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ARTICLE

Mhealth hearing screening for children by non-specialist health workers in communities

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ABSTRACT

Objectives: To compare outcomes of a community-based hearing screening programme using smartphone screening audiometry operated by specialist (School Health Nurses – SHNs) and non-specialist health workers (Community Health Workers – CHWs) in school children.

Design: This study used a two-group comparison of screening outcomes as conducted by SHNs and CHWs using smartphone screening for children in communities.

Study sample: The study included 71 CHWs and 21 SHNs who conducted community-based hearing screening on 6805 children. One thousand one hundred and fifteen hearing screening tests were conducted by the CHWs and 5690 tests by the SHNs.

Results: No significant difference in screening outcome was evident between CHWs and SHNs using a binomial logistic regression analysis considering age, test duration and noise levels as independent variables. Final screening result was significantly affected by age ($p < 0.005$), duration of test ($p < 0.005$) and noise levels exceeding at 1 kHz in at least one ear ($p < 0.005$). Test failure was associated with longer test duration ($p < 0.005$; B: 119.98; 95% CI: 112.65–127.30). CHWs had significantly ($p < 0.005$) longer test durations (68.70 s; 70 SD) in comparison to SHNs (55.85 s; 66.1 SD).

Conclusion: Low-cost mobile technologies with automated testing facilitated from user-friendly interfaces allow minimally trained persons to provide community-based screening comparable to specialised personnel.

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KEYWORDS
Adult or general hearing screening; hearing conservation/hearing loss prevention paediatric; non-specialist hearing screening

Introduction

The absence of trained healthcare workers threatens the overall health services a country can provide to its population (WHO 2007). The vast majority of persons with hearing loss globally are not identified early enough as they are unable to access diagnostic services and have no intervention options available to them (Olusanya, Wirz, and Luxon 2008). The progress is still limited, especially in low- and middle-income countries (LMICs), due to insufficient local capacity to scale up proven interventions at all levels of healthcare delivery (Davis and Hoffman 2019). The World Health Organisation (WHO) estimates that there is only one audiologist per 0.5 to 6.25 million people in the developing world (WHO 2013), with countries in sub-Saharan Africa typically presenting with less than one audiologist for every million people, and has shown no increase over the past 10 years (Fagan and Jacobs 2009; Mulwafu et al. 2017). Furthermore, the burden of disabling hearing loss is greatest in LMICs, where access to ear and hearing care is further compounded by poor infrastructure and resource constraints (Swanepoel et al. 2010). Lack of awareness on the impact of a hearing loss is a key contributor to the current situation, where a high prevalence is compounded by poor availability of services as well as financial resources for ear and hearing health (Chadha 2013).

Hearing loss is increasingly recognised as core to health and overall well-being; however, clinic-based hearing care is not adequately addressing the growing global burden (Suen, Bhatnagar, et al. 2019). Drawing on public health approaches used with other prevalent conditions, community-delivered hearing care offers new approaches to task shifting through community health workers (CHWs) (Suen, Bhatnagar, et al. 2019). Digital technologies, such as smartphones and tablets, are powerful enablers of this new cadre of providers who may be minimally trained persons (e.g. CHWs or lay health workers) but who can facilitate a range of services from screening through to diagnostics in partnership with professional healthcare providers (Eksteen et al. 2019; Suen, Bhatnagar, et al. 2019). Recent studies demonstrate the potential of CHWs to provide hearing screening in the field using simple mobile technologies like smartphone applications as opposed to conventional audiometers (Bright et al. 2019; Eksteen et al. 2019). However, evidence is lacking as to whether the key hearing assessments can be reliably conducted by a non-specialist (Bright et al. 2019). Mendenhall et al. (2014) describe a non-specialist healthcare worker as any type of community or lay health worker who is not a specialist in health but may have had some training in these fields. Therefore, CHWs are seen as a type of non-specialist healthcare worker.

