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COMMUNITY-BASED HEARING AND VISION SCREENING AT SCHOOLS IN A LOW-RESOURCED COMMUNITY: AN EVALUATION STUDY

by

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Millions saw the apple fall from the tree, but only Newton asked, Why?

-Bernard Baruch

- *To my husband, Jacques, thank you for encouraging me and believing me. This process was daunting, but your support helped make it easier.*
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LIST OF ABBREVIATIONS

dB HL	decibels hearing level
ECD	Early Childhood Development
ENT	Ear, Nose and Throat Surgeon
ETDRS chart	Early treatment diabetic retinopathy study chart
GBD	Global burden of disease
HICs	High-income countries
kHz	Kilo Hertz
LHW	Lay healthcare worker
LMICs	Lower-middle income countries
LogMAR	logarithmic minimum angle of resolution
mHealth	Mobile health
PEEK	Portable eye examination kit
PHC	Primary Healthcare
SPL	sound pressure level
WHO	World Health Organization

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ABSTRACT

Hearing and vision loss in children pose significant academic, social, and developmental challenges. Currently, there are limited studies on dual sensory screening programmes. This study aimed to describe a dual sensory screening programme for school-aged children using mHealth technology facilitated by lay health workers (LHWs).

During the duration of the programme, six LHWs (but only three LHWs were employed at any given time) were trained to provide hearing and vision screening using validated smartphone applications (apps) for hearing screening (hearScreen™), air conduction threshold audiometry (hearTest™) and vision screening (PEEK™ acuity) which was conducted between September 2017 to April 2019. LHWs evaluated children with a mean age of 6.0 years (0.9 SD) and 5.8 years (0.9 SD), for hearing and vision screening, respectively. Programme performance was evaluated, and logistic regression analysis was used to determine the effect of age, gender, and noise levels on hearing screening outcomes. Logistic regression analysis was also used to identify the effects of gender and age on vision acuity screening outcomes.

A total of 4888 participants underwent the hearing screening (49.7% female) and 4933 underwent the vision screening (50.2% female). The duration of screenings was 105.1 seconds (+/-102.5 SD) for hearing screening and 111.0 seconds (+/- 60.5 SD) for vision screening. Overall, 1.6% of participants referred the hearing screening and 3.6% referred vision 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). The logistic regression analysis showed that gender was a

significant predictor for hearing screening outcomes and age was a significant predictor for vision screening outcomes. Exceeded permissible noise levels during hearing screening were minimal and did not significantly influence outcomes.

Community-based smartphone sensory screening facilitated by LHWs provided hearing and vision services to schools in a low-income community. Those children who attended follow-up services and were identified with potential sensory deficits were referred to a secondary hospital or private facility for diagnostic testing. Follow-up rates were low but the screening programme was cost-effective.

1. INTRODUCTION

1.1 Prevalence of hearing and vision loss

Hearing and vision loss contribute significantly to the global burden of disease (World Health Organization, 2012). Approximately 34 million children younger than 15 years old are estimated to live with disabling hearing loss (World Health Organization, 2018), of which 7.5 million of the children are younger than five years old (World Health Organization, 2012). Nineteen million children worldwide have vision loss (World Health Organization, 2017a, 2017c), of which an estimated 12.8 million children aged between five and 15 years, have vision loss due to refractive error (Resnikoff, Pascolini, Mariotti, & Pokharel, 2008). The majority (60%) of childhood hearing loss and vision loss (80%) can be treated or prevented (World Health Organization, 2017c, 2017a).

The incidence of permanent congenital hearing loss, in high-income countries (HICs), is considered to be three per 1000 births (Shargorodsky, Curhan, Curhan, & Eavey, 2010) and six per 1000 live births in lower-middle income countries (Olusanya & Newton, 2007). These figures emphasise the need for an early hearing screening. The improvement in technology, which has led to the development of handheld otoacoustic emission and/or auditory brainstem response screeners has resulted in timely identification of infants and young children with hearing loss (Dedhia, Kitsko, Sabo, & Chi, 2013; Meyer, Swanepoel, le Roux, & van der Linde, 2012; Morton, & Nance, 2006; Olusanya, 2015; Olusanya, 2011; Swanepoel, Ebrahim, Joseph, & Friedland, 2007). Early detection and follow-up are essential to identify disabling hearing loss and provide necessary early intervention, however not all hearing loss can be identified in infancy as hearing loss can have a delayed onset, be acquired or be progressive in nature (Prieve, Schooling, Venediktov, & Franceschini, 2015; Weber & Guiberson, 2011).

Approximately 10% to 20% of permanent hearing loss will not be detected by new-born hearing screening (Gravel, White et al., 2005; Grote, 2000). Research studies in the United Kingdom indicated that there was a significantly higher prevalence of hearing loss in the school-aged population compared to those identified during their infancy (H. M. Fortnum, Summerfield, Marshall, Davis, & Bamford, 2001). New-born hearing screening reportedly identifies approximately 50% of children with hearing loss (Stenfeldt, 2018). This highlights the importance of school-aged hearing screening (American Academy of Audiology, 2011; Prieve, Schooling, Venediktov, & Franceschini, 2015) in addition to new-born hearing screening to identify all children with hearing loss and ultimately support optimal speech and language development.

Like hearing loss, vision loss affects a large proportion of children with an estimated 12.8 million children aged five to 15 years presenting with vision loss due to refractive error (Resnikoff et al., 2008). Myopia accounts for 90% to 95% of childhood vision loss; it can affect the reading of the blackboard and academic performance. It has been estimated that 90% of vision loss occurs in lower-middle income countries (LMICs) (Pascolini & Mariotti, 2012). There is a scarcity of data available on childhood vision loss in South Africa, although it has been estimated that refractive error accounts for 1.8% of vision impairment in South Africa (Naidoo et al., 2003). The South African National Blind Guidelines estimated the prevalence of childhood vision loss to be 0.47 per 1000 (Department of Health, 2002).

1.2 Screening for hearing and vision loss

Screening has been considered as the foundation of preventative healthcare (Iragorri & Spackman, 2018). The global annual cost of untreated hearing loss is estimated at 750 to 790 billion US dollars (World Health Organization, 2017a, 2017b) and the annual cost of untreated refractive error is estimated at 220 000 million US dollars (Smith, Frick, Holden, Fricke, &

Naidoo, 2009). Public health interventions for screening and early intervention of hearing and vision loss has been shown to be the most cost-effective strategy (Smith et al., 2009; World Health Organization, 2017b). Early screening and intervention services have been shown to be the best option in curbing costs and providing optimal outcomes in treating hearing and vision loss bearing in mind the massive costs of untreated sensory losses (Smith et al., 2009; World Health Organization, 2017b, 2017c).

School hearing screening is traditionally carried out by using a portable audiometer with calibrated headphones. Pure-tone audiometry is considered the gold standard for evaluating hearing sensitivity (American Academy of Audiology, 2011; South African Speech-Language and Hearing Association, 2011). The frequencies assessed during school hearing screening are 0.5 kHz, 1 kHz and 2 kHz and the intensity level should not exceed 25dB HL (American Academy of Audiology, 2011). The American Academy of Audiology recommends school-aged screening at ages four, five, six, eight and ten and at either 12 or 14 years old (American Academy of Audiology, 2011; American Speech and Hearing Association, 2002). School-aged screening at these intervals would identify approximately 70% of hearing loss (American Academy of Audiology, 2011). The South African Speech-Language and Hearing Association (2011) recommends that screening should be administered at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz at 25 dB HL (or 30 dB HL at 500 Hz depending on ambient noise). School-aged screening is recommended for children from three years to Grade 3 and should be administered annually (South African Speech-Language and Hearing Association, 2011). Children from Grade 4 should be screened once every three years, and those children who have been identified with a hearing loss should be referred to the audiologist for adequate diagnostic evaluation and management (South African Speech-Language and Hearing Association, 2011). Conductive hearing loss is the most common type of hearing loss in young children, followed by sensorineural hearing loss and mixed hearing loss (American Academy of Audiology, 2011; Taha et al., 2010; Yousuf Hussien, Swanepoel, & Mahomed-Asmail, & Biagio de Jager, 2018).

The ambient noise needs to be controlled during a school-based hearing screening, exceeded maximum permissible ambient noise levels (MPANLs) may negatively impact the results obtained (American Academy of Audiology, 2011; Eksteen et al., 2019). Based on a 20 dB HL screening level, the allowed ambient noise, if an individual has 0 dB HL is 50, 58- and 76-dB SPL at 1000, 2000 and 4000Hz, respectively (ANSI S3.1-1999). Most school systems do not have the equipment to measure ambient noise; alternatively, a biological noise check can be conducted. This is described as obtaining hearing thresholds of 10 dB HL below the screening level at all frequencies for a person with known normal hearing (American Academy of Audiology, 2011; South African Speech-Language and Hearing Association, 2011). However, ambient noise levels in schools differ; it would be time-consuming and impractical to conduct biological noise checks throughout the school day.

