenya specifically, there are 1.2 otolaryngologists and 0.12 audiologists per 1,000,000 people, respectively. The United Kingdom’s (UK’s) National Health System is designed to apportion health care providers according to census data. As such, there are 10 otolaryngologists and 41 audiologists in practice per 1,000,000 people in the UK. Extrapolating these figures, Kenya has just 12.1% and 0.3% of the capacity of otolaryngologists and audiologists, respectively, compared with an appropriately proportioned developed country. Shortages of otolaryngology and audiology services

1Vanderbilt University Medical Center, Department of Otolaryngology, Nashville, Tennessee, USA
2Vanderbilt University School of Medicine, Nashville, Tennessee, USA

Corresponding Author:
Asitha D. L. Jayawardena, MD, MPH, Vanderbilt University Medical Center, 7209 Medical Center East-South Tower, 1215 21st Avenue South, Nashville, TN 37232-8605, USA.
Emails: jayawardena.asitha@gmail.com, asitha.d.jayawardena@vanderbilt.edu

Creative Commons CC-BY-NC: This article is distributed under the terms of the Creative Commons Attribution 4.0 License (http://www.creativecommons.org/licenses/by/4.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
in Kenya and other LMICs pose challenges to early identification and treatment of otologic pathology.4

Despite having limited access to hearing health care providers, Kenya, like many LMICs, has a surprisingly robust telecommunications infrastructure.5 In fact, an estimated 88% of Kenyan adults have a cellphone and 81% have access to the Internet.6,7 These numbers, which are only increasing, have allowed e-Health and m-Health platforms to play a significant role in expanding the capacity of health care providers in LMICs.5,8,9

In an effort to expand the capacity for otolaryngologists and audiologists to identify treatable hearing loss, we piloted a novel, presurgical screening tool designed to be conducted by nurses and nonmedical staff with minimal training using existing infrastructure (mobile and Internet technology). The screening tool consisted of a 2-armed system employing a tablet-based play audiometry and otoscopic endoscopy to record dual objective measures that can be used by otolaryngologists to determine patient candidacy for audiologic (ie, preferential classroom seating, hearing aids) or surgical intervention. The program was designed to be simple, portable, language independent, and cost-effective to optimize it for use in low-resource settings. This study tests the feasibility of the aforementioned screening program in multiple health care settings.

Methods

Study Design

A cross-sectional hearing screening program was used to assess patients across a variety of settings in semirural Malindi, Kenya. Screenings took place during an annual 2-week head and neck surgical mission in October 2016. Participants underwent a formal audiometric evaluation and otologic endoscopic examination. Local Kenyan nurses, community health workers (CHWs), and nongovernmental organization volunteers were trained and completed the audiograms and examinations. Exams were performed by local staff primarily without assistance unless assistance was required, in which otolaryngology training staff were available to troubleshoot.

Data were collected and organized using Microsoft Excel (Redmond, Washington, USA). Basic statistics were completed using IBM SPSS Statistics for Macintosh Version 24 (Armonk, New York, USA). Categorical variables were analyzed using a χ2 test. This study was financially supported by a voucher grant from the Vanderbilt Institute for Clinical and Translational Research. Further funding was obtained from the American Academy of Otolaryngology—Head and Neck Surgery Foundation Humanitarian Grant (A.D.L.J. and C.N.K. were recipients). This study was reviewed by the Vanderbilt University Medical Center Institutional Review Board (IRB) as IRB exempt because of minimal risk to the subjects. Verbal consent was obtained from all participants prior to proceeding, and all recorded data were deidentified.

Subjects

Patients were recruited from multiple locations. The walk-in clinic at Tawfiq Muslim Hospital (TMH) in Malindi, Kenya, was advertised with flyers in the community as well as by word of mouth. Screenings also took place in three schools, 2 of which serve deaf students (Gede Special School for the Deaf and the Kakayuni Special School for the Deaf) and 1 that serves nondeaf students (Gede Primary School). Local schools were contacted in advance to identify students who would benefit from audiometric evaluation. Three children from the Silali Special School traveled to TMH and participated in the walk-in clinic at TMH. In addition, 8 patients from a local tuberculosis (TB) ward traveled to TMH for screenings to monitor for ototoxicity. Participants who expressed discomfort with audiometric evaluation or otologic examination were excluded.