Utilising CHWs in community-based hearing programs has been proposed as a way to improve access to ear and hearing health care (Wilson et al. 2017) with the goals of improving access to healthcare and decreasing morbidity and mortality rates (WHO 2007). These programs aim to lower the costs in seeking medical advice and create self-reliance and local participation in community healthcare (WHO 2007). Increasing access to

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resources and community participation in turn improves coverage and equity across a country (WHO 2007). A recent study suggests that CHWs can successfully raise community awareness of ear disease and hearing loss and promote participation in screening programmes (O'Donovan et al. 2019). In low resource settings, CHWs build bridges between formal health systems and communities, working to improve the relevance, acceptability and accessibility of health services (Rotheram-Borus et al. 2011; Suen, Bhatnagar, et al. 2019). Recent evidence shows that community-based hearing care by CHWs within an integrated ehealth framework can address some of the main barriers, like shortage of specialised healthcare professionals, costs, accessibility to healthcare, in traditional models of hearing care (Swanepoel 2020). Smartphone hearing testing using automated protocols and interpretation allows for screening and diagnostics provided by CHWs (Swanepoel 2020). Several unique mhealth app features address the lack of formally trained screeners, the complexity of traditional test equipment and the poor surveillance that characterises screening programmes (Swanepoel et al. 2019; Yousuf-Hussein et al. 2018). These new technologies enable the delivery of reliable audiometric assessments outside of the traditional clinic-based model, including in community-based primary care settings by CHWs (Mahomed-Asmail, Swanepoel, Eikelboom, Myburgh, et al. 2016; Suen, Marrone, et al. 2019; Swanepoel 2020; Swanepoel et al. 2019).

Traditionally hearing care in schools has been facilitated by School Health Nurses (SHNs) who are healthcare professionals also trained in audiometry (SHN) (ASHA 2017; South African Speech Language and Hearing Association (SASLHA), 2011). Nursing shortages, especially in LMICs and for school health, are a worldwide issue despite the integral part nursing plays in the healthcare system (Fraher, Spetz, and Naylor 2015; Wofford, 2019). In an effort to address health provider shortages, task shifting from higher cadre health providers to CHWs has become more common. Using these lower-level health workers to compensate for low human resources is an important strategy to expand access at the community level for primary healthcare services (Keller et al. 2017; Liu et al. 2011; Perry et al. 2014). For young children SHNs are considered healthcare professionals trained in hearing screening (WHO 2020) whereas CHWs are generalist healthcare workers (Mendenhall et al. 2014) and it raises the question about whether the screening performance of SHNs and CHWs on children in communities using mhealth technologies is comparable (Bright et al. 2019).

This study compares the outcomes of healthcare professionals trained in audiometry referred to as "trained professionals" (SHNs) and non-specialist (CHWs) healthcare workers conducting hearing screening with a smartphone audiometer in communities. Screening outcomes by SHNs and CHWs are evaluated in terms of child age and gender, headphone type, test duration and environmental noise levels exceeding the maximum permissible ambient noise levels (MPANLs).

Materials and methods

This project received institutional review board clearance from the Research Ethics Committee of the University of Pretoria (Reference no: 1201155-HUM048/0519) prior to the commencement of data analysis. As a retrospective analysis of services delivered permissions to analyse the de-identified data was required and obtained from the City of Tshwane and hearX Group prior to applying for institutional review board clearance.

Context

The study was conducted in underserved communities (Mamelodi, Laudium, Eersterust, Soshonguve, Tshwane Central, Hammanskraal and Cullinan) of the City of Tshwane in the Gauteng Province of South Africa by the Tirelo Bosha organisation. It was implemented and managed by the City of Tshwane in partnership with the hearX Group, a South African company that develops mobile applications to test hearing. Data were collected over a period of 18 months, excluding school holidays and campaign periods.

Participants

The study consisted of two groups of participants – those participants who conducted the screening test (also referred to as the testers) and those children who received the screening services.