Unlike hearing, the visual system is not fully developed at birth and infants are born hyperopic (Metsing, Hansraj, Jacobs, & Nel, 2018). Visual acuity (VA) is the resolving power of the eye or the ability to see two separate objects as separate; the normal eye can accomplish this if adequate illumination and contrast is present as well as an angular distance of one minute of arc (Bailey, 2006). VA is the spatial resolving capacity of the visual system and expresses the angular size detail that can just be resolved by a person (Bailey, 2006). VA can be measured using detection acuity, resolution acuity or recognition acuity (Osaiyuwu & Atuanya, 2015) . VA is a critical component of the ocular health assessment and gives insight into the child's visual status (Osaiyuwu & Atuanya, 2015). An adult with normal visual acuity has a 0.0 logarithmic minimum angle of resolution (logMAR), whereas an infant has a 1.0 logMAR. Between ages, 5 to 6 years old a child with normal vision acuity will have a 0.0 logMAR, similar to an adult with normal visual acuity (Pan, Tarczy-Hornoch, Susan, Ge Wen, Borchert, Azen, & Varma, 2010).

The first year of life is when the visual system develops and therefore measuring visual acuity in infancy poses a challenge, and many paediatric eye specialists are not familiar with performing visual acuity tests in infants (Gogate, Parikshit, Gilbert, & Zin, 2011). The red reflex test is utilised in infancy to detect any ocular malformations (Eventov-Friedman, Leiba, Flidel-Rimon, Juster-Reicher, & Shinwell, 2010). It has been noted that timely detection and treatment of vision loss is imperative as nearly 75% of learning can be attributed to the visual system in early childhood (Gogate, Parikshit, Gilbert, & Zin, 2011).

Pre-school vision screening is useful in identifying amblyopia, detection and remediation of strabismus and refractive error (Logan & Gilmartin, 2004; Mathers, Keyes, & Wright, 2010) whereas school-aged vision screening is important in detecting vision loss that may affect reading efficiency or identifying those children at-risk for developing age-related visual problems (Register, 2010). Vision screening globally differs, and there seems to be no agreed-upon standardisation of school vision programmes in terms of equipment, ages at which vision screening is conducted, frequency of vision screening or vision screening personnel (Metsing, Hansraj, Jacobs, & Nel, 2018). In the United States of America, vision screening is conducted on all new entrants to the school system as well as high-risk children, in some states (Kansas Department of Health and Environment Bureau for Children, 2004; The University of the State of New York & The State Education Department, 2018). Comprehensive vision screening is recommended once during a students' career either in preschool or Grade 1 (Kansas Department of Health and Environment Bureau for Children, 2004; The University of the State of New York & The State Education Department, 2018). In the United Kingdom in the mid-1900s and early 2000s, periodic vision screening occurred for pre-school and school-aged children using the Snellen VA chart. The lack of evidence, insufficient resources to provide mass screening and budget cuts led to discontinuation of these screening programmes (Solebo, & Rahi, 2013).

In South Africa, the integrated school health policy (ISHP) states that all children who enter primary school and Grade 8 should be screened for VA. In Grade 8, a near point convergence (NPC) test is included as part of the screening battery, in addition to distance and near VA measures (Stigler, 2012). Distance VA screening has been considered a reliable measure to identify vision loss. Various charts have been used to measure VA; these include the Snellen chart, LEA symbols, illiterate E, HOTV, lighthouse or number charts (Cook, & Pasio, 2013; Grossman et al., 2017; Kansas Department of Health and Environment Bureau for Children, 2004; The University of the State of New York & The State Education Department, 2018).

1.3 Challenges to hearing and vision screening services in LMICs

Sensory impairments such as hearing and vision loss affect developmental outcomes, quality of life and academic achievement (Olusanya, Neumann, & Saunders, 2014; Register, 2010; Tomblin, Harrison, Ambrose, Walker, Oleson, & Moeller, 2015). Socio-economic conditions and an under-resourced primary healthcare (PHC) system further exacerbate developmental and educational outcomes (Metsing, Jacobs, & Hansraj, 2018; Meyer et al., 2012).

Human resource constraints pose an obstacle to service delivery in the public healthcare sector. According to Health Professions Council of South Africa (2019) statistics, there were a total of 781 Audiologists and 1450 dual-qualified Speech therapists and Audiologists registered in South Africa (Health Professions Council of South Africa, 2019), who service approximately 59 million South Africans (Worldometer, 2020). It has been reported that only 5% of LMICs have more than one audiologist per million people (World Health Organization, 2013). This highlights the need to make hearing healthcare accessible in human resource-constrained areas (O’Donovan, Verkerk, Winters, Bhutta, & Chadha, 2019).

Similarly, the Health Professions Council of South Africa reported that there were 3859 registered optometrists (Health Professions Council of South Africa, 2019). There is an uneven distribution of optometrists between the public and private healthcare sector in South Africa. It is estimated that in the private sector the ratio is 1:10 000 people and in the PHC sector, the estimates are 1: 543 000 of the population, this inequality results in the service not being easily accessible (The South African Department of Health, 2011). Compared to other countries, Australia reports a ratio of 1:4541 of the population, and the United States reports 1:7848 (Gilbert & Foster, 2001). The WHO recommends a minimum ratio of 1: 100 000 (World Health Organization, 2007). Maake & Moodley (2018) noted that the lack of optometry services in rural areas in South Africa posed a significant barrier to accessing vision services (Maake & Moodley, 2018). There are many inequalities that exist between the South African private healthcare sector and the overburdened public healthcare sector (Ataguba, 2010; Blecher, & Harrison, 2006; McIntyre et al., 2008). A National Health Insurance (NHI) has been proposed to address these issues. The implementation of the NHI aims to improve equity in financing, improving the distribution of funds and resources, and by making health care delivery more affordable and accessible for the population (The South African Department of Health, 2015). The report released by the Department of Health (2015) highlighted an increased need for services for speech, vision and audiology assessments for school going children (The South African Department of Health, 2015). The increased prevalence of non-communicable diseases globally and in South Africa is contributing to at least 33% of the burden of disease (Global Burden of Disease 2016 and Injury Incidence and Prevalence Collaborators, 2017). PHC has been re-engineered into four streams, namely Municipal ward-based primary healthcare outreach teams (WBPHCOTs), integrated school health programme (ISHP), District Clinical Specialist Teams (DCST) and contracting of private healthcare practitioners at non-specialist level, as part of the National Health Insurance (NHI) scheme (The South African Department of Health, 2015). The ISHP aims to provide a holistic health service to school-aged children (Shung-King, Orgill, & Slemming, 2014; Stigler, 2012).

The ISHP has the potential to reach an estimated 12 million learners (Shung-King, Orgill, & Slemming, 2014). The services provided can be classified as health promotion, preventive, curative and specifically screening for health-barriers to learning that includes identification of hearing and vision loss. Since the implementation of the ISHP, the programme has identified

201 770 learners with physical barriers to learning (hearing, vision, speech and oral health) (The South African Department of Health, 2015). A reported 7% were referred for follow-up hearing services (14 202/201 770), and 21% of learners were referred for follow-up vision services (43 319 /201 770) (The South African Department of Health, 2015). There is an increased need to provide hearing and vision screening to children. Still, due to human resource constraints, funding and equipment expenditure, the implementation of the ISHP has been turbulent (Stigler, 2012).

LMICs are faced with the high cost of specialised equipment to render these services (Swanepoel, Myburgh, Howe, Mahomed, & Eikelboom, 2014). Audiological equipment can be expensive, and some may require fixed structures such as a soundproof booth (Swanepoel et al., 2010). In contrast, the equipment needed to conduct a visual acuity screening is minimal and low-cost, but these too have limitations (Bastawrous et al., 2015). The Snellen chart, which is widely used to assess visual acuity, is limited by the non-geometric progression and an inconsistent number of letters per line (Laidlaw, Abbot, & Rosser, 2003). Different letters or optotypes have varying legibility at the same size and secondary effects such as crowding are known to affect patient's ability to identify optotypes correctly and can lead to this measurement bias (Laidlaw, Abbot, & Rosser, 2003). This in effect led to the development of the logMAR chart, however the logMAR chart requires a power supply, and it is not portable or robust and therefore cannot be used in outdoor conditions (Bastawrous, 2016). Yet, to gain access to low-resourced areas, screening equipment needs to be cost-effective and portable. mHealth , which is the use of communication devices such as smartphones and tablets to assist in delivering healthcare services (World Health Organization, 2011), may provide a viable solution (Cunningham et al., 2016; Herselman, Botha, Toivanen, Fogwill, & Alberts, 2016; Khatun et al., 2015).