Screening Process

Each participant underwent otologic examination and screening audiometric evaluation. Prior to screening, each participant underwent a brief otoscopic examination to ensure the presence of a patent external auditory canal. Patients with cerumen impaction underwent a limited cerumen removal prior to endoscopic examination and audiometric evaluation. Endoscopic images of the tympanic membrane were captured using either a wireless otoscope (Firefly Global DE550, Palo Alto, California, USA) or a smartphone-enabled otoscope (Cellscope, San Francisco, California, USA; Figure 1). Smartphone-otoscope images were captured with and stored on an iPhone 6 (Apple, Cupertino, California, USA) using Cellscope-Oto for Clinicians software (Cellscope). Wireless otoscope images were captured with a Firefly DE550 wireless otoscope (Firefly Global) and stored on a 32-Gb HP Stream laptop (Hewlett Packard, Palo Alto, California, USA). Costs of equipment used are described in Table 1. Of note, Shoebox and Firefly Global offer humanitarian discounts for select cases beyond what is quoted in Table 1. Patients from the TB ward underwent audiometric evaluation but were excluded from otologic endoscopy to prevent possible equipment contamination.

Audiometric evaluation was conducted using an automated, language-independent, clinically validated, play audiometry system (Shoebox Professional Audiometer by Clearwater Clinical, Ottawa, Ontario, Canada) on an iPad Mini 2 tablet (Apple; Figure 2). “Play audiometry” is presented to the patient as a game in which the participant indicates whether he or she can hear a presented sound. Sounds are played at various frequencies with increasing decibel (dB) intensity via a modified Hughson-Westlake method in an increasing-decreasing fashion until the correct threshold is determined. Silent cues are presented at random to ensure participant understanding and compliance with the test. Continuous, frequency-specific background noise is monitored during the test, and tones presented during times of increased background noise are repeated. Unmasked pure-tone air and bone-conduction thresholds were performed using a calibrated TDH-50 air transducer and a B-81 bone transducer (Clearwater Clinical). Participants who self-reported normal hearing underwent a screening audiogram
If found to have a deficit, or in cases of self-reported hearing loss, participants underwent diagnostic evaluation (thresholds tested included 500, 1000, 2000, and 4000 Hz). Pediatric participants were guided through the test by a trained provider. Adult participants received instructions on how to use the application and self-administered the testing under supervision of local trained providers. All audiometric testing was completed in a quiet room. Audiograms were automatically encrypted, saved locally on the tablet, and uploaded to a secure Internet backup during WiFi availability. Patients were assigned a unique medical record number to match their audiograms to their endoscopic images.

Outcomes

Audiogram results were categorized into mild (30-40 dB), moderate (41-60 dB), severe (61-80 dB), and profound (≥80 dB) hearing loss. Ambient room noise prohibited accurate measurements less than 30 dB. Hearing loss was further categorized into sensorineural hearing loss (SNHL), conductive hearing loss (CHL), and mixed hearing loss. If a patient provided consistent affirmative responses in the absence of a tone, the audiogram was automatically deemed unreliable by the software. Unreliable audiograms were excluded. Otoscopic images were reviewed by both A.D.L.J. and C.N.K. and classified as normal, cerumen impaction, active perforation, healed perforation, possible cholesteatoma, and granulation tissue. Discrepancies between A.D.L.J. and C.N.K. were resolved by J.L.N.

Results

One hundred seventy-four ears (n = 87 patients) were tested in 5 different settings (Table 2), including 2 deaf schools (n = 12 and 9; Gede Special School for the Deaf and the Kakayuni Special School for the Deaf), a nondeaf school (n = 9; Gede Primary School), patients from a TB ward (n = 8), and a walk-in otology clinic at TMH (n = 49).

Of patients tested, 17 had unreliable audiograms. Most (65%, 11/17) unreliable audiograms were obtained from patients screened in deaf schools (Table 3). In fact, patients screening in a deaf school were more likely to complete an unreliable audiogram than patients screened in other settings (P < .01). Deaf children demonstrated poor understanding of the play audiometry application despite sign language explanations provided by their teachers. Only patients with reliable audiograms (n = 70) were included in the following descriptive statistics (Table 2).

Three of nine (33%) children in the nondeaf school (Gede Primary School) had mild SNHL; the remainder of children screened had normal hearing. Most (73%; 8/11) patients from the 2 deaf schools were found to have severe-to-profound SNHL. Notably, 1 patient in the deaf school had unilaterally normal hearing, 1 had only mild SNHL, and another had moderate SNHL. Of patients from the TB ward, 50% (4/8) had normal hearing and 50% (4/8) had moderate SNHL.

