Community-based hearing and vision screening in schools in low-income communities using mobile health technologies

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Abstract

Introduction: Globally, more than 50 million children have hearing or vision loss. Most of these sensory losses are identified late due to a lack of systematic screening, making treatment and rehabilitation less effective. Mobile health (mHealth), which is the use of smartphones or wireless devices in healthcare, can improve access to screening services. mHealth technologies allow lay health workers to provide hearing and vision screening in communities.

Purpose: To evaluate a hearing and vision school screening program facilitated by lay health workers (LHWs) using smartphone applications in a low-income community in South Africa.

Method: Three LHWs were trained to provide dual sensory screening using smartphone-based applications. The hearScreen™ app with calibrated headphones was used to conduct screening audiometry and the Peek Acuity™ app was used for visual acuity screening. Schools were selected from low-income communities (Gauteng, South Africa) and children aged between 4 to 9 years received hearing and vision screening. Screening outcomes associated variables and program costs were evaluated.

Results: A total of 4888 and 4933 participants children received hearing and vision screening, respectively. Overall, 1.6% of participants failed the hearing screening and 3.6% failed visual acuity screening. Logistic regression showed that females were more likely to pass hearing screening (OR:1.61; 95% CI: 1.11-2.54) while older children were less likely to pass visual acuity screening [OR: (0.87, 95% CI:0.79-0.96). A third (32.5%) of referred cases followed up for air conduction threshold audiometry and one in four (25.1%) followed up for diagnostic vision testing. A high proportion of these cases were confirmed to have hearing (73.1%; 19/26) or vision loss (57.8%; 26/45).

Conclusion: mHealth technologies can enable LHWs to identify school-aged children with hearing and/or vision loss in low-income communities. This approach allows for low-cost, scalable models for early detection of sensory losses that can affect academic performance.

Introduction

Hearing and vision loss are significant contributors to the Global burden of disease (Global Burden of Disease 2016 and Injury Incidence and Prevalence Collaborators, 2017; Olusanya, Wright, Nair, Boo, Halpern, Kuper, Abubaker, Almasri, Arabloo, Arora, Backhaus, Berman, Breinbauer, Carr, de Vries, del Castillo-Hegyi, Eftekhari, Gladstone, Hoekstra…Kassebaum, 2020). Approximately 34 million children younger than 15 years of age are estimated to live with disabling hearing loss (World Health Organization, 2018). Among children, the prevalence of hearing loss (includes both transient and/or permanent hearing losses) increases with age, from 0.9% amongst children less than a year old to 5.9% amongst adolescents aged 15 to 19 years old (Olusanya et al., 2020). The incidence of permanent congenital hearing loss, in high-income countries (HICs), is considered to be 3 per 1000 births (Shargorodsky, Curhan, Curhan, & Eavey, 2010) and 6 per 1000 live births in low-middle income countries (Olusanya & Newton, 2007).

Countries are categorized according to gross national income (GNI) per capita, with low-income countries having a GNI per capita of $1,036 to $4,045 (United States Dollars, USD) (The World Bank, 2020b). Upper-,middle income countries have a GNI per capita of $4,046 to $ 12,535 and high income countries have a GNI per capita of $12,536 or more (The World Bank, 2020b). South Africa is classified as an upper-middle income country with a GNI per capita of $6,040 (The World Bank, 2020a). Overall, 80 to 90% of children with disabling hearing loss reside in low- and middle income countries [LMICs] (Olusanya & Newton, 2007; Olusanya, 2015; Stevens, Flaxman, Brunskill, Mascarenhas, Mathers & Finucane,2013; World Health Organization, 2017a).

Vision loss is also common in children. Refractive error alone affects an estimated 12.8 million children aged between 5 and 15 years (Resnikoff, Pascolini, Mariotti & Pokharel, 2008). The Global Burden of Disease study reported an increase in prevalence of vision loss from 1.1% in children less than a year old to 3.9% in adolescents aged 15 to 19 years old (Olusanya et al., 2020). These sensory impairments are commonly co-occurring, with an estimated 40 to 60% of children with hearing loss also having some degree of vision loss (Bakhshaee, Banaee, Ghasemi, Nourizadeh, Shojee, Shahriari & Tayarani, 2009; Nikolopoulos, Lioumi, Stamataki, & O' Donoghue, 2006).