1.4 Utilisation of mHealth technologies for hearing and vision screening

Sub-Saharan Africa has seen exponential mobile growth, with 456 million unique mobile subscribers in Sub-Saharan Africa in 2018, making the penetration rate of 44%. Around 239 million people, equivalent to 23% of the population, also use the mobile internet regularly (Global Spéciale Mobile Association-Intelligence, 2019). Total mobile penetration has doubled on the African continent since 2000. Countries such as Nigeria, South Africa, Uganda, Democratic Republic of Congo and Cote d'Ivoire have more mobile communication devices than fixed lines (David & Grobler, 2020). The Independent Communications Authority of South Africa reported that smartphone mobile penetration increased from 81.7% in 2018 to 91.2% in 2019 (Independent Communications Association of South Africa, 2020).

The use of mHealth technologies can drastically reduce the cost of equipment needed to perform audiological tests (Swanepoel, Myburgh, Howe, Mahomed, & Eikelboom, 2014). This provides tools that are mobile, clinically validated and has real-time environmental monitoring capability (Eksteen et al., 2019; Jayawardena et al., 2020; Swanepoel et al., 2014; van Tonder, Swanepoel, Mahomed-Asmail, Myburgh, & Eikelboom, 2017; van Wyk, Mahomed-Asmail, & Swanepoel, 2019; Yousuf Hussein, Swanepoel, Mahomed, & Biago de Jager, 2018). The Portable Eye Examination Kit (Peek) was shown to be accurate and repeatable when compared to the logMAR (Bastawrous et al., 2015). The tester is masked to the optotypes thus eliminating tester bias, the luxmeter will notify the tester when the ambient light is too bright to obtain a reliable reading (Bastawrous, 2016). These Smartphone-based applications have proven to be portable, reliable and easily operated by lay health workers (LHWs), who are individuals who have not had formal tertiary training but have received some basic training for healthcare duties that they are required to perform with a particular intervention (Bastawrous, 2016; Bastawrous et al., 2015; Lodhia, Karanja, Lees, & Bastawrous, 2016; Mahomed-Asmail et al., 2016; Rono et al., 2018; Swanepoel, 2017; van Tonder, Swanepoel et al., 2017; World Health Organization, 2008; Yousuf Hussein et al., 2018).

1.5 Community-based hearing and vision screening by Lay Health Workers (LHWs)

The re-energising of LHW programmes have focused on the shortage of health care workers and could provide a solution in response to these limitations (World Health Organization, 2008). LHWs have been utilised to connect impoverished communities to health services or provide home-based care (Trafford, Swartz, & Colvin, 2018). Over the years lay health workers have also been used to assist with the HIV epidemic and compliance of maternal-infant health (Lewin, Dick, Pond, Zwarenstein, Aja, van Wyk, Bosch-Capblanch, & Patrick, 2005; Schmitz et al., 2019). Benefits of the LHW programmes include patient compliance with appointments and treatment (Clarke, Dick, Zwarenstein, Lombard, & Diwan, 2005; Lewin, Munabi-Babigumira, Glenton, Daniels, Bosch-Capblanch, van Wyk, Odgaard-Jensen, Johansen, Aja, Zwarenstein, Scheel, 2010; Lewin et al., 2006) as well as community awareness and successful implementation of the programme (Cook & Pasio, 2013). Previous studies have been successful in implementing smartphone hearing and/or vision screening services facilitated by LHWs (Eksteen et al., 2019; Jayawardena et al., 2020;Yousuf Hussein et al., 2016; Yousuf Hussein et al., 2018) The utilisation of LHWs could improve community awareness and advocate for hearing and vision screening services (Cook, & Pasio, 2013; Sithole, 2017).

Establishing an mHealth dual sensory screening programme facilitated by LHWs within the school system enables children who have health barriers to learning, to be identified (Shung-King, 2013). A school health programme may be seen as an entry point to identifying these children (Eksteen, Launer, Kuper, & Eikelboom, 2019; World Health Organization, 1998; Yousuf-Hussein, Swanepoel, Biagio De Jager, & Mahomed-asmail, 2018). School Health Programmes are not without their own challenges as it can be difficult to manage unequal distribution of resources and lack of healthcare personnel (Shung-King, & Slemming, 2014;

Stigler, 2012). The use of mHealth solutions, together with LHWs, will improve accessibility to essential hearing and vision screening services.

1.6 Study rationale

Previous studies have shown that community-based hearing and vision screening services; can improve accessibility, are reliable and cost-effective (Bastawrous, 2016; Eksteen et al., 2019; Lodhia et al., 2016; Morjaria, & Bastawrous, 2017; Rono et al., 2018; Swanepoel, Maclennan-Smith, & Hall, 2013; Yong et al., 2020; Yousuf Hussein et al., 2016; Yousuf Hussein, Swanepoel, Mahomed, et al., 2018). These investigations have further created community awareness and improved advocacy for hearing and vision screening services. Minimal information is available regarding combined hearing and vision screening (Eksteen et al., 2019; Kemper, Fant, Bruckman, & Clark, 2004). Fortnum et al. (2001) highlighted the importance of school-aged hearing screening. Likewise, the early identification of vision loss will improve the visual morbidity of a child; these services are essential in identifying potential sensory deficits (Fortnum et al., 2001; Reddy & Bassett, 2017; Register, 2010; World Health Organization, 2017c). A recent study conducted in the Western Cape, reported hearing and vision screening services for children four to seven years old (Eksteen et al., 2019). Eksteen et al. (2019) utilised mHealth technologies facilitated by LHWs to provide essential hearing and vision services. The current study expanded on this by reporting on a hearing and vision screening programme for children aged four to nine years old. This study aimed to evaluate a community-based hearing and vision screening programme at schools in a low-income community. The following research question therefore arises: *What is the feasibility of a smartphone hearing and vision screening programme for school-aged children facilitated by LHWs in a low-income community?*

2. METHODOLOGY

2.1 Aim and Objectives

2.1.1 Study Objectives

The main objective of this study was to evaluate a community-based hearing and vision screening programme for children aged four to nine years old, facilitated by lay health workers (LHWs), utilising mHealth technologies. The programme was evaluated in terms of the following parameters:

a) Referral rate of hearing screening, air conduction threshold audiometry and vision screening
b) The effect of gender, age and exceeded noise levels on hearing and vision screening outcomes
c) Follow-up rate for air conduction threshold audiometry and further vision testing at private retail practice/secondary hospitals.
d) Prevalence of hearing and vision loss

2.1.2 Research Design

A retrospective, limited feasibility research design was used. The limited feasibility study was concerned with the providing of hearing and vision screening services in a low-income community, the outcomes of the dual sensory programme, the resources needed and the cost of running the dual sensory screening programme, as well as the sustainability of community-based sensory screening programmes (Bowen, Kreuter, Spring, Cofta-Woerpel, Linnan, Weiner, Bakken, Kaplan, Fabrizio & Fernadez, 2009; Orsmond & Cohn, 2015).

2.2 Research context

A school-based hearing and vision screening programme 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 programme was conducted as a collaborative project between hearX group, a local consulting business and Pheme Group. Ethical clearance for the hearing and vision programme (GW20171104HS) was obtained prior to data collection (Appendix A). Permission was obtained from principals at ECD preschools/primary schools as well as consent to conduct the screening programme at ECD preschools/primary schools (Appendix D). The project reached 98% of the preschools and primary schools in the Ivory Park and Tembisa area. In the period analysed in this study, 118 schools participated in the hearing and vision programme (85 preschools [72%] and 33 primary schools [28%]). The schools were selected for inclusion based on consent from school management. All participants were aged from four to nine years of age years and attended the selected pre- and primary schools. The screening programme was conducted between September 2017 and August 2019. This study requested permission to utilise the programme data as part of a master’s dissertation (Appendix B). Permission to utilise the screening programme data was granted by the CEO of the hearX group (Appendix C), Data from the time between September 2017 and April 2019 was analysed. Ethical clearance (GW20181007HS) was obtained for the retrospective study (Appendix F).

2.3 Participants

The programme evaluated, employed six screeners throughout the course of the screening programme (only three screeners were employed at any given time). Five of the six screeners resided in the Tembisa area and were trained to provide hearing and vision screening services. The other LHW acted as a project team leader and was trained previously in terms of hearing and vision screening as well as air conduction threshold audiometry. The LHWs were paid a monthly salary for the duration of the programme which was included in the programme costs. The LHWs underwent a one-day training programme hosted by the on-site project coordinator and the off-site project coordinator (audiologist), the cost of which was included in the project administration fee. The training programme involved both the theory and practice of administering the hearScreen™ and Peek acuity smartphone applications. The off-site project coordinator evaluated the LHWs' ability to conduct the tests reliably. The LHWs were continuously monitored by the on-site project coordinator throughout the programme. The LHWs' quality indices were monitored remotely via the web-based server, to which the smartphone-based application was linked.