Testers

Stratified sampling was utilised to differentiate the tester participants. The testers consisted of 21 SHNs and 71 CHWs. The SHN's were formally trained health workers who have obtained a tertiary qualification in school health nursing and have experience in conventional hearing screening using a manual audiometer. The SHNs conducted the hearing screening tests at schools in the local community where they provide other health screening services such as vision, dental and nutrition screening as well as the provision of vaccinations. The CHWs are healthcare workers from the community that have no formal education and have been informally trained to assist with government health programmes. The CHWs conducted the hearing screenings at Early Childhood Development (ECD) centres, clinics, home visits and health campaigns. This was part of their participation in community health programmes and the data were used towards this study.

Both groups of testers received training by an audiologist on the use of the smartphone application, information on ear and hearing care and setting up of the test environment as well as the referral process. The training covered a step by step use of the smartphone application, the anatomy and physiology of the ear, common signs of infections how to determine ambient noise levels and the criteria on when a referral was required. In addition, the training also covered the provision of test results to the parents which included an explanation to the parents that the test was a screening test and further assessment was necessary.

Children screened

The second group of participants consisted of children who received the hearing screening services. Convenience sampling was used to obtain participants in this group. The Integrated School Health Programme (ISHP) of South Africa (Department of Health and Basic Education 2012), states that children in grade 1 (1–7 years), 4 (9–11 years) and 8 (13–15 years), as well as those at risk should be screened for hearing loss. The smartphone hearing screening was implemented as part of the ISHP in the place of conventional audiometers. This allowed for the integration of the smartphone hearing screening into an existing health programme that was already being implemented as well as contribution to data that was to be used for analysis in this study. Hearing screenings were performed by the SHNs on children, male and female, at schools in the local community, aged

5–10 years, whose parents or caregivers provided consent. The CHWs performed hearing screening tests in the community (home visits and visits to ECD centres) and at the local clinic. The children screened by the CHWs were male and female, aged 3–10 years, whose parents or caregivers provided consent. Participant consent to have their hearing screened was obtained as follows: (a) parental and/or caregiver consent was provided on behalf of participants tested by the SHNs upon signing a general school health screening form, that included the consent to cover hearing screening; (b) verbal consent was provided to the CHWs by the parent/caregiver when testing a child at a home or clinic visit; (c) the CHWs provided the ECD centres with consent forms for general health screenings which included hearing screening, the ECD centres were responsible for distributing these forms to the parents and thereafter signed parental consent was provided to ECDs so that participants underage could receive the tests.

Equipment

The hearScreen™ smartphone application was installed and operated on 92 Samsung J3 Galaxy smartphones (Android OS, 5.1) which were connected to supra-aural Sennheiser HD280 Pro2 circumaural headphones (Sennheiser, Wedemark, Germany) and were used by SHNs. The hearScreen™ application was installed and operated on Vodafone Smart Tab N8 10.1 Quad-Core Tablet (Android 7.0) which were used by the CHWs. The Vodafone tablets were connected to supra-aural Sennheiser HD202 Pro headphones (Sennheiser, Wedemark, Germany) and were used by the CHWs. Thus, the same application was used but on two different devices and two different Sennheiser headsets.

Prior to the study the headphones were calibrated according to International Standardisation Organisation (ISO) standards (ISO 389-1:2017) using a G.R.A.S. RA0039 artificial ear and a RION NL-52 sound level metre complying with ISO 60318-1:2009 and ISO 60318-2:1998. A plate adapter was used on the artificial ear for the HD280 Pro for circumaural headphones. The headphones used for hearScreen™ were calibrated on software calibration function according to prescribed standards (ISO 389-1:2017) adhering to equivalent threshold sound pressure levels determined for the HD280 Pro (Madsen & Margolis, 2014) and HD202 Pro (Van der Aerschot et al. 2016). Specified reference equivalent threshold sound pressure level (RETSPL) values were used to calibrate the test equipment to ensure the reliability of the results (Van der Aerschot et al. 2016).