Patients who presented to the walk-in clinic at TMH presented with a variety of otologic complaints and had subsequently variable audiogram results. Sixteen patients (38%) presented with normal hearing, 19 (45%) had SNHL, and 7 (17%) had CHL (Table 2).

Otoscopic examination revealed various patients with abnormal tympanic membrane pathology. One patient presented with a large, unilateral nasopharyngeal mass and was found to have a serous effusion with associated conductive hearing loss (Figure 3). Two ears revealed healed perforations, and 2 ears demonstrated active perforations. One cholesteatoma was
identified. There were no discrepancies noted between A.D.L.J. and C.N.K. in interpreting otoscopy results.

**Discussion**

The global burden of disabling hearing loss is overwhelming, with eastern Asia, southern Asia, and Sub-Saharan Africa most significantly affected.\(^2\) In Sub-Saharan Africa, the calculated deficits of otolaryngologists and audiologists when compared with UK service ratios are 4669 and 20,406, respectively.\(^4\) This proof-of-concept study suggests that basic otologic and audiologic data can be captured by individuals without formal otolaryngology or audiology training, thus shifting the burden away from already overwhelmed health care providers. Inferences about the incidence and prevalence of hearing loss and otologic pathology in rural Kenya are outside of the scope of this study.

Given the relative paucity of hearing health care providers and the growing number of CHWs, the path moving forward should foster development of programs that use our CHW colleagues. It is estimated that there are more than 1

---

**Figure 2.** iPad audiometry can be administered by either the patient (A) or an assistant (B), in the case of a child.

**Table 2.** Severity of Hearing Loss by Screening Site.\(^a\)

| Degree of Hearing Loss by Site | Normal | Mild | Moderate | Severe | Profound | Total |
|-------------------------------|--------|------|----------|--------|----------|-------|
| Gede Primary School           | 6      | 3    | 0        | 0      | 0        | 9     |
| Gede Special School for Deaf | 1      | 1    | 1        | 5      | 0        | 8     |
| Kakyuni Special School for Deaf | 0    | 0    | 0        | 1      | 2        | 3     |
| Tawfiq Hospital walk-in clinic | 16   | 8\(^b\) | 11\(^b\) | 4      | 3        | 42    |
| Tuberculosis ward             | 4      | 0    | 4        | 0      | 0        | 8     |
| Total                         | 27     | 12   | 16       | 10     | 5        | 70    |

\(^a\)Expectedly, deaf schools had more severe to profound hearing loss than nondeaf settings.

\(^b\)Of note, 8 patients at Tawfiq walk-in clinic had conductive hearing loss (1 mild, 7 moderate). No other sites reported conductive hearing loss.

**Table 3.** Characteristics of Patients Obtaining Unreliable Audiograms.\(^a\)

| Setting                                      | Reliable Audiograms | Unreliable Audiograms | Total |
|----------------------------------------------|---------------------|-----------------------|-------|
| Patients from deaf schools                   |                     |                       |       |
| Gede Special School for the deaf             | 3                   | 6                     | 9     |
| Kakyuni Special School for the deaf          | 8                   | 4                     | 12    |
| Total screened from deaf schools             | 11                  | 10                    | 21*   |
| Patients screened in other settings          |                     |                       |       |
| Tawfiq Muslim Hospital walk-in clinic        | 42                  | 7                     | 49    |
| Gede Primary School                          | 9                   | 0                     | 9     |
| Tuberculosis ward                             | 8                   | 0                     | 8     |
| Total screened in other settings             | 59                  | 7                     | 66*   |

\(^a\)Patients screened in deaf schools were more likely to complete an unreliable audiogram than patients screened in other settings; \(^*P < .01\).
million paid CHWs in Asia and Sub-Saharan Africa.10 Many of these CHWs are using mobile technology to expand their reach in LMICs.11 In fact, several of our colleagues in other surgical subspecialties have capitalized on mobile technology use among CHWs. Ophthalmologists are using CHWs to gather vision screening data using smartphone technology.12-14 The African Teledermatology Project has CHWs store and forward suspicious cases on a smartphone to expert dermatologists for diagnosis.15 Orthopaedic surgeons and urologists are using smartphone technology to teach best-practice surgical techniques to those in the LMICs.16,17 Although both tablet play audiometry and wireless endoscopic otoscope systems have been clinically validated in both high- and low-resource settings, to our knowledge, this is the first CHW-based program in the field of otolaryngology in LMICs.18-23