The programme participants included a paediatric population (aged between four to nine years old). The research participants attended pre- or primary schools in the Tembisa and Ivory Park areas. The hearX group employed convenience sampling during their screening program. This study analysed the anonymised data of 4888 participants who had undergone hearing screening and 4933 who had undergone vision screening. The data was collected over 20 months between September 2017 to April 2019.

2.4 Ethical Considerations

Leedy and Ormrod (2010) stated that ethical considerations fall into one of four categories, namely protection from harm, informed consent, right to privacy and honesty with professional colleagues (Leedy, & Ormrod, 2010). The advancement and evolving nature of mHealth technology has created new and unique ethical challenges; these included anonymity and de-identification, storage and transmission of data, communication of clinically relevant results, access to mHealth technologies and regulation of mHealth technologies (Carter, Liddle, Hall, & Chenery, 2015).

Informed consent

Special considerations regarding informed consent must be taken since this study followed a retrospective research design (Junod & Elger, 2010). Participants who partook in the programme, of which the data was used, were made aware that the test data collected may be used as part of a research study. In the programme, each participant obtained parental/guardian consent (Appendix E). The parent/guardian of the participant was informed of the possibility that the testing data collected may be utilised for research purposes.

Right to privacy, anonymity and de-identification

During this research study, the researcher was provided with raw anonymised data which had been collected by six LHWs. The data anonymisation is broadly referred to as de-identification (Chevrier, Foufi, Gaudet-blavignac, & Robert, & Lovis, 2019). The de-identification of the data allows the medical data to be shared and protects the privacy of the participants (Carter, Liddle, Hall, & Chenery, 2015; Chevrier, Foufi et al., 2019). The study followed a retrospective design, and as such, data was provided to the research already anonymised. No participants' identifying information was included in the data provided to the researcher.

Honesty

The hearing and vision screening programme remained transparent and honest by making results available to parent/guardians. The details of the screening programme as well as possible future use of data collected, as in the current study, was clearly communicated in the parent/guardian consent form (Appendix E). This study itself will be both internally and externally moderated, as well as peer-reviewed.

Plagiarism

The results of the study were written up in the form of a research article and master's dissertation by the researcher. Any sources cited were referenced using American Psychological Association 6th edition (APA 6th Ed), a list of cited references was made available. A declaration form against plagiarism was signed (page i-ii).

Storage and transmission of data

During the hearing and vision screening programme, the data collected was uploaded onto an encrypted cloud-based server. The data was uploaded via a private, secure wireless network. This ensured the security and privacy of the data. Electronic data of the current study was stored at the University of Pretoria, in the Communication Pathology Building and will be kept for a minimum of 15 years.

Regulation of mHealth technologies

The medical community is embracing mobile technology due to its cost-effectiveness and accessibility. However, it is critical that mHealth technology is rigorously evaluated for their effectiveness and safety (Bastawrous et al., 2015; Carter et al., 2015). The hearScreen™ application was shown to obtain validated results, according to prescribed standards (American National Standards Institute, 2010; International Standardization Organization, 1998a; Swanepoel et al., 2014). The hearTest™ smartphone application was found to elicit comparable thresholds to conventional manual pure-tone audiometry (van Tonder, Swanepoel, Mahomed-Asmail, Myburgh, & Eikelboom, 2017). The Peek™ visual acuity (VA) application was validated and performed well when compared to the Snellen and was accurate when compared to the early treatment diabetic retinopathy (ETDRS) chart, and was found to be repeatable and reliable (Bastawrous et al., 2015). The hearing and vision screening, as well as air conduction threshold audiometry, employed smartphone applications which had been validated and shown to be reliable, accurate and obtain repeatable results (Bastawrous et al., 2015; Swanepoel et al., 2014).

2.5 Research Apparatus

The apparatus utilised in the hearing and vision screening programme is discussed below.

2.5.1 Samsung Galaxy A3 smartphones

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.

2.5.2 Smartphone screening audiometer

The hearing screening was conducted using the hearScreen™ application (hearX group, Pretoria, South Africa) coupled with supra-aural Sennheiser HD280 Pro headphones. Headphones which 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 60318-1:2009 and ISO 60318-2: 1998 standards (International Standardization Organization, 1998b, 2009). 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).

2.5.3 Smartphone air conduction threshold audiometry

Air conduction threshold audiometry was performed using the clinically validated hearTest™ application (hearX group, Pretoria, South Africa) together with the supra-aural Sennheiser HD280 Pro headphones. The 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 60318-1:2009 and ISO 60318-2: 1998 standards (International Standardization Organization, 1998b, 2009). The Air conduction threshold audiometry was only conducted if a participant was referred (failed) the hearing screening.

2.5.4 Smartphone vision screening application

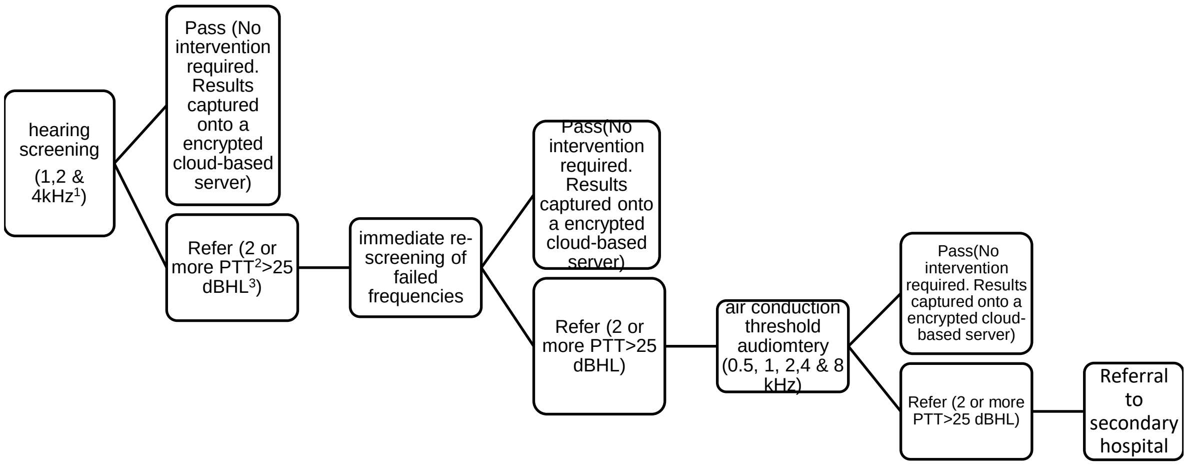
The LHWs used the Portable Eye Examination Kit (PEEK) to conduct vision screening (Peek vision, London, United Kingdom). The application would run on a smartphone using android technology. Peek™ acuity follows the standard Early treatment diabetic retinopathy study (ETDRS) chart design with a 5x5 grid optotype letter 'E' displayed in one of four orientations (90°, 180°, 270°, and 0°). The participant would be required to indicate the direction of the optotype using a hand gesture.

2.5.5 Encrypted cloud-based server

mHealth Studio Cloud (hearX group, Pretoria) is a web-based platform which allows for secure online data management, surveillance, referrals and report generation. It has automatic upload functionality, calibration management for headphones and allows for central management for supported applications.

2.6 Programme Procedures

The procedures followed during the hearing and vision screening programme are outlined in Figure 2.1. Each participant was instructed in their home language by the LHW with regards to the testing procedures. While conducting the screening hearing screening, the participant was required to raise his/her hand in response to hearing a tone, regardless of the intensity of the tone. A conditioning tone was presented at 35 dB HL at 1 kHz, and if the participant responded appropriately, testing commenced. If a participant did not respond appropriately, they were re-instructed. The frequencies tested during the hearing screening for each participant were 1, 2, and 4 kHz. Any pure tone threshold (PTT) worse than 25 dB HL at two or more frequencies constituted a referral (fail). If a participant was referred, the failed frequencies were immediately re-tested. If the participant passed, no further intervention was required. If a participant still referred the immediate re-screening, the participant underwent air conduction threshold audiometry. The test results were uploaded to a secure cloud-based server. The test data was continuously monitored at the backend, by the project coordinator. This allowed the projector coordinator to continuously monitor the hearing and vision screening programme, remotely.



1 Kilo Hertz, a measure of frequency equivalent to 1,000 cycles per a second

2 Pure tone thresholds are the lowest level that a response could be elicited from a participant

3 decibels hearing level refers to a clinical measure of sound intensity

Figure 2.1: Procedures carried out during a hearing screening

A trained LHW administered the air conduction threshold audiometry. The test was administered in a school environment. The participant was required to raise his/her hand in response to whether a tone was heard regardless of the intensity. A conditioning tone at 1 kHz at 35 dB HL was presented to each participant. The following frequencies were tested: 0.5, 1, 2, 4 and 8 kHz, as part of the threshold audiometry protocol. The LHWs were required to present each frequency. The hearTest application has an intensity range from 0 to 90 dB HL. If a participant had two or more PTTs greater than 25 dB HL, it constituted a referral to the audiologist, at a secondary hospital, for diagnostic audiological testing and further management. Every parent/guardian(s) was provided with a text message stating the results of the screening programme. If a participant required smartphone-based diagnostic audiological services, the parent/guardian(s) were advised accordingly. All test results entered into the smartphone-based application were captured onto a secure cloud-based server, where the researcher had access to data for analysis.

