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ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

Community health worker-based hearing screening on a mobile platform: A scalable protocol piloted in Haiti

Asitha D. L. Jayawardena MD, MPH[1] | Ashley M. Nassiri MD, MBA[1] | Dylan A. Levy BS[2] | Vienna Valeriani RN[3] | Alison J. Kemph AuD[4] | Charissa N. Kahue MD[1] | Nathaniel Segaren MD, MPH, MBA[3] | Robert F. Labadie MD, PhD[1] | Marc L. Bennett MD, MMHC[1] | Carl A. Elisée MD[5] | James L. Netterville MD[1]

[1]Department of Otolaryngology, Vanderbilt University Medical Center, Nashville, Tennessee

[2]Frank H. Netter MD School of Medicine, Quinnipiac University, North Haven, Connecticut

[3]Caris Foundation Haiti, Port-au-Prince, Haiti

[4]Department of Hearing and Speech Sciences, Vanderbilt University Medical Center, Nashville, Tennessee

[5]Department of Otolarhinolaryngology, Hopital de L'Universite d'Etat d'Haiti, Port-au-Prince, Haiti

Correspondence
Asitha D. L. Jayawardena, MD MPH, Department of Otolaryngology, Vanderbilt University Medical Center, 7209 Medical Center East-South Tower, 1215 21st Avenue South, Nashville, TN 37232-8605.
Email: jayawardena.asitha@gmail.com

Abstract

Objective: To establish the feasibility of a systematic, community health worker (CHW)-based hearing screening program that gathers Health Insurance Portability and Accountability Act-compliant electronic data (otoscopic images of tympanic membrane and audiometric evaluation) on a smartphone in an effort to streamline treatment options in resource-limited communities.

Methods: This is a cross-sectional study in which four schools were screened in Port-au-Prince, Haiti, during in April 2018. A total of 122 subjects (61% female) aged 5-17 years underwent an initial brief audiometric screen followed by a more comprehensive air conduction audiometric evaluation if they failed their initial screen. Participants with more than 35-dB loss in any frequency on their comprehensive audiometric evaluation received endoscopic otoscopy.

Results: Seventy-five percent of subjects (91/122) passed their initial screen. Of those who failed, 9% (4/44 ears) had a severe or profound hearing loss on comprehensive evaluation. Abnormal otoscopic findings (11/36 ears, 31%) included are cerumen impaction (n = 6), myringosclerosis (n = 3), tympanic membrane perforation (n = 1), and tympanic membrane retraction (n = 1). The average duration of the initial testing was 100 seconds (SD = 74 seconds), whereas the duration of comprehensive testing was 394 seconds (SD = 175 seconds). Extrapolating from these data, we estimate that a group of seven trained CHWs could gather formal audiologic and otologic data points for 100 children per hour using this protocol.

Conclusions: A systematic approach that utilizes local resources (CHWs) and existing infrastructure (cell phones and the Internet) can significantly reduce the burden of hearing healthcare specialists while simultaneously facilitating early diagnosis and management of disabling hearing loss in low-resourced settings.

Level of evidence: Level 4.

KEYWORDS

community health workers, global health, hearing screening, low- and middle-income countries, mobile technology, pediatric audiology, public health, scalable hearing screening

1 | INTRODUCTION

Hearing loss is the fourth leading cause of global disability, affecting over 466 million individuals.[1] It is estimated that over 32 million (7%) of these are children.[1] Unfortunately, the burden of disabling hearing loss falls disproportionately upon low- and middle-income countries (LMICs).[2] In fact, the prevalence of childhood hearing loss increases exponentially as national income decreases.[3] Therefore, the highest rates of childhood hearing loss occur in the countries with the fewest available resources to treat this disability.[4] Although the World Health Organization has declared the implementation of hearing screening programs as an important global health priority, LMICs have struggled to assemble and organize resources.[1,5] Most LMICs have a shortage of trained hearing healthcare specialists (audiologists and otolaryngologists) who are able to identify and treat children with hearing loss.[6,7]