Although CHW-based programs such as this can serve to reduce some of the clinical burden of otolaryngologists in LMICs, a number of barriers still exist. First, our pilot program uses multiple platforms (laptop, smartphone, and tablet), which is cumbersome for a CHW to collect efficiently. The ideal platform would collect both audiograms and otoscopy on the same interface, which would eliminate extra steps in organizing the data collected. Second, no existing audiogram application effectively accounts for ambient noise, which can cause falsely positive hearing screening failures in noisy settings. In addition, no audiogram platform accounts for children who are unable to participate in traditional audiometry (developmentally delayed and children younger than 4-5 years). The ideal platform would also include otoacoustic emissions or automated auditory brainstem responses to capture prelingual children to optimize the effectiveness of the intervention. In addition, bone-conduction measurements are limited as they are not available with masking in the play audiometry mode. Therefore, the ability of a CHW to gather information regarding CHL versus SNHL is limited, as masked bone conduction is not available in an automated, easy-to-use format.

Despite testing only iPad-based audiometry, we did not find that the features of an iPad (larger screen size, storage space, etc) provided an essential advantage that would make having an iPad, as opposed to a mobile phone or laptop, an essential component to a CHW-based hearing screening program. Smartphone-based audiometer applications have been recently released and are available for lower cost (HearX Premium, $899) than iPad audiology. As this hardware was released after our study concluded, the HearX Premium was not tested during our pilot. This study has established that CHW-based hearing screening is feasible; however, further testing should be completed regarding the efficacy of newer alternate mobile audiology platforms.

Establishing the efficacy of a CHW to gather basic objective audiologic and otoscopic data can have a significant impact on the number of patients an otolaryngologist in a low-resource setting can treat. In these settings, audiologists are even more rare than otolaryngologists, which makes audiograms very valuable. Adding reliable audiograms and otoscopic data to a patient’s chart prior to an initial visit with an otolaryngologist can allow a provider to appropriately screen patients to increase the likelihood of identifying patients with surgically treatable pathology. Therefore, a CHW-based hearing screening program can significantly augment an otolaryngologist practicing in a low- and middle-income country.

Otolaryngology in LMICs has 2 main players: local otolaryngologists and international otolaryngologists who participate in surgical and educational service work. Telemedicine programs such as this can bridge the gap between these 2 groups. Future implications include the ability for surgical mission trips to understand the pathology of the patients they will treat prior to their arrival. In addition, this program will allow local otolaryngologists to communicate with international surgeons regarding questions that may emerge during postsurgical follow-up. This program will need to be trialed in other countries prior to broader conclusions being drawn about the use of CHW-centered telemedicine in otolaryngology.

**Conclusion**

This study highlights the utility of a CHW-based screening tool to identify and document audiometric evaluations and otologic endoscopic examinations. The combination of these 2 objective measures may identify candidates for hearing
aids or otologic surgery and may help treat hearing loss in areas bereft of audiologists and otolaryngologists.

Acknowledgments
This work would not be possible without the organizational and financial support of 2 nongovernmental organizations, More Than Medicine and the Caris Foundation. Individuals trained to perform evaluations included Moses Gona, Tina Nakapuyusi, Chris Nicholson, Iddy Nicholson, and Jim Reppart, who were instrumental in organizing and implementing the screening protocol.

Author Contributions
Asitha D. L. Jayawardena, study design, implementation/execution, data analysis, manuscript creation; Charissa N. Kahue, study design, implementation/execution, data analysis, manuscript editing; Samantha M. Cummins, data analysis, manuscript editing; James L. Netterville, study design, implementation/execution, manuscript editing.

Disclosures
Competing interests: None.
Sponsorships: None.
Funding source: Both A.D.L.J. and C.N.K. received the American Academy of Otolaryngology—Head and Neck Surgery Foundation Humanitarian Grant, which partially funded travel expenses to Kenya. The Shoebox audiometer (Clearwater Clinical) was purchased with a grant from the Vanderbilt Institute for Clinical and Translational Research (Vanderbilt University Medical Center, Nashville, Tennessee, USA).