For the vision screening, the LHW was seated at a testing distance of two meters away from the participant and held the device at the eye level of the participant. The participant was then required to cover one eye with the palm of his/her hand. The participant was required to point their hand or arms in the direction of the “E”, and the tester used the touchscreen to swipe in the indicated direction as shown by participant. The tester was masked to the presented optotype and was unaware whether the participant was providing the correct response, this reduced verbal and non-verbal cues. Single optotypes were shown to reduce confusion (Bastawrous et al., 2015). A failed response, 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 did not undergo a re-screening. If a participant failed, they were referred to the optometrist at Tembisa Provincial Hospital or SpecSavers (The Boulders) in Midrand. The smartphone application collected test results and loaded it onto a secure cloud-based server. Figure 2.2 below illustrates the procedures carried out by the hearX group during the vision screening programme.

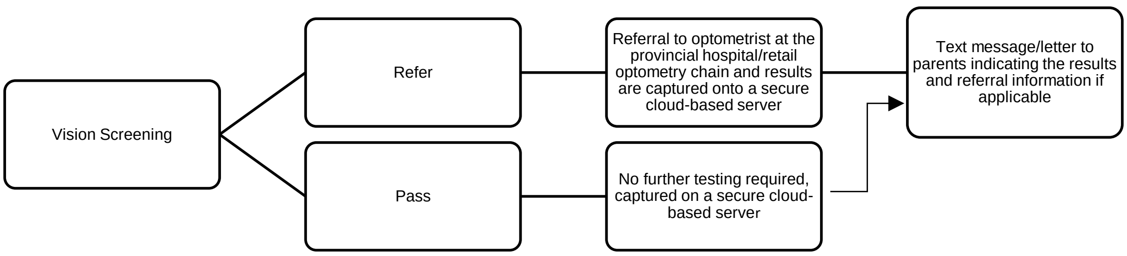


Figure 2.2: Procedures carried out during the vision screening

2.7 Data processing and analysis

Once permission had been obtained, the raw anonymised data from the hearing and vision screening programme with the records of over four thousand participants was provided to the researcher. The anonymised data was provided in the form of an excel sheet. The data was cleaned; any incomplete testing data or duplicate entries were excluded. The quantitative data was then represented on an excel spreadsheet. The spreadsheet was then read into the IBM Statistical Package for Social Sciences (SPSS) version 25, to analyse the data. Logistic regression analysis was used to determine the effects of maximum permissible noise levels, gender, and age on hearing screening outcomes. Similarly, logistic regression analysis was used to determine if age or gender was a significant predictor of vision screening outcomes.

2.8 Reliability and Validity

Reliability

Reliability is described as dependable or consistent. It suggests that the same process repeated under identical conditions, will yield similar results (Neuman, 2014). The hearScreen™ and hearTest™ applications are smartphone-based testing applications with features that monitor the environmental noise, the responses obtained from the participant and the input from the screener, to determine whether each response is valid (Swanepoel et al., 2014). The Peek acuity test follows the standard ETDRS chart with a 5x5 optotype letter “E”. The peek acuity test was developed and has been compared previously regarding test-retest variability and measurement time with that of the Snellen and ETDRS-based tumbling E logMAR in controlled and uncontrolled settings (Bastawrous et al., 2015). These smartphone-based applications have been clinically tested and shown to be reliable and repeatable (Bastawrous et al., 2015; Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017).

- ***Measurement reliability*** is concerned with the fact that numerical results, as an indicator, do not differ because of the characteristics of the measurement process or measurement instrument itself (Neuman, 2014). The instruments used in this study underwent rigorous testing which elicited reliable responses (Bastawrous et al., 2015; Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017).

- ***Stability reliability*** is broadly defined as reliability across time (Neuman, 2014). Stability reliability describes the ability of an instrument to yield the same results when applied to a different period. Using test-retest has merits and can verify an indicator's degree of stability. In the hearing screening programme, if a research participant was referred (failed), the referred frequencies were immediately re-screened. A variation of the test-retest method is to give an alternative form of the test, which may yield similar results to the original (Neuman, 2014). During the screening programme, the hearTest™ was utilised to provide threshold audiometry for participants who were referred for the screening audiometry. If the participants were referred for failing the threshold audiometry, they were referred for diagnostic audiometry; all the mentioned tests would yield pure tone thresholds but in different environments and at different times. The correlation between the screening audiometry and threshold audiometry

The reliability of the hearing and vision screenings results obtained was ensured in the following manner:

- Clear, concise instructions to participants in their home language where possible, this would ensure that the participant understood the instructions.

- Trained LHWs who had undergone a one-day training on administration of the smartphone-based applications for hearing and vision screening. The training resulted in capable, knowledgeable LHWs and guaranteed reduction in tester error.

- Continuous monitoring at the backend of the applications to pick up any tester errors or unreliable participant results.

To improve reliability, clearly, conceptualised constructs and the use of a precise level of measurement was considered. (Neuman, 2014).

- ***Clearly conceptualised constructs:*** Reliability increases when each measure indicates one concept. Constructs as such, should be specified to eliminate distracting or interfering information (Neuman, 2014). The hearScreen™ and hearTest™ have built-in noise monitoring protocols as well as the ability to monitor the testers' reliability in administering the testing procedure and the reliability of the participant in terms of their responses (Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017).

- ***Precise level of measurement:*** Clinically validated smartphone-based applications were used in this hearing and vision screening programme. The results yielded from these smartphone-based applications have been shown to be comparable to industry normative testing, manual pure-tone audiometry in the case of hearing screening (Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017) and the Snellen and ETDRS when evaluating visual acuity (Bastawrous et al., 2015).

Validity

The validity of a measurement instrument is the extent to which the instrument measures what it is intended to measure (Leedy, & Ormrod, 2010). Validity can be described regarding face validity, content validity, criterion validity and construct validity.

- ***Face validity:*** According to the scientific community, is when an indicator measures the construct (Neuman, 2014). In this research study, the indicators, are the smartphone-based applications and the constructs are the hearing and vision loss. These smartphone-applications have been shown to obtain reliable results which were comparable with industry standards (Bastawrous et al., 2015; Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017). Therefore, there is adequate face validity, considering that the smartphone-based applications have been clinically validated.

- ***Content validity:*** Addresses the question whether the full content of a definition is reflected in a measure (Neuman, 2014). When considering this research study, the smartphone-based mHealth applications have been shown to be an accurate reflection of hearing thresholds (Mahomed-Asmail, Swanepoel, & Eikelboom, 2016; Swanepoel, 2017; Swanepoel et al., 2014; Swanepoel, 2017) and visual acuity (Bastawrous, 2016; Bastawrous et al., 2015; Morjaria, & Bastawrous, 2017). Consequently, the smartphone-based applications utilised in this study have been developed to measure both hearing sensitivity and visual acuity. They have also been shown to be accurate when compared to traditional methods of testing hearing sensitivity and visual acuity.

- ***Criterion validity:*** The validity of an indicator is verified by comparing it with another measure of the same construct (Neuman, 2014). In this study, the hearScreen™ and hearTest™ hearing thresholds were compared to each other, both these mHealth applications evaluated the hearing thresholds, and both procedures were conducted on a smartphone device. This study has been shown to have adequate criterion validity.

- ***Construct validity:*** Addresses if a measure is valid and whether the various indicators operate in a consistent manner (Neuman, 2014). The mHealth solutions have been shown to be consistent and appropriate instruments to screen for hearing loss and visual acuity (Bastawrous et al., 2015; Swanepoel et al., 2014; van Tonder, Swanepoel et al., 2017). As such, the smartphone-applications employed in this study were adequate to measure hearing sensitivity and visual acuity.

2.9 Bias

In research, bias is any influence, condition or set of conditions that singly or in combination distort data (Leedy, & Ormrod, 2010). During the hearing and vision screening programme, the following types of bias were identified and minimised where possible:

- ***Measurement bias:*** Refers to possible device inaccuracy, environmental conditions or self-reported measurements which can affect the data collected (Althubaiti, 2016). The hearX group utilised supra-aural HD280 Pro headphones that were annually calibrated according to ISO/ANSI standards to account for these possible effects on bias. The hearScreen™ and hearTest™ applications have algorithms that continuously monitor environmental noise and provide real-time feedback to the LHW. This information is captured onto a secure cloud-based server allowing the researcher (during data analysis) to account for the impact of environmental noise. The utilisation of smartphone-based screening relies on the trained screener, as well as the subjective responses of the participant.