Recently, mobile technologies have been utilized to extend the reach of existing hearing health services in LMICs.[8-13] Programs using calibrated headphones, tablet computers, and smartphones have been clinically validated in collecting accurate audiometric thresholds in pediatric populations.[14,15] Specialized cameras have also been developed for smartphone applications to provide reliable otoscopic imaging as a proxy for physical examination, which is used for diagnostics and medical decision-making for hearing loss.[9,16,17]

In the setting of limited access to hearing specialists, community health workers (CHWs) utilizing mobile technology can play an important role in screening projects. The concept of CHW-driven screening using mobile technology has been successfully employed in ophthalmology, dermatology, and orthopedics.[18-21] CHWs are generally available and can act as an intermediary between children in rural settings and the advanced healthcare personnel (such as audiologists and otolaryngologists) that are otherwise scarce in LMICs.[22-24] Using these intermediaries allows for the scalability of these programs as their initial screening process allows for selective referrals, thereby reducing the burden upon the more scarce specialized hearing healthcare professionals.

A recent report at the World Congress of Pediatric Otolaryngology (2019) outlined a longitudinal effort to develop, implement, and refine a hearing screening paradigm that is both scalable and sustainable in LMICs.[25] A multitiered screening algorithm in which CHWs gather both audiometric data and otoscopic images using a unified smartphone-based platform was described (Figure 1). This study presents the first data gathered from this novel screening algorithm administered in a cross-sectional study of children living in Port-Au-Prince, Haiti.

2 | MATERIALS AND METHODS

2.1 | Study design and setting

This study implemented a cross-sectional study design. Hearing screening was performed in four different schools in Port-au-Prince, Haiti, over a 5-day period in April 2018. Port-au-Prince (population 2.6 million) is the capital of Haiti, one of the poorest countries in the Western Hemisphere.[26] Haiti is classified as a low-income country according to the World Bank, with more than 57% of Haitians living below the poverty line ($2.41 USD daily).[26] Furthermore, Haiti has one of the lowest internet penetrations in the world, with approximately 12% of the population having access.[27]

The four schools were selected based on the proximity to the treatment facility (Haiti Adventist Hospital, Port-au-Prince, Haiti) and the school's availability and amenability to participation in the hearing screening program. The schools participating in the study ranged from preschool to eighth grade, and varied from 40 to 150 students at each location. All four schools were located within a 30-mile radius from the Haiti Adventist Hospital in Port-Au-Prince. Schools included are Institution Mixte Lumiere de Diquini, Ecole Saint Marie, Ecole Mixte Sainte Elizabeth, and Hopital St. Damien. A quiet testing location (eg, classroom) within the school was requested at each site. All testing was administered by local CHWs in Haitian Creole, the native language of the CHWs and the test subjects.

This study was approved by the Vanderbilt University Medical Center (VUMC) Institutional Review Board and local Haitian Institutional Review Board (Le Comité National de Bioéthique). Verbal consent was obtained and documented electronically for each participant directly into the smartphone platform. Waiver of parental consent was justified in order to not violate the ethical principle of justice and therefore systematically exclude children with an inability to gather parental consent (illiterate parents, poor access to parents, or deceased parents but no local documentation for power-of-attorney) in this otherwise noninvasive, minimal risk hearing screening protocol.