Periodic hearing and vision screening are considered integral strategies for preventative paediatric health care (American Academy of Pediatrics, 2017). According to the World Health Organization (WHO), the majority (60%) of childhood hearing loss and vision loss (80%) can be corrected or prevented (World Health Organization, 2017b, 2017a). Screening for these conditions is therefore important, as early detection allows for earlier and more effective treatment and rehabilitation (Eksteen, Launer, Kuper, Eikelboom, Bastawrous & Swanepoel, 2019; Rono, Bastawrous, Macleod, Wanjala, DiTanna, Weiss & Burton, 2018), and optimisation of learning outcomes (American Academy of Pediatrics, 2015; Eksteen et al., 2019; Kemper, Fant, Bruckman, & Clark, 2004; Porter, Sladen, Ampah, Rothpletz, & Bess, 2013; Reddy & Bassett, 2017; Register, 2010; Rono et al., 2018; Yousuf Hussein, Swanepoel, Mahomed & Biago de Jager, 2018).

Different options exist for screening and early detection of hearing loss. Universal newborn hearing screening has been implemented in many high-income countries (HICs), but remains largely unavailable in LMICs due to lack of equipment and trained staff, and the high proportion of births outside of clinical settings (Meyer, Swanepoel, le Roux, & van der Linde, 2012; Morton, & Nance, 2006; Olusanya, 2015; Olusanya, 2011; Swanepoel, Ebrahim, Joseph, & Friedland, 2007; Thomson & Yoshinaga-Itano, 2018). A 2017, South African study revealed that of 30 PHC facilities surveyed (Gauteng and North West Provinces) none of offered neonatal hearing screening. The 24 secondary and tertiary hospitals surveyed (Gauteng and North West Provinces) offered some form of screening, with 67% performing targeted newborn screening and 33% performing universal newborn screening (Khoza-Shangase, Kanji, Petrocchi-Bartal, & Farr, 2017), whereas the private sector reported 53% of their birthing units offering some form off hearing screening, with 14% performing universal hearing screening (Meyer et al., 2012). Even in HIC, 10 to 20% of permanent childhood hearing loss may not be detected at birth, due to late-onset and acquired hearing loss (Bamford, Fortnum, Bristow, Smith, Vamvakas, Davies, Taylor. Watkin, Fonseca, Davis & Hind, 2007; Dedhia, Kitsko, Sabo, & Chi, 2013; Gravel, White, Johnson, Vohr, Palmer, Maxon, Sullivan-Mahoney, Weirather & Meyer, 2005; Grote, 2000; Shargorodsky, Curhan, Curhan, & Eavey, 2010; Stenfeldt, 2018). For instance, in the United Kingdom, it is estimated that for every 10 children with a permanent bilateral hearing loss detected by newborn screening, there are approximately 5 to 9 children who would only manifest with such a hearing loss by 9 years of age (Fortnum et al., 2001). As a result, repeated hearing screening is required throughout childhood (Stenfeldt, 2018; Yong, Panth, McMahon, Thorne & Emmett, 2020).

In contrast, screening for vision loss in infancy is difficult as the visual system is not fully developed (Gogate, Gilbert, & Zin, 2011). The red reflex test is widely used in infancy to detect ocular malformations (Eventov-Friedman, Leiba, Flidel-Rimon, Juster-Reicher & Shinwell, 2010). Preschool and primary school vision screening programs has shown to be effective in efficiently and accurately detecting vision loss (Kemper et al., 2004, 2011; Lowry & De Alba Campomanes, 2016; Rono et al., 2018).

Considering both hearing and vision loss can be accurately detected in a school-aged population provided the resources and personnel is available (Eksteen et al., 2019; Kemper et al., 2004; Mahomed-Asmail et al., 2016; Metsing, Hansraj, Jacobs, & Nel, 2018; Rono et al., 2018; Yong et al., 2020; Yousuf Hussein, Swanepoel, & Mahomed-Asmail, & Biagio de Jager, 2018), there is a rationale for combining hearing and vision screening to maximize efficiency, as these conditions often co-occur, however, very few studies have investigated a combined hearing and vision screening program (Eksteen et al., 2019; Kemper et al., 2004).

School-based health programs are potentially a valuable platform for providing hearing and vision screening given the high levels of school attendance in most countries (Eksteen et al., 2019; Olusanya, Neumann, & Saunders, 2014; Rono et al., 2018; Shinn, Jayawardena, Patro, Zuniga, & Netterville, 2019). Typically, South African learners are mandated to enrol in grade 1, in the year they turn 7, prior to this a preparatory year in Grade R is compulsory (Department of Basic Education, 2019). Approximately 9 out of 10 learners attend public primary or secondary schools in South Africa (Statistics South Africa, 2017). In 2016 there were a reported 12 342 283 learners and 381 394 educators who attended or serviced 23718 public schools, respectively (Department of Basic Education, 2018). The National learner educator ratio was estimated at 30.9:1 in 2016 (Department of Basic Education, 2018). The high learner to educator ratio and the substantial number of schools also contribute to the difficulty in efficiently running school-based health programs (Dibakwane & Peu, 2018). There are a number of challenges to the implementation of school-based programs in LMICs, including a shortage of healthcare professionals, equipment constraints and inadequate data management (Stigler, 2012).