- ***Participant/Tester bias:*** Was minimised during the duration of the hearing and vision screening programme in the following manner—the participants were minors and were instructed, and re-instructed if the need arose. By utilising screeners from the community where the screening took place, one ensured that they were able to instruct the participant in their home language. The Peek acuity test eliminated bias by means of having the tester masked to the presented optotype and ensuring that he/she was unaware of whether the participant was providing the correct response. Single optotypes were used to reduce confusion (Bastawrous et al., 2015). The smartphone-based screening monitored input from the screeners and could determine if an input were false, at which stage the screener received re-training. Since this study was conducted retrospectively, this eliminated researcher bias, as only anonymised data was used. Information such as environmental noise levels and time proficiency was also captured onto the secure cloud-based server. This information allowed the researcher to analyse the data provided holistically and account for possible influences on the data collected.

3. COMMUNITY-BASED HEARING AND VISION SCREENING IN LOW-INCOME SCHOOLS USING MOBILE HEALTH TECHNOLOGIES

Status of article: accepted for publication

(The editing of this chapter will differ as Journal specifications are followed)

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Journal: Language, Speech and Hearing services in schools

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3.1 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.

3.2 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 et al., 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). It should be noted that although South Africa is classified as an UMIC, there are many low-income communities within South Africa, which has limited health resources (Charman, 2017; Khoza-Shangase, et al., 2017; Mushongera, et al., 2018). Overall, 80 to 90% of children with disabling hearing loss reside in low- and middle income countries [LMICs] (Olusanya & Newton, 2007; Olusanya, 2015; Stevens et al.,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 et al., 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, 2017c, 2017a). Screening for these conditions is therefore important, as early detection allows for earlier and more effective treatment and rehabilitation (Eksteen, et al., 2019; Rono et al., 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 et al., 2007; Dedhia, Kitsko, Sabo, & Chi, 2013; Gravel, White et al., 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; Kemper, Helfrich, Talbot, Patel, & Crews, 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 (The South African 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 (The South African Department of Basic Education, 2018). The National learner educator ratio was estimated at 30.9:1 in 2016 (The South African 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 et al., 2020, Bright et al., 2019; Jayawardena et al,, 2020; Morjaria, & Bastawrous, 2017; Reddy & Bassett, 2017; Rono et al., 2018; Shinn et al., 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.

3.3 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. South Africa has 11 official languages and therefore language is an important consideration when developing a community-based programme. The three dominant languages spoken in Tembisa are Sepedi 33.14%, isiZulu 21.67% and Xitsonga 13.31% (Statistics South Africa, 2011). In Ivory park the dominant languages are Sepedi 23.29%, Xitsonga 22.45% and isiZulu 21.39% (Statistics South Africa, 2011). 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 et al., 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 (The South African 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 3.5).

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 (Figure 31.).

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 3t al., 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 3.1), 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.

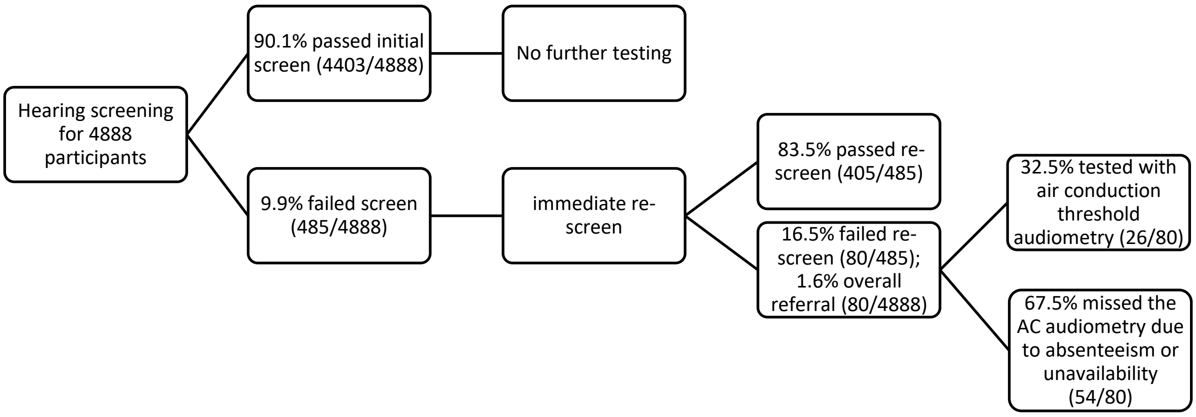

Figure 3.1: Community-based hearing screening utilising mHealth technologies, Gauteng, South Africa, September 2017 to April 2019

Failure of the rescreening resulted in partcipant undergoing air conduction threshold audiometry (Figure 3.2). 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..

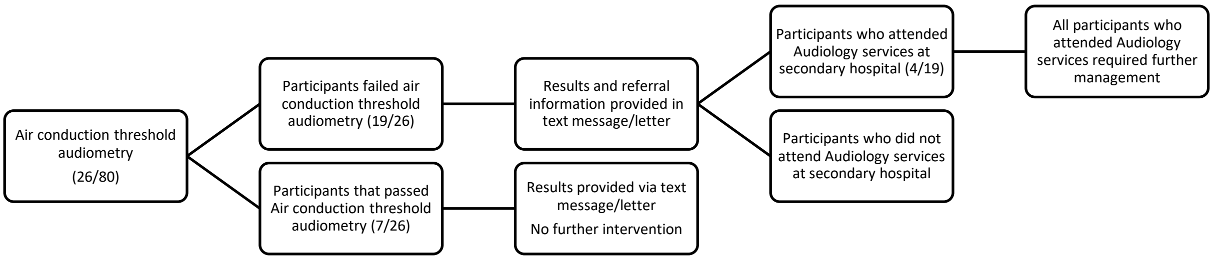

Figure 3.2: Air conduction threshold audiometry utilising mHealth technologies, Gauteng, South Africa, September 2017 to April 2019

The vision screening (Figure 3.3) 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.

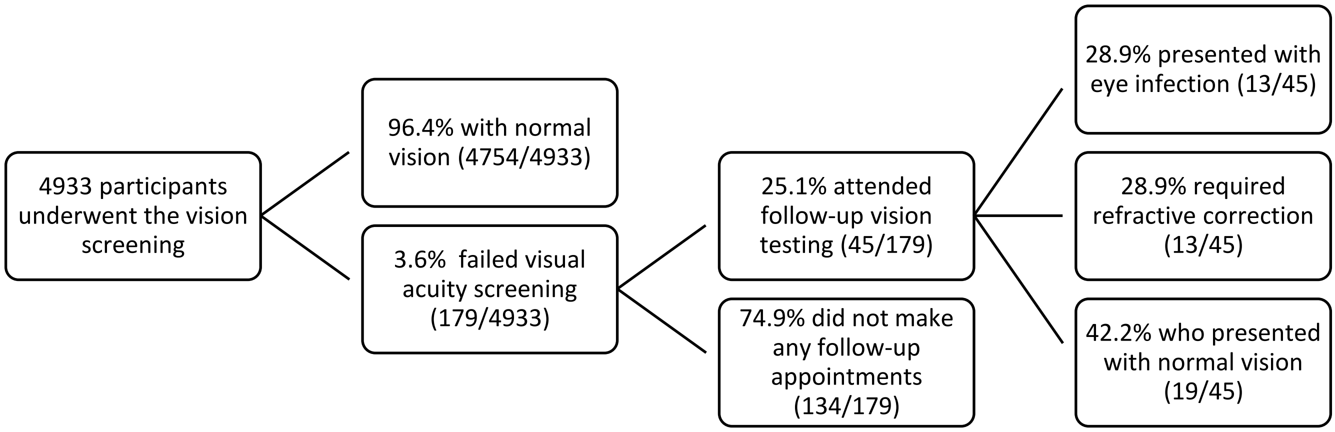

Figure 3.3: Community-based vision screening utilising mHealth technologies, Gauteng, South Africa, September 2017 to April 2019

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.

3.4 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 3.1). 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). 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. 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.