References
1. WHO global estimates on prevalence of hearing loss. Geneva, Switzerland: World Health Organization; 2012. http://www.who.int/pbd/deafness/estimates. Accessed November 24, 2016.
2. Olusanya BO, Neumann KJ, Saunders JE. The global burden of disabling hearing impairment: a call to action. Bull World Health Organ. 2014;92:367-373.
3. Fagan JJ, Jacobs M. Survey of ENT services in Africa: need for a comprehensive intervention. Glob Health Action. 2009;2.
4. Fagan JJ. Developing world ENT: a global responsibility. J Laryngol Otol. 2012;126:544-547.
5. Kumar P, Paton C, Kirigia D. I’ve got 99 problems but a phone ain’t one: electronic and mobile health in low and middle income countries. Arch Dis Child. 2016;101:974-979.
6. Communications Authority of Kenya. First quarter sector statistics report for the financial year 2015/2016 (July–September 2015). http://www.ca.go.ke/images/downloads/STATISTICS/ Sector%20Statistics%20Report%20Q1%202015-16.pdf. Accessed September 6, 2017.
7. Internet World Stats. AFRICA 2017 population and Internet users statistics for 2017. http://www.internetworldstats.com/stats1.htm (updated June 30, 2017). Accessed September 6, 2017.
8. Obasola OL, Mabawonku I, Lagunju I. A review of e-Health interventions for maternal and child health in Sub-Saharan Africa. Matern Child Health J. 2015;19:1813-1824.
9. Lewis T, Synowiec C, Lagomasino G, et al. E-health in low- and middle-income countries: findings from the Center for Health Market Innovations. Bull World Health Organ. 2012;90:332-340.
10. Earth Institute of Columbia University Technical Task Force on Community Health Workers. One Million Community Health Workers. Technical Report of the Earth Institute. New York, NY: Columbia University; 2011.
11. Macleod B, Phillips J, Stone AE, Walji A, Awoonor-Williams JK. The architecture of a software system for supporting community-based primary health care with mobile technology: the Mobile Technology for Community Health (MoTeCH) Initiative in Ghana. Online J Public Health Inform. 2012;4(1). pii: ojphi.v4i1.3910.
12. Bastawrous A, Rono HK, Livingstone IA, et al. Development and validation of a smartphone-based visual acuity test (peek acuity) for clinical practice and community-based fieldwork. JAMA Ophthalmol. 2015;133:930-937.
13. Bastawrous A, Giordani ME, Bolster NM, et al. Clinical validation of a smartphone-based adapter for optic disc imaging in Kenya. JAMA Ophthalmol. 2016;134:151-158.
14. Livingstone IA, Tarbert CM, Giordani ME, Bastawrous A, Middleton D, Hamilton R. Photometric compliance of tablet screens and retro-illuminated acuity charts as visual acuity measurement devices. PloS One. 2016;11:e0150676.
15. Weinberg J, Kaddu S, Gabler G, Kovarik C. The African Teledermatology Project: providing access to dermatologic care and education in sub-Saharan Africa. Pan Afr Med J. 2009;3:16.
16. Bernstein RM, Cozen CB, Watts HG, Hohl W. Mobile Pediatric Orthopaedic Education (MoPOEd): a unique program teaching sustainable pediatric orthopaedics in the developing world. J Bone Joint Surg. 2011;93:e134(131-135).
17. Campain NJ, MacDonagh RP, Mleta KA, McGrath JS, Urolink B. Over the horizon—future innovations in global urology. BJU Int. 2015;116:318-320.
18. Yeung J, Javidnia H, Heley S, Beaugregard Y, Champagne S, Bromwich M. The new age of play audiometry: prospective validation testing of an iPad-based play audiometer. JAMA Otolaryngol Head Neck Surg. 2013;42:21.
19. Thompson GP, Sladen DP, Borst BJ, Still OL. Accuracy of a tablet audiometer for measuring behavioral hearing thresholds in a clinical population. Otolaryngol Head Neck Surg. 2015;153:838-842.
20. Kohlert S, Bromwich M. Mobile tablet audiometry in fluctuating autoimmune ear disease. J Otolaryngol Head Neck Surg. 2017;46:18.
21. Rourke R, Kong DC, Bromwich M. Tablet Audiometry in Canada’s north: a portable and efficient method for hearing screening. Otolaryngol Head Neck Surg. 2016;155:473-478.
22. Yeung JC, Heley S, Beaugregard Y, Champagne S, Bromwich MA. Self-administered hearing loss screening using an interactive tablet play audiometer with ear bud headphones. Int J Pediatr Otorhinolaryngol. 2015;79:1248-1252.
23. Moshtaghi O, Sahyouni R, Haidar YM, et al. Smartphone-enabled otoscopy in neurotology/otology. Otolaryngol Head Neck Surg. 2017;156:554-558.