Some of these barriers can be overcome by employing novel mobile health (mHealth) technologies for sensory screening, which enable new service delivery models where services are delivered by persons with minimal training, including by school staff (Bernstein, Besser, Maidment, & Swanepoel, 2018; Bright, McComrick, Phiri, Mulwafu, Burton, Polack, Mactaggart, Yip, Swanepoel & Kuper, 2020, Bright, Mulwafu, Phiri, Ensink, Smith, Yip, Mactaggart & Polack, 2019; Jayawardena, Nassiri, Levy, Valeriani, Kemph, Kahue, Segaren, Labadie, Bennett, Elisée & Netterville, 2020; Morjaria, & Bastawrous, 2017; Reddy & Bassett, 2017; Rono et al., 2018; Shinn, Zuniga, Macharia, Reppart, Netterville & Jayawarenda, 2019; Swanepoel, 2017). Smartphone-based applications (apps) have been used in previous studies to successfully screen the hearing of preschool (Yousuf Hussien, Swanepoel, & Mahomed-Asmail, & Biagio de Jager, 2018) and school-aged (Jayawardena et al., 2020; Mahomed-Asmail, et al., 2016) children.

Automated test protocols and intuitive user interfaces on these smartphone screening apps allow lay health workers (LHWs) or community health workers (CHWs) to facilitate hearing and vision testing (Bright et al., 2020; Eksteen et al., 2019; Jayawardena et al., 2020; Rono et al., 2018; Yousuf Hussein et al., 2016; Yousuf Hussein, Swanepoel, & Mahomed-Asmail, & Biagio de Jager, 2018). A recent study confirmed that training CHWs in primary ear and hearing care identification can be feasible and accurate (Bright et al., 2019). Non-specialist personnel were able to carry out hearing screening using mobile technologies and the results obtained indicated similar accuracy to specialist personnel, such as ENT specialists, ENT medical officers or audiologists (Bright et al., 2019). Similarly, a Kenyan study assessing visual acuity utilising mHealth technology showed that teachers could successfully screen for vision loss (Rono et al., 2018).

A South African study recently reported the first smartphone-based hearing and vision screening for preschool children, aged between 4 to 7 years old (Eksteen et al., 2019). The findings demonstrate that the use of mHealth technology facilitated by LHWs was cost-effective and efficient in identifying hearing and vision loss. Yet, no research on combined smartphone-based hearing and vision screening for school-aged children exists. This study, therefore, evaluated the feasibility of smartphone hearing and vision screening in school-aged children from a low-income community in South Africa, facilitated by LHWs.

Method

This study evaluated the feasibility of a combined hearing and vision program at low-income schools across screening outcomes, associated variables (environmental noise, age, and gender), and program costs. The project received research ethics clearance from the University of Pretoria institutional review board (GW20181007HS).

Participants

A school-based hearing and vision screening program was conducted in two low-income communities, Tembisa and Ivory Park townships, in the Gauteng province of South Africa. These townships suffer a lack of resources, and households affected by poverty are commonplace. Recent statistics indicate that 1 in 5 households in these townships have no income and the middle-class comprises less than 5% of this population (Charman, 2017). These communities are part of the Ekurhuleni Metropolitan Municipality, which had an unemployment rate of 27.7% in 2019, compared to the national average of 29.1% (Ekurhleni Metropolitain Municipality, 2018; Mushongera, Tseng, Kwenda & Benhura, Zikhali & Ngwenya, 2018; Statistics South Africa., 2019; Statistics South Africa, 2015; The World Bank, n.d.).

The dual sensory screening program was conducted as a collaborative project between hearX group, and Pheme Group. The hearX group is a digital health technology company that provides mHealth solutions for hearing healthcare (hearX Group, n.d.) and the Pheme Group is a local business consulting company who provide enterprise development projects, management and community liaison solutions (Pheme group, n.d.). The screening program ran between September 2017 to August 2019, however, this study analysed data from the time between September 2017 to April 2019.

The school-based health program is often the first point of access to hearing and vision screening services for South African children. These services are recommended throughout the formal school system (Grade 1 to Grade 12) but are specifically required for foundation phase learners (Grade R to Grade 3; 6 to 9 year olds) (Stigler, 2012). Given the need for timely detection and treatment of hearing and vision loss, this program targeted children in preschool (4 to 7 years) and if time allowed, included learners in foundation phases (7 to 9 years). During the hearing and vision screening programme, 98% of preschools and primary schools contacted, were willing to participate. In the time period analysed in this study, 118 schools participated in the hearing and vision program [85 preschools (72%) and 33 primary schools (28%)]. The schools were selected for inclusion based on consent from school management. All participants were aged between 4 to 9 years and attended the selected pre- and primary schools.