Ambient noise levels were recorded by the smartphone hearing screening application, for each person being tested, during testing (Swanepoel, Myburgh, et al. 2014). The study by Swanepoel, Myburgh, et al. (2014) validated the noise monitoring employed by the smartphone screening application. Noise levels were measured to determine which noise levels exceeded the MPANLs at 1 kHz (110 dB HL), 2 kHz (105 dB HL) and 4 kHz (90 dB HL) (Van der Aerschot et al. 2016). The test results were recorded locally on the smartphone device used for testing and then uploaded (when connected to the internet) on to the mHealth Studio Cloud™ which is a cloud-based server, where the test results were viewed remotely and analysed.

Procedures

CHWs and SHNs were trained to use the hearScreen™ smartphone hearing screening application by an audiologist. Following training, the CHWs and SHNs administered the hearing screening tests by integrating into their daily work routine. The hearScreen™ application employed an automated test protocol. The test protocol parameters were set to test children, in which 25 dB HL at 1, 2 and 4 kHz was set as the criteria to pass the screening test. In order to ensure that the child being tested understood what was expected, testing began in the left ear with an initial conditioning tone at 1 kHz at an intensity level of 35 dB HL. The tone was presented at 35 dB HL (10 dB HL above 25 dB HL which is the criteria for a pass result). If the child did not respond at 35 dB HL the intensity was increased by 20 dB HL (55 dB HL then 75 dB HL) until the child responded or was recorded as a refer result. The child was instructed to indicate if he/she heard the tone presented by raising his/her hand each time the tone was presented. A sweep was then performed at the test frequencies of 1, 2 and 4 kHz at a screening intensity of 25 dB HL (ASHA 1997; Louw et al. 2017; Yousuf-Hussein et al. 2016). The same process was repeated for testing in the right ear.

Both tester groups conducted screening outside of conventional sound-treated environments. The test settings used by both testers were similar in terms of ambient noise levels. SHN's used the school hall or library to conduct the tests, and the CHW's conducted the tests in quiet rooms/libraries at ECD centres, community halls for health campaigns and at the homes of the patients upon home visits.

The smartphone application makes use of a smart noise monitoring algorithm which records the noise levels and provides live feedback if the noise levels are exceeding the MPANLs. MPANLs for testing at the specific frequency and intensity were used to monitor noise levels during the presentation of each test tone. The MPANLs indicate how much background noise is allowed before the accuracy of the thresholds are compromised (Van der Aerschot et al. 2016). When the noise levels exceed the MPANLs, a warning notification is provided to the testers who could then move to a quieter test environment or reduce background noise before continuing with the test. Failure to hear a pure tone at any frequency in either ear constituted a "refer" result and an immediate rescreen was conducted which followed the same procedure (AAA 2011). When the child failed one frequency or more in either ear in the immediate rescreen, the result constituted a refer. The child was then referred for a diagnostic hearing assessment to the local clinic for an assessment by an Audiologist. The referral letter was provided by the SHNs or CHWs using the referral pathways established with the closest local primary healthcare (PHC) clinic.

Data analysis

Data were extracted from the cloud-based server to an MS Excel (Office 365) sheet and retrospectively analysed using SPSS v25 (Chicago, Illinois). Referral rates, test duration, noise levels and tester type were analysed using descriptive statistical measures. A series of chi-square tests were performed to examine the variables that independently influence the final result in order to perform a logistic regression based on the influencing variables (test outcome, test duration, gender, headphone type, tester group and noise exceeding MPANLs at 1, 2 and 4 kHz). Final result refers to the test outcome, whether the result was a "pass" or "fail". The ambient noise levels were recorded in both test settings during the testing of 1, 2 and 4 kHz in left and right ears. Noise monitoring determined whether MPANLs for individual frequencies were exceeded during each frequency tested as

Table 1. Referral rate of children ($n = 6805$) screened by CHWs and SHNs.