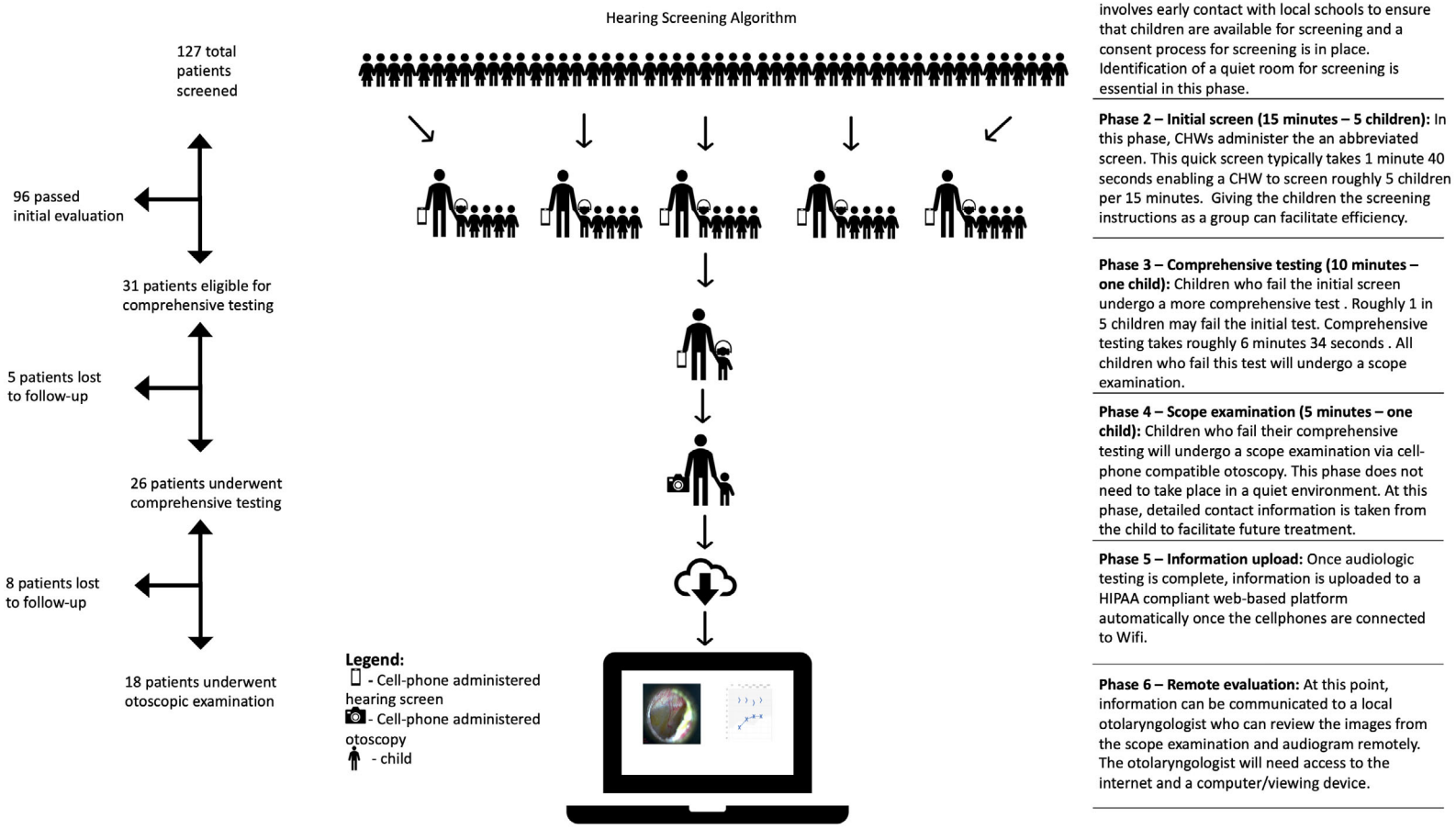

FIGURE 1 This figure represents the algorithm in which children are screened, re-screened and ultimately scoped in a streamlined manner by CHWs to facilitate treatment by an otolaryngologist

2.1.1 | Teaching strategy

Local CHWs were trained in testing procedures by otolaryngologists from VUMC's Department of Otolaryngology. CHWs were selected by the local NGO team. Criteria included are fluency in Haitian Creole, employment at the Caris Foundation, basic health literacy (assessed locally), and a lack of specialty training in otolaryngology or audiology. Initially, the test was taught to local primary care physicians and nurses who then trained local volunteers. CHW competency was evaluated by direct observation from an otolaryngologist prior to CHW-initiated independent screening. If necessary, further "spot training" was given to CHWs that needed further intervention. CHW competency using this training methodology in cellphone-based testing has previously been validated against an otolaryngologist conducting similar testing.[28]

2.1.2 | Participants

Subjects were recruited by school teachers and directors. Inclusion criteria were any child participating in school between the ages of 5 and 18 years of age. Children were screened on a class-by-class basis, with school directors guiding which specific classes to be screened in order to minimize interruptions to the school day. The screening protocol excluded any child who demonstrated discomfort or voiced desire for exclusion; however, this did not occur during our testing period. Participants were tested in groups of five to six, depending on the classroom space available. The CHWs explained the testing procedure to the group initially and provided repeat instructions on an individual basis for children who had difficulty completing the task.