Screening staff

LHWs were recruited for the study through application and an internal selection process was conducted by the project coordinators. The screening program employed three LHWs at any given time (a total of six LHWs was employed throughout the duration of the screening program). There were personal extenuating circumstances that resulted in 50% staff turnover, this was not planned, and measures were taken to ensure newly recruited staff were trained in administering sensory screening. The LHWs were paid a monthly salary of $555.83 which is competitive when compared to the reported national minimum wage rate of $203 (Department of Employment and Labour, 2020).The salaries of the LHWs were included in the screening program costs. The LHWs underwent a one-day training course which was conducted by the project coordinator (audiologist). The training comprised of a theoretical and practical component. The course included knowledge on the auditory and visual systems, causes of hearing and vision losses and an overview of the treatment for hearing and vision losses. The practical component focused on use of smartphone-applications and factors to consider (e.g. environmental noise, participant attention etc.). LHWs conducted simulated hearing and vision screening on each other. One of the LHWs had experience from a previous hearing screening program in another community (Yousuf-Hussein, Swanepoel, Biagio De Jager, & Mahomed-Asmail, 2018) and was appointed as the project administrator. The LHWs were monitored for three days by the project administrator. The cost of the training course was included in the project management fee (Table 5).

Material and Apparatus

During the course of the dual sensory screening program, the hearScreen™, hearTest™ (hearX group, Pretoria, South Africa) and Peek Acuity™ (Peek Vision, London, United Kingdom) smartphone applications were utilized to conduct smartphone-based hearing screening, air conduction threshold audiometry and vision screening. These smartphone applications form part of a suite of services and enabling integrated service delivery (Eksteen et al., 2019). Biological listening checks were completed monthly by the LHWs. Results of the tests conducted were uploaded to an encrypted cloud-based server. The security of the mHealth app and server was maintained by utilizing local data encryption at rest using Advanced Encryption standard 256 bit. These smartphone-based applications were installed and used on Samsung Galaxy A3 smartphones with the latest Android operating system (Google, Mountain View, United States of America) available at that time.

The hearing screening, air conduction threshold audiometry and vision screening were conducted on school premises by LHWs. The screening took place in an extra classroom/staff room. The room chosen was located away from other classrooms to minimise noise. Children attended screening in small groups or individually. Participants were seated away from distractions (e.g. posters) and LHWs continuously monitored environmental noise.

Hearing Testing

The hearing screening and air conduction threshold audiometry was conducted using the clinical validated hearScreen™, hearTest™ (hearX group, Pretoria, South Africa) applications on smartphones connected to supra-aural Sennheiser HD 280 Pro headphones (Sennheiser, Wedemark, Germany) (Madsen, & Margolis, 2014). Headphones were calibrated using a G.R.A.S. RA0039 artificial ear (with plate adapter for circumaural headphones) and a RION NL-52 sound level meter complying with ISO 60318-1:2017 standards (International Organization for Standardization, 2017). Ambient noise levels were recorded during the hearing screening with the hearScreen™ application ambient noise monitoring function, using the smartphone microphone (Swanepoel, Myburgh, Howe, Mahomed, & Eikelboom, 2014; Yousuf Hussien et al., 2018).

Frequencies tested during the hearing screening for each participant included 1, 2, and 4 kHz, presented at an intensity of 25 dB HL. Participants were conditioned at 1 kHz, using a 35 dB HL tone. This referral criterion was chosen based on evidence from previous community-based studies in order to reduce the referrals to over-burdened secondary hospitals (Yousuf Hussein, Swanepoel, Mahomed, et al., 2018).

Participants who failed the hearing screening were subsequently referred for air conduction threshold audiometry (Figure1).

Air conduction threshold audiometry was conducted using the hearTest ™app (hearX group). Air conduction threshold audiometry was conducted by LHWs on the school premises on a different day. The frequencies evaluated were 0.5, 1, 2, 4 and 8 kHz. The smartphone-based application has an intensity range from 0 to 90 dB HL. If a participant had two or more pure tone thresholds (PTTs) greater than 25 dB HL, it constituted a referral.

Vision Testing

The vision screening followed the standard early treatment diabetic retinopathy study (ETDRS) chart design, with a 5x5 grid optotype letter "E" displayed in one of four orientations (90°,180°,270°and 0°). This test is capable of producing accurate, reliable results that are comparable to the logMAR charts (Bastawrous, Rono, Livingstone, Weiss, Jordan, Kuper & Burton, 2015; Rono et al., 2018). A failed response of the vision screening constituted a visual logMAR of 0.3 or less in both eyes or 0.4 logMAR in one eye. Participants who failed the vision screening were referred to the optometrist at the secondary hospital or a retail optometrist offering free services to children aged 6 to 12 years old.