	CHW		SHN		All	
Age (Years)	Total *n*	Referral % ($n = 62$)	Total *n*	Referral % ($n = 227$)	Total *n*	Referral (%)
3	17	0	0	0	17	0
4	125	7.2	1	0	126	0
5	312	8.3	6	0	318	0
6	205	3.4	88	0.1	293	2.0
7	152	5.2	1766	1.4	1918	4.1
8	97	5.2	2758	2.1	2855	4.2
9	92	3.3	973	0.3	1065	1.9
10	115	3.5	98	0.1	213	1.4
Total	1115	5.6	5690	4.0	6805	4.2

validated in the study by Swanepoel, Myburgh, et al. (2014), and then compared to determine if it affected one ear, both ears or none. A cross tabulation was then performed on these results to determine the effect on the final result.

A binomial logistic regression was performed to ascertain the combined effect of age, gender, duration, tester type, headphone type and the noise levels exceeding the MPANLs at 1 kHz, on the final test result in children, with $p < 0.005$ used to indicate a significant effect. An independent-samples *t*-test was run to determine if there were differences in the duration of the test based on the final test result. A Pearson's product–moment correlation was run to assess the relationship between the test duration and the final result, headphone type, gender, tester group and the noise exceeding MPANLs at 1, 2 and 4 kHz. A multiple regression analysis was carried out to investigate if the final result, headphone type, gender, tester group and the noise exceeding MPANLs at 1, 2 and 4 kHz could significantly predict the test duration. There was independence of residuals, as assessed by a Durbin–Watson statistic of 1.987. An independent-samples *t*-test was run to determine if there were differences in the duration of the test based on the noise exceeding the MPANLs at 1 kHz in one ear compared to two ears.

Results

A total of 6805 children were screened (50.4% female) between 3 and 10 years of age with an average age of 7.62 years (1.17 SD). The majority (83.6%) of these tests were conducted by SHNs and the rest (16.4%) by CHWs (Table 1).

The Chi-square ($p < 0.05$; Chi-square) test showed that the only variable significantly associated with the final result was noise exceeding MPANLs at 1 kHz ($p = 0.00$) (Table 2). A binomial logistic regression was performed to ascertain the combined effect of age, gender, duration, tester type, headphone type and noise levels exceeding MPANLs at 1 kHz, on the final test result. The logistic regression model was statistically significant (X^2 (9) $= 551.41$, $p < 0.005$) and the strength of the model was 26% (Nagelkerke *R* Square) and correctly classified 95.0% of the cases. The final result was significantly affected by age ($p < 0.005$; *B*: −0.214; 95% CI: 0.71–0.81) indicating that for every year younger the child was 0.214 times more likely to fail the test. The final result was also affected by duration ($p < 0.005$; *B*: 0.001; 95% CI: 1.01–1.02), indicating that an increased test duration is likely to be a refer result. Noise levels exceeding permissible levels at 1 kHz in at least one ear ($p < 0.005$; *B*: 0.30; odds ratio, OR: 3.2; 95% CI: 1.77–3.12) also increased the likelihood of a refer result. The results obtained indicated that the noise levels were significant at 1 kHz but not at 2 and 4 kHz when analysed independently. A Pearson correlation was performed taking into account all the variables, and the results obtained showed no correlation between the tester group and the noise levels exceeding the MPANL's. Gender, tester type or headphone type did not have any significant effect on screening outcome ($p > 0.005$).

Table 2. Noise levels exceeding the MPANLs at frequencies tested.