	Hearing screening (n=4888)	*Vision screening (n = 4933)*	*Hearing and vision screening (n=9)*
Participants that failed initial screening	**9.9% (485/4888)**	**3.6% (179/4933)**	**0.2% (9/4888)**
Males who failed initial screening	8.7% (213/2460)	3.3% (80/2455)	0.04% (1/2460)
Females who failed initial screening	11.2% (272/2428)	4% (99/2478)	0.3% (8/2428)
Participants that failed hearing re-screening	**1.6% (80/4888)**	**n/a**	**0.16 % (8/4888)**
Males who failed hearing re-screening	2.0 % (49/2460)	n/a	0.04% (1/2460)
Females who failed hearing re-screening	1.3 % (31/2428)	n/a	0.3% (7/2428)
Mean Age (years) of participants (SD)	**6.0 (0.9)**	**5.8 (0.9)**	**6.0 (0.9)**
4 to 7.0 year olds, who failed the screening	1.7% (71/4168)	3.5% (148/4194)	88.9% (8/9)
7.1 to 9 year olds, who failed the screening	1.1 % (8/720)	4.2% (31/739)	11.1% (1/9)
Mean Test Duration (SD), sec	**105.1(102.5)**	**111.0 (60.5)**	**521.2 (453.8)**
4 to 9 year olds that passed the screening	102.4 (97.9)	109.1 (55.9)	n/a
4 to 7.0 year olds that passed the screening	107.2 (101.3)	111.6 (58.6)	n/a
7.1 to 9 year olds that passed the screening	74.5 (68.4)	94.4 (34.1)	n/a
4 to 9 year olds that failed the screening	266.5 (201.2)	163.1 (123.4)	521.2 (453.8)

4 to 7.0 year olds that failed the screening	278.9 (200.8)	170.0 (130.7)	503.1 (466.0)
7.1 to 9 year olds that failed the screening	154.6 (178.1)	130.5 (72.7)	666

Table 3.1: Outcomes of hearing and vision screening facilitated by LHWs using mHealth technology

Two-thirds (67.5%) of participants who failed the hearing screening did not follow-up for air conduction threshold audiometry (54/80) (Table 3.2). 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 3.3). 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. Half of the participants presented with cerumen impaction (50%, 2/4), A quarter of participants presented with either otitis media (25%, ¼) or for diagnostic testing (25%, ¼). All participants who followed up for audiological services required further management.

	Hearing Screening (n=80)		***Vision Screening (n=179)***	
	Did not attend follow up	***Attended follow up***	***Did not attend follow up***	***Attended follow up***
Male	42.6 % (23/54)	50% (13/26)	47% (63/134)	40% (18/45)
Female	57.4 % (31/54)	50% (13/26)	53% (71/134)	60% (27/45)
Mean Age	**5.7 (0.9)**	**6.2 (0.9)**	**5.6 (1.3)**	**6.0 (0.9)**
4 to 7.0 year	*1.2% (50/4168)*	*0.5% (22/4168)*	*2.7% (115/4194)*	*1.0% (40/4194)*
7.1 to 9 year	*0.6% (4/720)*	*0.6% (4/720)*	*2.6% (19/739)*	*0.7% (5/739)*
Mean Test Duration (sec)	**304.8 (228.9)**	**437.1 (184.9)**	**177.0 (162.7)**	**151.5 (131.6)**

Table 3.2: Distribution of participants who failed screening (did not follow-up, for air conduction threshold testing and diagnostic vision testing versus those who attended follow-up)

Outcome	Air conduction threshold audiometry (n=26)
Gender	
Male	50% (13/26)
Female	50% (13/26)
Age Categories	
4 to 7.0 year olds, who failed air conduction threshold audiometry	88.5% (23/26)
7.1 to 9 year olds, who failed air conduction threshold audiometry	11.5% (3/26)
Mean duration, Standard deviation (SD), sec	**413.27 (163.60)**
Type of hearing loss	
Unilateral	15.8% (3/19)
Bilateral	84.2% (16/19)
****Hearing loss severity (worst ear)***	
Normal (<20 dB PTA)	26.9% (7/26)
Mild (26 – 40 dB PTA)	38.5% (10/26)
Moderate (41-60 dB PTA)	7.7% (2/26)
Severe (61-80 dB PTA)	11.5% (3/26)
Profound (>81 dB PTA)	15.4% (4/26)

Table 3.3: Air conduction threshold audiometry for referred cases who followed-up (26/80)

*****(Olusanya, Davis, & Hoffman, 2019)

A total of 179 children (3.6 %,179/4933) failed the vision screening (Table 3.1). 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).

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. Of the 0.16% (8/4888) of participants that failed both hearing and vision screening, 50% (4/8) attended the air conduction threshold audiometry and all presented with a degree of hearing loss. Only one participant went on to attend appointments for hearing and vision services at the Secondary hospital.

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 3.4). 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 3.4). 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.

	1 kHz	***2 kHz***	***4 kHz***
Right	3.8% (187)	0.1 % (5)	0.1% (5)
Left	3.9% (191)	0.1% (7)	0.12% (6)

Table 3.4: Maximum permissible ambient noise levels (MPANLs) exceeded during initial hearing screening (n=4888)

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 3.5).

Service/goods	US $[a]			
	Total cost of program [b]	Cost per month	Cost per child screened [c]	Cost per child referred [d]
Mobile testing devices (3 hardware sets)	2073.50	103.68	0.38	10.5
Software (hearScreen™, hearTest™ and peek acuity™)	2329.66	116.48	0.42	11.8
Device calibration	240.21	12.01	0.04	1.21
Salaries of LHWs (2 LHWs)	11 116.66	555.83	2.01	56.14
Salary of project administrator/screener	7250.00	362.50	1.32	36.62
Project Management	4027.78	201.39	0.73	20.34
Travelling	4970.02	248.50	0.90	25.10
Telecommunications	1078.80	53.94	0.20	5.45
Program resources (stationery, power banks etc.)	2204.00	110.20	0.40	11.13
Administration	1450.00	72.50	0.26	7.32
Total	**36 740.61**	**1837.03**	**6.67**	**186.87**

Table 3.5: Cost of hearing and vision screening using smartphone-based technologies, September 2017 to April 2019

LHWs: Lay Health Workers, US $: United States Dollar

[a] In June 2020, 1 South African Rand (ZAR) was equivalent to 0.058 United States Dollar (US $)

[b] Hearing and vision screening over a 20-month period from September 2017 to April 2019

[c] During the course of the testing, 4888 children underwent dual sensory screening

[d] 198 children (69% for vision) referred for diagnostic follow-up and treatment, if indicated

3.5 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, Mulwafu, Thindwa, Zuurmond, & Polack, 2017; Mclaren, Ardington, Cally, & Leibbrandt, 2014; Yong, Panth, 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, Panth, 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, 2017c).

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, Panth, 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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3.6 References

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4. DISCUSSION, CLINICAL IMPLICATIONS AND CONCLUSION

Childhood hearing and vision loss can pose significant academic challenges (Bamford et al., 2007; Metsing, Hansraj, Jacobs, & Nel, 2018; Reddy & Bassett, 2017; Stenfeldt, 2018), in light of this, school health programmes have been proposed to address health barriers to learning (Shung-King, Orgill, & Slemming, 2013; Shung-King, 2013; Stigler, 2012). School health programmes are often the first point of access to essential hearing and vision screening services in LMICs (Dibakwane & Peu, 2018; Eksteen et al., 2019; Morjaria, & Bastawrous, 2017; Zeng et al., 2020). The South African integrated school health policy has proven difficult to implement and maintain due to lack of resources, large classroom sizes and personnel constraints (Dibakwane & Peu, 2018; Shung-King, Orgill, & Slemming, 2014; Stigler, 2012). In recent years several studies has shown that community-based hearing and vision screening can be successfully implemented by LHWs using smartphones (Eksteen et al., 2019; Jayawardena et al., 2020; Rono et al., 2018; Shinn, Jayawardena, et al., 2019). These studies were cost-effective and improved accessibility to hearing and vision screening services.

4.1 Summary of findings

This research study reported on a community-based hearing and vision screening programme, which was facilitated by LHWs. Similar to previous findings, the utilisation of smartphone-based technology improved access and affordability of hearing and vision services without compromising the reliability of the test results (Abdalla, & Omar, 2011; Eksteen et al., 2019; Swanepoel, 2017; van Tonder, Swanepoel et al., 2017; Yousuf Hussein, Swanepoel, Mahomed, et al., 2018).

The initial hearing screening referral rate was 9.9% (485/4888). An immediate re-screening was conducted to reduce false-positives, with a final referral rate of 1.6% (80/4888), which is low compared to studies employing the same technology (Eksteen et al., 2019; Mahomed-Asmail et al., 2016). The vision screening rate obtained was 3.6 % (179/4933), which was similar to results reported by Eksteen et al. (2019) who found a vision screening referral rate of 2.1% for 4 to 7 year olds.

Logistic regression analysis for screening audiometry outcomes indicated that females were 1.608 times (OR: 1.688) more likely to pass the final screening audiometry. Logistic regression analysis was used to compare the effects of gender and age on visual acuity screening outcomes. The results revealed that the older the children were 12.7% [(1-0.873) *100] less likely to pass the visual acuity screening.

Maximum permissible noise levels (MPANLs) for this study were categorised according to allowed ambient noise levels and exceeded ambient noise levels. In a previous study exceeded MPANLs at 1 kHz was found to be a significant predictor of hearing screening outcomes (Eksteen et al., 2019). During this study, the largest number of noise levels that were exceeded was found at 1 kHz (n=378); as the frequencies increased there was a drastic reduction in the number of tests that exceed MPANLs. Due to the relatively small percentage of exceeded MPANLs, 8.2% (n=401), this was found not to be a significant predictor for screening audiometry outcomes.