2.1.3 | Hearing screening

All data were collected using Android-based cellphones (Samsung A3, Seoul, South Korea) equipped with hearX applications (hearX Group, Pretoria, South Africa). All devices were paired with precalibrated supra-aural Sennheiser HD280 Pro headphones (Wedemark, Germany). The following demographic data were collected from each participant: name, age, and test location. Test results were immediately stored on the phones and automatically uploaded wirelessly to Health Insurance Portability and Accountability Act-compliant web-based patient charts once the phones had internet connectivity.

The screening platform has a clinically validated background noise monitoring system that has been previously described.[29] The ambient noise levels during testing were recorded, and testing was automatically paused if ambient noise levels were deemed too high by the software.

This study utilizes a multitiered hearing screening algorithm (Figure 1). First, all children underwent a preliminary audiologic screening (HearScreen). For this screen, subjects were presented pure-tone stimuli separately for each ear at 1000, 2000, and 4000 Hz frequencies. All preliminary screen stimuli were presented at 35 dB, the threshold determined by the Global Burden of Disease Expert Group on Hearing Loss as the threshold in which intervention is definitively warranted.[30] To participate, children were instructed to raise their hand when they perceived a tone. Children were "conditioned" how to participate in the screening via the conditioning feature on the cell phone software that allows the tester to play a loud sound on command to facilitate test understanding. During the examination, if the participant raised their hand after a tone was presented, the tester would mark "correct" for that frequency. If a participant did not raise their hand after a tone, the tester would mark "incorrect" for that frequency, and move on to the next frequency. If the participant was marked "incorrect" for a frequency, the software was programmed to retest this frequency at the end of the screen. A "pass" for the preliminary screen indicated a raised hand for every presented frequency in both ears, whereas a "fail" indicated at least one frequency that was incorrect.

Any subject who failed the first stage of screening proceeded to the second stage of more comprehensive testing (HearTest). This more comprehensive test was administered using the same hardware and headphones as the preliminary screen. However, stimuli presented at this point included 500, 1000, 2000, and 4000 Hz for each ear. Unlike the preliminary test, the comprehensive test obtained hearing thresholds in the traditional Hughson-Westlake method by bracketing the threshold in an up-down fashion. For each ear, a pure tone average (PTA) was automatically calculated by the application (average of the thresholds at 500, 1000, and 2000 Hz frequencies). Similar to the preliminary screen, stimuli were presented at 35 dB and above. A "fail" for the comprehensive examination indicated a hearing level greater than 35 dB at any of the four tested frequencies. Comprehensive testing was done on the same day as the initial screen, also by CHWs.

A "fail" on the comprehensive examination prompted otoscopy to rule out transient causes for hearing loss—the third phase of testing. The endoscopic (HearScope) examination implements the use of camera software in addition to an endoscopic camera specifically designed to capture images of the external ear canal and tympanic membrane. Otoscopic images were stored along with audiologic testing results on a secure server in the cloud. Of note, the HearScope technology used in this study was a prototype. Otoscopic images obtained were reviewed by two senior authors (otologist and neurotologist).[31]

2.1.4 | Statistical analysis

Data collected in the field were uploaded from smartphone devices to the cloud. These data were then exported and analyzed using Microsoft Excel (Redmond, Washington, DC). Audiometric data herein are presented according to the 1995 American academy of otolaryngology - head and neck surgery consensus guidelines. Continuous variables were reported as means with SDs when normally distributed and medians with ranges when not normally distributed. Student

t tests were used to compare preintervention and postintervention means with normally distributed data, while a Mann-Whitney test was applied to medians with nonparametric values, with all tests two sided.