	1 kHz		2 kHz		4 kHz	
	n	%	*n*	%	*n*	%
None	4950	72.7	6501	95.5	6754	99.3
One ear	1046	15.4	231	3.4	47	0.7
Both ears	809	11.9	73	1.1	4	0.1

Average test duration for all children across tester groups was 58 s (66.91 SD). Test duration was significantly shorter ($p < 0.005$) for a pass (52.81 s; 59.75 SD) compared to a refer outcome (173.95 s; 104.4 SD). Multiple regression analysis investigated the predictive variables affecting test duration with independent variables including test outcome, headphone type, gender, tester group and whether noise exceeded MPANLs at 1 kHz. The regression model was significant ($F(3, 6801) = 365.12$, $p < 0.0005$) and explained 13.9% of the variation in test duration (adjusted $R^2 = 13.8\%$). Only hearing test failure, tester type and age were significant predictors for test duration. Test failure was associated with longer test duration ($p = 0.000$; *B*: 119.98; 95% CI: 112.65–127.30) and tester type ($p = 0.020$; *B*: 7.13; 95% CI: 2.65–11.61) with CHWs showing longer test durations (68.70 s; 70 SD) in comparison to the SHNs (55.85 s; 66.1 SD). Age, which was negatively correlated to test duration ($R(-0.83) = 0.000$, $p < 0.0005$), was associated with longer test durations in younger children ($p < 0.05$; *B*: −2.66; 95% CI: −4.08 to −1.25) (Table 3). For every year, a child is younger, they take 2.61 s longer on average (Table 3).

Discussion

The current study demonstrates no significant difference in screening outcome, controlling for age, gender, headphone type and the noise levels, between trained professional SHNs and non-specialist CHWs using the mhealth technology. Test durations on average were slightly longer for CHW's compared to SHN's (69 vs. 56 s) but is clinically insignificant. A recent study by Bright et al. (2019) also indicated that the accuracy for detecting hearing loss by a trained audiology officer, CHW and nurse were similar using a mobile-based automated audiometry. CHWs are more widely available in LMICs than specialist ear and hearing professionals and therefore these results support their ability to provide hearing screening using new mhealth audiometry technologies (Manafa et al. 2009; O'Donovan et al. 2019; Qureshi et al. 2013; Suen, Bhatnagar, et al. 2019; Swanepoel 2020; Van Amelsfoort et al. 2010). CHWs have already been compared to specialists by as they obtained similar results using cell-phone based hearing screening tools compared to otolaryngologists in low resourced settings (Shinn et al. 2019). These types of "task shifting" approaches, supported by mhealth technologies, are recommended by the WHO as a method to overcome the shortage of hearing care in LMICs (WHO 2006; Suen, Bhatnagar, et al. 2019).

Hearing screening referral rates in the current study were higher in younger children between ages of 3–5 years (7.6% vs. 4%), with a decrease in referral rates in children between the ages 6–10 years. Previous studies have reported similar findings with a decrease in referral rate as the age of children increase

Table 3. Test durations (s) for children screened.

	CHW (mean; SD) $n = 1115$	SHN (mean; SD) $n = 5690$	All (mean; SD) $n = 6805$
Overall test duration ($n = 6805$)	68.70; 70.00	55.85; 66.10	57.96; 66.91
Pass ($n = 6516$)	62.06; 60.88	51.03; 59.37	52.81; 59.75
Refer ($n = 289$)	181.45; 108.53	171.90; 103.39	173.95; 104.40
Overall test duration; 3–5 years of age ($n = 461$)	77.38; 77.01	62.29; 49.00	77.15; 76.66
Pass ($n = 426$)	66.97; 61.65	62.29; 49.00	66.90; 61.42
Refer ($n = 35$)	202.1; 122.29	0	202.1; 122.29
Overall test duration; 6–10 years of age ($n = 6344$)	62.73; 64.05	55.84; 66.11	56.56; 65.93
Pass ($n = 6090$)	58.81; 60.19	51.01; 59.38	51.83; 59.51
Refer ($n = 254$	154.74; 82.28	171.90; 103.39	170.07; 101.35