Procedures

The screening team visited preschools/primary schools to discuss the hearing and vision screening programme. If a school was willing to participate in the hearing and vision screening programme, the school management, was then provided with consent forms. The consent forms were distributed to each eligible learner and teachers ensured consent form return prior to screening dates. Schools were geotagged (which is the embedding of data in a digital media file to indicate geographical information), by the LHWs prior to screening on the mHealth studio data management app incorporating the hearing and vision screening apps (hearX group). The sequence of school visits was through convenience sampling. Consent was obtained from the school to conduct the screening, and thereafter caregiver consent was obtained before any child was tested. Less than 10% of caregivers failed to return consent forms and those children were not included in the sensory screening program. Approximately 1 to 3 days were spent testing at each preschool and 5 to10 days at each primary school. The number of learners screened depended on the learner enrolment, a minimum of 10 learners were screened daily at small preschools and up to 100 learners were screened daily at larger preschools/primary schools. During this study, there were no known children with hearing or vision loss. All children aged between 4 to 7 years at the selected schools were invited to participate in this study and 7.1 to 9 year olds were included, time permitting.

Participants were explained the testing procedures in their home language by the LHWs, who are from the same community. During the hearing screening and air conduction threshold audiometry (Figure 1), the participant was required to raise his/her hand in response to any tone heard, regardless of intensity. A conditioning tone was presented at 35 dB HL at 1 kHz. The hearing screening was conducted by LHWs at each pre- or primary school. If a participant failed the initial hearing screening, he/she underwent an immediate re-screening conducted by a LHW.

Failure of the rescreening resulted in partcipant undergoing air conduction threshold audiometry (Figure 2). The air conduction threshold audiometry (hearTest. hearX group) was adminstered by a trained LHW, which occurred on a different day at the school premises. If a participant failed to hear two or more pure tone frequencies at 25 dB HL, in one or both ears, this resulted in a referral. The severity of hearing loss was determined by the pure tone average (PTA). The participant was referred to the audiologist at the local primary healthcare facility (PHC) or secondary hospital for diagnostic audiological testing and further management. Each participant who required clinic-based follow-up treatment was presented with a referral letter and/or text message addressed to the caregiver, stating the results and information on the referral pathway for further testing. South Africa has very high mobile phone penetration estimated at 91.2% in 2019 (Independent Communications Association of South Africa, 2020) making text messages a favoured communication method (Richardson, van der Linde, Pillay & Swanepoel, 2020) The audiologist at the secondary hospital received a referral letter including the air conduction threshold audiometry results..

The vision screening (Figure 3) was administered on the school premises. During the vision screening, the LHW stood or sat at a testing distance of 2 meters away from the participant and held the smartphone at the participant's eye level. The participant was presented single optotypes and would be required to indicate the direction that the letter 'E' was facing by means of hand gestures. Each eye was screened individually. Caregivers were informed of the screening results with a referral letter sent home with the participant, as well as a text message. The participants were referred to the optometry department at the local secondary hospital or retail optometry chain with a free pediatric vision intervention program for follow-up testing. The optometrist at the secondary hospital/retail chain received a referral letter with the results of the vision screening. The project administrator kept a record of the running costs of the dual sensory screening program.

Data analysis

Anonymized electronic data was encrypted onto a Microsoft Excel spreadsheet (Microsoft, Redmond, USA). The results were coded according to pass/fail and severity of impairment (normal, mild, moderate and severe). Data analysis was completed using IBM Statistical Package for Social Sciences, version 25 (IBM, Armonk, USA). Logistic regression was used to predict test outcomes with the predictors being gender, age, and exceed noise levels. When considering the hearing screening, the maximum permissible ambient noise level (MPANL) at 25 dB HL was compared to the test outcomes. The MPANLs for the Sennheiser HD 280 pro at 1, 2 and 4 kHz was 56, 69 and 68 dB SPL (Madsen , & Margolis, 2014). Testing did not stop if MPANLs were exceeded. Data were presented according to age and gender, time proficiency of the hearing and vision screening and the referral rate of hearing and vision screening program. The cost of the dual sensory screening program was analyzed according to the total cost per a month, cost per a child, cost per a child referred and total program costs, these costs were subsequently compared to traditional hearing and vision screening.

Results

Four thousand eight hundred and eighty-eight participants underwent hearing screening, of whom 49.7% were female (2428/4888). Four thousand nine hundred and thirty-three participants underwent vision screening, of whom 50.2% were female (2478/4933). In order to facilitate early hearing and vision loss identification prior to entry in the formal education system, the 4 to 7.0 year olds were the targeted age group, if time allowed the 7.1 to 9 year old were included. Initial hearing screening failure rate was 9.9% (485/4888), which was slightly higher in females (11.2%, 272/2428) than males (8.7%, 213/2460) (Table 1). An immediate, automated rescreen of failed frequencies reduced the failure rate to 1.6% (80/4888), which was higher in males (2.0%, 49/2460) than females (1.3%, 31/2428).Logistic regression analysis compared age, gender and exceeded MPANLs in one or both ears across frequencies

(1000, 2000 and 4000 Hz) to hearing screening outcomes. Gender was the only significant predictor (p=0.04) of hearing screening outcomes with females 1.61 times (OR:1.61; 95% CI: 1.11-2.54) more likely to pass the hearing screening.