3 | RESULTS

3.1 | Phase one: Population identification

A total of 127 individual subjects were screened in five different settings, of which 60.6% (77/127) were female. Many subjects did not know their exact date of birth, so subject age was recorded as their current age rounded down to the nearest whole number. Average subject age was 11.4 years (range, 5-17 years).

3.2 | Phase two: Initial screening

A total of 127 subjects completed the preliminary screen. Of note, the first eight subjects were tested at the default intensity of 25 dB, while all subsequent subjects were tested at 35 dB. Audiometric data from 25-35 dB were excluded from our analysis on the first eight subjects. Additionally, 5 of these 127 subjects were found to have duplicate charts with different test results. It is unclear if these second charts represent the same subject or a second subject inadvertently tested under the wrong patient's name. As such, all charts with duplicate names were excluded from analyses. A total of 122 preliminary screen results were included in analyses, consisting of 732 thresholds. Each subject with a failed preliminary screen (47/122 subjects, 38.5%) automatically underwent immediate retesting of all initially failed thresholds as an included software-driven aspect of the initial screening (116/732 thresholds, 15.8%).

After this retesting, most (31/122 subjects, 25.4%) ultimately remained as failures (68/732 thresholds, 9.3%). Therefore, 91/122 patients (74.5%) passed the preliminary screen. The average duration of preliminary screening, including repeat testing when necessary, was 100 seconds (SD = 74 seconds).

3.3 | Phase three: Comprehensive testing

There were 26 completed comprehensive hearing screens. Similar to the preliminary screen, two subjects had duplicate charts requiring that these data sets be excluded from analyses. Two subjects were inadvertently administered a comprehensive test by CHWs despite passing the preliminary screen and therefore, these children were not included in this subsample, despite completing the comprehensive testing. Therefore, there were a total of 22 data sets that were analyzed as independent entries. The majority (20/22 subjects, 90.1%) had failed the previous preliminary screen. Of the 44 tested ears, 13 had no further loss than the 35 dB initially established on the preliminary screen. The remaining ears were classified as mild hearing loss (n = 21), moderate hearing loss (n = 6), severe hearing loss (n = 1), or profound hearing loss (n = 3). The PTA for comprehensive evaluation was 42.7 dB, and the threshold for each frequency was not significantly different (P = .13, analysis of variance [ANOVA]; 500 Hz: 45.1 dB; 1000 Hz: 43.3 dB; 2000 Hz: 39.7 dB; 4000 Hz: 40.8 dB). The average testing duration for comprehensive screening was 394 seconds (SD = 175 seconds).

3.4 | Phase four: Scope examination

A total of 18 subjects underwent endoscopy. Abnormal findings (11/36 ears, 31%) included are cerumen impaction (n = 6), myringosclerosis (n = 3), tympanic membrane perforation (n = 1), and tympanic membrane retraction pocket suggestive of cholesteatoma (n = 1). Eight subjects were lost to follow-up at this stage. There were no children in which otoscopy was attempted and failed due to child cooperation or provider inability to obtain an exam. A representative sample image of the clarity of tympanic membrane capture is included in Figure 2.

3.5 | Phase five: Information upload and data analysis

Narrow-band, frequency-specific ambient noise levels were recorded during preliminary screening (average at 1000 Hz: 51.8 dB; 2000 Hz: 46.5 dB; 4000 Hz: 41.2 dB) and were found to be louder at lower frequencies (P < .01). Furthermore, the rate of screening failure was higher in the lower frequencies: 1000 Hz: 27.0%; 2000 Hz: 11.2%; 4000 Hz: 9.4% (P < .01, ANOVA). The association between higher ambient noise and higher rates of screening failure in lower frequencies is illustrated in Figure 3.