(Dodd-Murphy, Murphy, and Bess 2014; Mahomed-Asmail, Swanepoel, and Eikelboom 2016; Sideris and Glattke 2006). Younger populations between the ages of 2 and 5 years typically have a higher incidence of middle ear disorders which typically lead to a higher referral rate (Biagio et al. 2014; Monasta et al. 2012; Swanepoel, Eikelboom, and Margolis 2014). Age is therefore an important factor in planning hearing screening programmes from a referral and follow-up service perspective (Swanepoel, Myburgh, et al. 2014). For example, an 80% reduction in referral rate for tympanometry in children ages 6 and 7 year compared to those five years of age was reported by Swanepoel, Myburgh, et al. (2014). A hearing screening protocol that facilitates the diagnosis and management of ear disease may offset future hearing disability, as ear infections are a significant contributor to permanent childhood hearing loss in LMICs (Hunt et al. 2017; Mulwafu, Kuper, and Ensink 2016; WHO 2004; Yancey et al. 2019).

Referral rates in the current study were slightly higher in females (4.8% vs. 3.7%) compared to males but was not a significant contributing factor in the regression analysis. In studies by Yousuf-Hussein et al. (2018) and Mahomed-Asmail et al. (2016), gender effects were also evident in smartphone hearing screening outcomes, with females also being more likely to refer than males. A possible reason was attributed to hair length or styles in girls that could have affected headphone placement (Mahomed-Asmail et al. 2016; Yousuf-Hussein et al. 2018). Noise levels had a significant influence on test results in this study corresponding to previous studies (Mahomed-Asmail, Swanepoel, and Eikelboom 2016; Yousuf-Hussein et al. 2018) reporting increased referral rates when MPANLs exceeded at 1 kHz. Ambient noise levels in screening environments are a substantial challenge and is one of the most important contributors to over-referrals and the subsequent inefficiency of hearing screening programs for children (AAA 2011; ; ASHA 1997; Bamford et al. 2007; FitzZaland and Zink 1984; Lo and McPherson 2013; Nelson and Rajan 2018). A smartphone-based mhealth solution like hearScreen utilises integrated noise monitoring that providing operators with real-time feedback on noise levels to allow testers to minimise noise levels and adjust test protocols based on test environments before continuing with tests (Yousuf-Hussein et al. 2018). In addition, cloud-based surveillance can inform making program adjustments like increasing screening intensities to 30 dB HL at 1 kHz (Eksteen et al. 2019).

Average test duration excluding the test preparation (set up of headphones on the child and provision of test instructions) was just over a minute (68.1 s) and is comparable with previous smartphone hearing screening studies at PHC clinics where it took 73.9 s (±44.5 SD) (Louw et al. 2017) and in community-based screening programmes where testing took between 60.9 and 73.5 s (Swanepoel, Myburgh, et al. 2014; Van Wyk, Mahomed-Asmail, and Swanepoel 2019). On average, longer test durations was associated with the CHWs (68.70 s; SD 70.00) in comparison to SHNs (55.85 s; SD 66.10). Although this difference was statistically significant it is not likely to be of clinical significance. In addition, a longer test duration was associated with a decrease in the age of the child. This is likely due to the need to re-instruct and recondition younger children more often than for older children. Similar results were obtained in the study by Yousuf-Hussein et al. (2018) in which mean screen times were significantly higher for younger children. Furthermore, the age distribution of the participants tested by the SHN's compared to those tested by the CHW's is a limitation of this study. An additional limitation is that the setting in which CHWs and SHNs tested was not controlled and therefore this was not a direct comparison of the two subject groups' ability to test in a similar environment.

Decentralised community-based hearing screening using non-specialist personnel has the potential to address access barriers to hearing care when supported by mhealth technologies. The findings of this study demonstrate that minimally trained non-specialist health workers are able to conduct hearing screening services equivalent to that of trained professional healthcare workers, when equipped with mhealth technologies, expanding the reach and quality of service delivery in underserved regions where access to specialist healthcare workers are limited.

Disclosure statement

The authors declared the following potential conflicts of interest with respect to the research, authorship and/or publication of this article: The fourth author's relationship with the hearX Group includes equity and consulting.

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