Two-thirds (67.5%) of participants who failed the hearing screening did not follow-up for air conduction threshold audiometry (54/80) (Table 2). The poor follow-up rate was due to participants being unavailable or unable to attend this follow-up assessment due to examinations, classroom work or absence from school on the day of testing. Twenty-six participants who failed the screening audiometry (32.5%, 26/80), went on to have air conduction threshold audiometry (Table 3). A failure rate of 73.1% was noted (19/26), these participants were referred to a secondary hospital for further intervention, which included cerumen management, otitis media treatment or diagnostic audiometry. Due to the relatively poor follow-rate an accurate prevalence of hearing loss could not be determined, but this will range between 0.4% (19/4888) (assuming none of the non-attenders had hearing loss) and 1.5% (73/4888) (assuming all of the non-attenders had hearing loss). Only 21% (4/19) of participants that failed the air conduction threshold audiometry followed-up at audiology services at the secondary hospital. All participants who followed up for audiological services required further management.

A total of 179 children (3.6 %,179/4933) failed the vision screening (Table1). The failure rate was similar in males (3.3%) and females (4.0%), but higher in 7.1 to 9 year olds (4.2%, 31/739) than 4 to 7.0 year olds (3.5%, 148/4194). Logistic regression analysis found the only significant predictor (p=0.006) of vision screening outcomes (OR:0.87,95% CI:0.79-0.96) to be age with every one year increase participants were 12.7% less likely to pass. Almost three-quarters (74.9%) of participants who failed the vision screening did not make the necessary follow-up appointments or keep their scheduled appointments (134/179) (Table 2) and some participants could not be contacted due to incorrect details or change of mobile number.

Of those who failed the vision screening, 25.1% (45/179) attended follow-up appointments at referral partners, secondary hospital, or retail optometrist. There were 26.7% of participants who were fitted with spectacles (12/45), 28.9% presented with an eye infection and were referred for further medical management (13/45), 2.2% presented with vision loss but parents refused spectacles as they felt it was unnecessary (1/45) and 42.2% presented with normal vision (19/45). There was a low uptake of follow-up services at referral partners and an accurate prevalence of vision loss cannot be established but this is estimated to range between 0.5% (26/4933) (assuming none of the non-attenders had vision loss) and 3.3% (160/4933) (assuming all the non-attenders presented with vision loss).

Dual sensory screening was conducted on 99.1% of children (4888/4933) with 45 children (0.9%) receiving vision but not hearing screening. These participants may have been unable to comply with screening audiometry and therefore only received vision screening. Overall, 0.2% of children failed both the hearing and vision screening (9/4888). The mean age of this group was 6.0 years (0.9 SD) with 88.9% (8/9) 4 to 7.0 year olds and 11.1% (1/9) 7.1 to 9 year olds. After the immediate hearing re-screening 0.16% (8/4888) still failed.

Maximum permissible noise levels (MPANLs) for this study were categorised according to whether they were within or exceeded permissible levels as measured during the presentation instance (Table 4). Minimal exceeded MPANLS instances were recorded at 1 kHz (7.7%; 387), 2 kHz (0.2%, 12) and 4 kHz (0.2%; 11) respectively (Table 4). Logistic regression analysis was used to determine whether exceeded MPANLs were a significant predictor of hearing screening outcomes. Due to the relatively small proportion of exceeded MPANLs (8.2%;401) it did not prove to be a significant predictor for hearing screening outcomes.

Overall, the hearing and vision screening program provided access to essential services at a relatively low cost. The cost of the screening program, including all costs, was $6.67 (USD) per child screened, and $186.87 per child (n=198;19 hearing loss and 179 vision loss) referred for diagnostic testing and treatment, if indicated (Table 5).

Discussion

This study evaluated the feasibility of a community-based hearing and vision screening program for school-aged children facilitated by LHWs. The program screened 4888 children for hearing loss and 4933 for vision loss. identifying 80 and 179 children who needed hearing and visual assessments, respectively. LHWs facilitating smartphone-based screening allowed for a combined sensory screening service that was affordable and efficient.