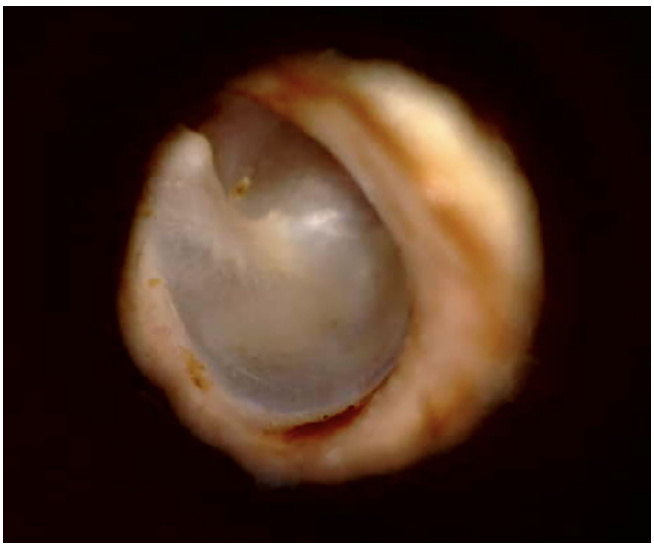

FIGURE 2 Image of a right ear taken by a community health worker using endoscopic otoscopy

There was no significant difference in the age of subjects and their ability to pass the hearing screen (pass: 11.5 years; fail: 11.2 years: $P = .36$). The facility in which the subjects were tested was also not correlated to their ability to pass the hearing screening ($P = .09$).

4 | DISCUSSION

Childhood hearing loss is an enormous global and public health issue with significant educational and development consequence for the untreated. Unfortunately, the greatest burden exists in LMICs where resources are the most limited. There is currently a lack of published data concerning the state of hearing loss in Haiti; however, in the larger region of Latin America and the Caribbean, the prevalence of childhood hearing loss is estimated to be 1.6% (ages 0-15).[3] Haiti and its 10.4 million people represent the dilemma faced by similar LMICs when it comes to addressing this public health crisis.

The past few years have seen a rapid expansion of available portable audiometric technology that can facilitate hearing screening outside of a soundbooth.[32] In our experience, we have found that utilizing phones is cheaper and has no inherent drawbacks when compared to using a larger screened tablet. In comparison to tablet-based hearing screening platforms (ie, SHOEBOX), the HearX system gathers similar data at a lower price point.[32] The SHOEBOX system does have the capability to gather bone conduction audiometry, but at a significantly higher cost. A major benefit of using smartphones is that they can be coupled with other devices allowing otoscopy to be utilized on the same platform. Smartphone-enabled otoscopes can easily capture images of the ear canal and tympanic membrane and save them to be shared and referenced in the future.[16,17] Furthermore, other smartphone attachments may facilitate other CHW-driven screening on the same platform, including vision screening.[34] Recruiting CHWs to participate in the screening process is an important aspect in ensuring the scalability and sustainability of these outreach projects.[24]

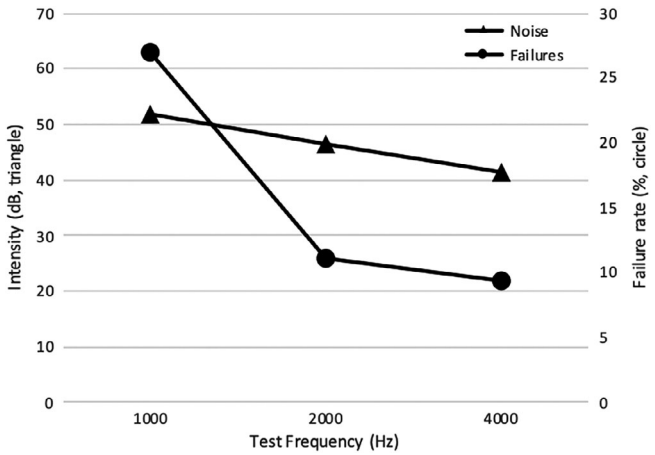

FIGURE 3 AMbient noise by frequency (n = 44) was recorded by the Samsung A3 and was significantly higher in lower frequencies ($P < 0.01$)

However, it is critical to recognize that their involvement is contingent on performing tasks that are manageable.