Few children (1.6%) required a referral after the community-based hearing screening. This figure is slightly lower than those reported in previous studies conducted in early childhood development (ECD) centres or school settings. For instance, Mahomed-Asmail et al. (2016) reported a referral rate of 5.6% in 6 to 12 year olds (Gauteng, South Africa), which is similar to findings in Eksteen et al. (2019), who found a referral rate of 5.4% for 4 to 7 year olds, (Western Cape, South Africa). In this study a referral criterion of two or more frequencies greater than 25 dB HL was employed with an immediate rescreen of failed frequencies, whereas previous studies utilised a referral criteria of one or more frequencies greater than 25 dB HL (Mahomed-Asmail et al., 2016). A second factor to consider, is that basic education in South Africa is mandated between the ages of 7 to 15 years of age (Hall, 2018). Early childhood education is not compulsory and it is possible that not all young children with sensory deficits attended preschool facilities (Eksteen et al., 2019) targeted in this study, which may have resulted in lower referral rates.

The reported referral rate for vision screening was 3.6%, which is comparable to the results reported by Eksteen et al. (2019) with a referral rate of 2.1% for children 4 to 7 years of age. Only 0.16% (8/4888) of participants failed both hearing and vision screening much like the results reported by Eksteen et al. (2019) for children between 4 to 7 years of age (0.2%; 19/8023). No further information could be found regarding the presence of dual sensory deficits in young pre- and school-aged children.

Approximately three in every four participants (78.9%, 15/19) did not follow-up for audiology services at the secondary hospital and did not follow-up for further vision tests (74.9%) at the secondary hospital/retail optometrist. In South Africa, the public healthcare system is funded through general tax, private insurance and out-of-pocket payments which are dependent on household income (Ataguba & McIntyre, 2012; McIntyre, Garshong, Mtei, Meheus, Thiede, Akazili, Ally, Aikins, Mulligan & Gouge, 2008). Even though these costs are low compared to private healthcare there are indirect costs of travel and food when attending follow-up appointments and possible loss of pay with parents/caregivers being away from work (Bright et al., 2017; Mclaren et al., 2014; Yong et al., 2020). The long waiting periods at the hospital as well as waiting periods between appointments has been cited as a cause of patient dissatisfaction and often results in patients skipping their appointments (Maphumulo, & Bhengu, 2013).

Over-burdened and poorly run PHC facilities (Blecher, & Harrison, 2006; Maphumulo, & Bhengu, 2013) result in many children with sensory deficits not being identified and treated. In this study it was noted that waiting periods for appointments at the secondary hospital or retail optometrist could be up to a month. Given the fact that a large number of the South African population rely on the public health sector the waiting times at public hospitals are much longer than anticipated (Ataguba & McIntyre, 2012; Ataguba, 2010; Maphumulo, & Bhengu, 2013; McIntyre et al., 2008). Whilst this study indicates promising community-based mHealth screening future studies should focus on ways to improve attendance for follow-up testing. Training of teachers and parents/caregivers regarding the importance of hearing and vision screening as well as attendance of follow-up appointments at secondary hospitals is imperative (Khoza-Shangase, 2019; Narayanan & Ramani, 2018). This reinforces a family-centred approach to assessment and treatment and improves follow-up attendance (Khoza-Shangase, 2019; Narayanan, & Ramani, 2018). .

It is notable that,73.1% of participants (19/26) who underwent air conduction threshold audiometry, presented with some degree of hearing loss. Furthermore, all participants (4/19) who attended audiology services required further intervention. The diagnostic hearing results could not be reported since it was part of the public healthcare facility information. Likewise, a significant number of participants who attended follow-up vision services presented with vision loss (57.8%, 26/45). Hearing loss prevalence therefore likely ranges between 0.4% and 1.5% and vision loss between 0.5% and 3.3%. Future research should investigate reasons for this non-compliance and how to address these barriers, including implementing dual sensory screening as part of the child wellness visits at local clinics (Yong et al., 2020).

Gender was a significant predictor for hearing screening outcomes with females 1.6 times more likely to pass hearing screening (OR:1.61; 95% CI: 1.11-2.54). Eksteen et al. (2019) however, found no gender differences in a pre-school population. In a South African study of school-aged children, males were more likely to fail the hearing screening (North-Matthiassen & Singh, 2007). Other studies have also reported that males are more likely to fail hearing screening but reasons for a potential gender effect is unclear and further investigation is needed (Osei, Larnyo, Azaglo, Sedzro, & Torgbenu, 2018; Rao, Subramanyam, Nair, Sreekumaran & Rajashekhar, 2002).

Age was also a significant predictor (p=0.006) of vision screening outcome with older children more likely to fail. If vision loss is not identified in early stages, the visual morbidity of an individual is negatively impacted (Reddy & Bassett, 2017; Register, 2010). Timely detection followed by intervention for vision loss is therefore essential to ensure optimal outcomes (World Health Organization, 2017b).