The second goal of this project is to demonstrate how this unified platform can, in the hands of CHWs, facilitate a novel paradigm for hearing screening that involves multiple tiers (Figure 1). The first stage of screening took an average of 1.7 minutes. While efficient, we recognize that this initial process of screening three frequencies at 35 dB does have its caveats. First, obtaining pure-tone thresholds at 1000, 2000, and 4000 Hz may inadequately identify subjects with isolated high- and/or low-frequency hearing deficits. Similarly, implementing a cut-off threshold of 35 dB is effective in mitigating the negative influence of concurrent background noise but may consequentially produce false-negative results for subjects with subtle, mild hearing deficits. More research may be warranted to explore the best combination of test frequencies and stimulus intensity to best screen for hearing loss in these settings, particularly because some otoscopic pathology manifests in low frequency hearing loss.

The average testing duration for comprehensive screening was about 6.7 minutes. Although substantially longer than the preliminary screen, this is still a relatively quick means of obtaining more accurate hearing thresholds across four different frequencies bilaterally. We estimate that the duration of image capture rarely exceeded 5 minutes, although this value was never specifically recorded. Altogether, the entire process of preliminary screening (with retesting of failures), comprehensive screening, and endoscopy can be accomplished in under 10 minutes for a single subject. Using 5 different smartphones, approximately 180 children can undergo preliminary screening in 1 hour, providing an efficient means for screening a large population of children. Extrapolating average failure rates, we estimate that a group of 7 CHWs could comprehensively evaluate 100 children per hour (including preliminary screen, comprehensive screen, and otoscopy).

At least some of the children who tested poorly (profound hearing loss, n = 4) likely had some degree of hearing as they were observed having conversations without difficulty with their peers. Some of these children's screening failure is likely secondary to a misunderstanding of how to participate in the hearing screening process. Further audiometric evaluation of these individuals is necessary to more precisely determine false failures. At the moment, gold standard soundbooth audiometry is not available in Haiti, or many other developing countries. However, this protocol allows select children with identified hearing loss to be targeted for mission audiology sessions in which they can undergo more formal audiometric evaluation including hearing aid fitting. We do not recommend this screening protocol be used in place of diagnostic testing when available.

Of the children who failed the first stage of screening, only 71% (22/31) successfully underwent the second stage. This large attrition rate is unfortunately representative of the challenging nature of performing hearing screening outreach in these low-resource settings. As this was a pilot study, we anticipate that future projects will have decreased attrition as more members of the team become familiar with the instructions and necessity to complete the algorithm in its entirety. At one location, the school day terminated during screening which required screening to stop prematurely as ambient noise levels

were too high to continue screening once surrounding classes was dismissed. Nonetheless, we firmly believe that this protocol accomplishes the goal of allowing CHWs to efficiently screen children for hearing loss in LMICs. The implementation and evaluation of this protocol in other LMICs is necessary to validate its scalability and sustainability.

5 | CONCLUSIONS

This study demonstrates the utility of an efficient, unified platform for performing pediatric hearing screening in a LMIC. By using a multitiered hearing screening paradigm coupled with a mobile otologic endoscope, CHWs can efficiently screen children for hearing loss and associated pathology. Converging this protocol onto a unified platform makes data collection less burdensome for the CHWs, and also streamlines the process by which this important data can be shared with other healthcare professionals.

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This project would not be possible without our local collaborators at the Caris Foundation, led by co-author Nat Segaren and Vienna Valeriani, and Tessa Lewis. Cathy Jones (Hear the World) led a subsequent audiology trip and fitted children identified who met criteria for hearing aids with hearing aids. Software and hardware discounts provided by the HearX Group also facilitated the feasibility of this project.

CONFLICT OF INTEREST

The authors have no financial interest in the HearX group.

ORCID

Asitha D. L. Jayawardena https://orcid.org/0000-0002-9932-8748
Ashley M. Nassiri https://orcid.org/0000-0001-9665-1868
Dylan A. Levy https://orcid.org/0000-0002-8744-9171
Charissa N. Kahue https://orcid.org/0000-0002-3066-1913
Marc L. Bennett https://orcid.org/0000-0002-0756-9772

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