This study emphasizes the potential of dual smartphone-sensory screening provided by non-specialist personnel as an efficient, and cost-effective approach to hearing and vision care. The low cost of the dual sensory program reported in this study (Table 5) can be further reduced with greater retention of LHWs. As the LHWs gain experience and reach more patients the test times should be reduced (Eksteen et al., 2019). A high attrition rate of LHWs with a 50% staff turnover during the 20 months of this project was recorded. Attrition was due to personal reasons and a previous study suggests that relationship with peers is one of the strongest predictors of LHW retention (Ngugi, Nyaga, Lakhani, Agoi, Hanselman, Lugogo, & Mehta, 2018). Improved retention of LHWs is important to sustain a successful community-based program. High LHW retention has previously been linked to a supportive environment, community-led selection process, functioning referral systems, monetary compensation, sufficient resources and adequate training, refresher training and skill development (Ludwick, Brenner, Kyomuhangi, Wotton & Kabakyenga, 2014; Ngilangwa, & Mgomella, 2018; Ngugi et al., 2018). A careful community-led selection process for future LHWs is recommended, clear expectations, incentives and renumeration should be discussed (Ludwick et al., 2014; Ngilangwa, & Mgomella, 2018; Ngugi et al., 2018).

LHWs are essential, when implementing a sustainable community-led hearing and vision screening programme (Eksteen et al., 2019; Jayawardena et al., 2020; Rono et al., 2018; Yousuf Hussein, Swanepoel, Mahomed, et al., 2018). The use of LHWs kept costs low, compared to the use of hearing health professionals (audiologist/ENT) or eye health professionals (optometrist/ophthalmologist), and this has also been demonstrated by other researchers (Bright et al., 2019; Eksteen et al., 2019; Mahomed-Asmail, et al., 2016; Rono et al., 2018; Yousuf Hussein et al., 2018).

The specific costs of the dual sensory smartphone screening was sourced from the project administrators of the Pheme Group and hearX group. The full-cost model estimated the sensory screening cost at $6.67 (US Dollars) per child. In contrast, pure-tone screening costs have been estimated at between $10.23 to $18.28 for hearing (Healthman, 2020) and at $13.03 for vision screening (Lowry & De Alba Campomanes, 2016), these figures include, supply, travel and staff costs. The reported costs for school hearing screening is variable. Nguyen et al. (2015) reported a cost of $ 63.08[a] per a child screened and Fortnum et al. (2016) reported a cost of $ 2.50[b] per a child screened (Fortnum et al., 2016; Nguyen, Smith, Armfield, Bensink, & Scuffham, 2015). Both these estimated costs were based on pure tone screening audiometry performed by a healthcare worker (Fortnum et al., 2016; Nguyen et al., 2015). The considerably lower cost per a child screened reported by Fortnum et al. (2016) is likely due to the study population size (10000) and the length of the program (4 years). The vision screening program entailed screening with a visual acuity chart and corneal light testing by a nurse (Lowry & De Alba Campomanes, 2016).

The program efficacy was limited by poor uptake of appointments at diagnostic services in the public health care system, where there were long waiting periods at the secondary hospital and parents/caregivers failed to attend follow-up appointments.

The poor follow-up rate in this program meant that the prevalence of hearing and vision loss could not be accurately established. The availability of healthcare facilities and the distance needed to travel to such facilities has been identified as some of the factors influencing uptake of hearing health services in low-income communities (Khoza-Shangase, 2019; Yong et al., 2020). Eksteen et al. (2019) reported better follow-up and attribute this to regular contact made with parents/guardians reminding them to follow-up. Post-screening follow-up may be necessary in ensuring that children identified with a possible hearing and vision loss receive the adequate follow-up services (Eksteen et al., 2019; Zeng et al., 2020). In a 2020 study conducted in Guangzhou, China, it was demonstrated that if specific follow-up appointments for vision services were given to patients there was an increased compliance in attending appointments (Zeng et al., 2020). Furthermore, teacher uptake of vision services and advocacy thereof has been seen to increase compliance, resulting in increased follow-up rate and spectacle wearing in a study conducted in Chennai, India (Narayanan & Ramani, 2018).

Community-based hearing and vision screening is essential in identifying sensory deficits in children. This study has provided further support to recent findings (Eksteen et al. 2019), especially for school-aged children, showing that low-cost dual sensory screening can be successfully provided by LHWs. In LMICs, school-based screening is often the first point of care for children (Eksteen et al., 2019; Olusanya et al., 2014; Shinn, Jayawardena, et al., 2019). Future research should develop standardized protocols for smartphone hearing and vision screening of young children in schools. This study provided valuable information on hearing and vision loss and future studies should be conducted on a larger scale and involving older children.

[a] 1 Australian Dollar equates to 0.73 US Dollars; 15 October 2020

[b] 1 British Pound equates to 1.30 US Dollars, 15 October 2020

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