There was low uptake of follow-up services with two-thirds of participants (67.5%) who did not attend air conduction threshold audiometry services, only 21% (4/19) of participants who failed air conduction threshold audiometry followed up for Audiology services, more than three-quarters of participants (78.9%) failed to follow-up for diagnostic audiology services and three fourths (74.9%) did not attend diagnostic vision testing.

An accurate prevalence of hearing and vision loss could not be determined due to the poor follow-up rate. The prevalence of hearing loss was estimated between 0.4% (none of the non-attendees presented with hearing loss) to 1.5% (all of the non-attendees presented with hearing loss) and the prevalence of vision loss could be estimated to be between 0.5% (none of the non-attendees presented with vision loss) to 3.3% (all of the non-attendees presented with vision loss). It is notable that 73.1% (19/26) of participants that followed up for air conduction threshold audiometry, presented with a hearing loss, furthermore, all participants (4/19) who attended audiology services required further intervention. The diagnostic hearing results were not available as public healthcare facilities are prohibited from sharing this information. Similarly, 57.8% of participants who attended diagnostic vision services presented with vision loss (26/45). Given these figures, a significant number of participants who attended follow-up services presented with hearing or vision difficulty. Only 0.16% (8/4888) of participants failed both hearing, and vision screening and these findings were in agreement with Eksteen et al. (2019), who found that 0.2% of participants failed both hearing and vision screening in a 4 to 7-year-old population.

4.2 Clinical Implications and Recommendations

The use of mHealth technology has been shown to be viable when the implementing a low-cost hearing or vision screening service (Jayawardena et al., 2020; Rono et al., 2018; Yousuf Hussein et al., 2018), however there are limited studies on dual sensory screening programmes (Eksteen et al., 2019; Kemper et al., 2004). This section focuses on clinical implications and recommendations that arose from the dual sensory screening study.

Task Shifting

Task shifting involves shifting specific tasks, where appropriate, to health workers with shorter training or qualifications (World Health Organization, 2008). The objective is to use the health workforce more efficiently whilst maintaining the quality of care standards and increasing access to necessary health services (World Health Organization, 2008).Task shifting is recommended with the intention of improving access to essential hearing and vision screening services. This study has demonstrated that LHWs can provide essential sensory screening services in resource-constrained areas (Eksteen et al., 2019; Rono et al., 2018; Shinn, Zuniga, et al., 2019; Yousuf Hussein, Swanepoel, Mahomed, et al., 2018). LHWs can provide a valuable contribution to community-based care, and several studies have noted the successful implementation of hearing and/or vision screening when implemented by LHWs (Cook, & Pasio, 2013; Eksteen et al., 2019; Jayawardena et al., 2020; Yousuf Hussein et al., 2016). It is important to note that when task-shifting occurs, adequate training of LHWs and ongoing support is required for implementation to be successful (Lehmann & Sanders, 2007; Ludwick et al., 2014)..

LHW Retention

This study reported a 50% staff turnover, which was due to personal extenuating circumstances. Relationship with peers has been cited as one of the strongest predictors of LHW retention, the high attrition rate negatively impacted the study as training of newly appointed LHWs was required. LHW retention is an important consideration when implementing a community-based programme. As LHWs gain experience, they become more efficient in administering screening measures (Eksteen et al., 2019). The sustainability and successful development of a community-based programme is dependent on LHW retention (Ngilangwa, & Mgomella, 2018). Improved LHW retention was noted where there was clear communication regarding duties during the recruitment process, community participation in the LHW selection was encouraged and individuals were more likely to stay due to accountability and responsibility towards their own communities (Ludwick et al., 2014). A careful community-led selection process for future LHWs is recommended, clear expectations, incentives and remuneration should be discussed (Ludwick et al., 2014; Ngilangwa, & Mgomella, 2018; Ngugi et al., 2018).

Implementation of community-based programmes within the framework of the NHI

The proposed re-engineering of the PHC sector has led to the development of two programmes that has the potential to ensure access to hearing and vision services for children, namely the Municipal-ward based Primary healthcare teams (WBPHCOTs) and integrated school health policy (ISHP). An example of task shifting within the NHI framework is the development of WBPHCOTs.

WBPHCOTs has been essential in delivering promotive and preventative healthcare services in low-resourced areas (The South African Department of Health, 2015). These teams are made up of a nurse and LHWs. WBPHCOTs have been successful in providing pre- and post-natal follow-ups and child wellness and identifying the need for referral to PHC facilities (The South African Department of Health, 2015). The use of LHWs to deliver promotive and preventative services has ensured access to basic healthcare services, in areas which are poorly resourced (The South African Department of Health, 2015). The use of WBPHCOTs may be an avenue to improve patient follow-up for further hearing and vision services and to advocate the importance of attendance of these appointments.

Similarly, to WBPHCOTs, the ISHP aims to address health concerns of school-aged children at community level. The ISHP reported that 7% of learners were referred for follow-up hearing services (14 202/201 770), and 21% of learners were referred for follow-up vision services (43 319 /201 770) (The South African Department of Health, 2015), the age distributions, geographic location nor screening methods were not available. In contrast this study evaluated 4888 participants for hearing loss and 4933 for vision loss. A reported 1.6% referred the hearing screening and 3.6% referred the vision screening, these numbers are significantly lower than those obtained by the ISHP and further strengthens the need for improved access to hearing and vision services for school-aged children.

mHealth Technologies

The mHealth technologies used in this study has been shown to be clinically validated and reliable (Lodhia et al., 2016; Mahomed-Asmail, Swanepoel, Eikelboom, Myburgh, & Hall, 2016; Swanepoel et al., 2014). In this study the use of mHealth technology was successfully implemented as part of a school screening. The environmental noise monitoring capabilities allowed accurate monitoring of noise levels throughout the screening process. The onsite data capturing reduced administrative time and ensured the results are captured and easily accessed on the encrypted cloud-based server (van Tonder, Swanepoel et al., 2017; Yousuf Hussein et al., 2016). The use of mHealth technologies demonstrates promise to address barriers to service delivery (i.e. equipment costs, increased administration).

The cost of dual sensory smartphone screening was estimated at $6.67 (US Dollars) per child. In contrast, conventional 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 portable, simple to use interface and synchronous data capturing, allows this technology to be integrated into different community-based settings, these smartphone-applications could easily be integrated into child wellness check-ups or at physician follow-ups for older patients. The low-cost of mHealth technologies makes it a viable option for communities who are poorly resourced (Bastawrous & Armstrong, 2013; Eksteen et al., 2019; Yousuf Hussein et al., 2018).

Stakeholders in the public healthcare system

A poor follow-up rate was reported in this study. To ensure improved follow-up rates various stakeholders (audiologist/optometrist) would need to play a pivotal role in improving the follow-up process. The streamlining of the follow-up services at secondary hospitals through an appointment, will improve patient follow-up and strengthen the PHC system.

4.3 Critical Evaluation of the hearing and vision screening programme

The strengths and limitations were critically analysed in an attempt to interpret research findings and guide future research:

Study strengths

This study highlighted the importance of school-aged screening and showed that mHealth technologies could be integrated as part of a school health programme. The use of LHWs reduced the burden of testing on school nurses and has shown that LHWs can successfully implement a hearing and vision screening programme (Dibakwane & Peu, 2018; Eksteen et al., 2019; Rono et al., 2018). LHW utilisation ensured that hearing and vision screening was accessible to many children and cost-effective. The asynchronous software allowed data to be captured and securely stored on a cloud-based server, this reduced the administrative workload and resulted in an efficient screening service (Lodhia et al., 2016; Mahomed-Asmail, Swanepoel, Eikelboom, et al., 2016; Swanepoel et al., 2014). The anonymity of the data protected the participants and ensured patient confidentiality.

Study Limitations

Limitations identified in this study included, the lack of a baseline, poor follow-up rate and low LHW retention. This study did not have a control group to compare the outcomes of the hearing and vision screening study to. The poor follow-up rate for air conduction threshold audiometry and at diagnostic audiology/optometry services. Due to the poor follow-up rate for hearing and vision services, an accurate prevalence of hearing and vision loss could not be determined. The PHC system is over-burdened, and the capacity to provide further assessments and interventions were greatly confounded by long-waiting periods between appointments. Furthermore, the hearing and vision screening programme was negatively impacted by the high staff turnover; this inevitably resulted in additional training costs and negatively impacted the efficiency of the programme.

4.4 Recommendations for future research

Analysis of the results obtained as well as the conclusions drawn have indicated several areas for further research. Poor follow-up rates for hearing and vision services were characteristic of this project. Only a third of participants attended air conduction threshold testing, less than a quarter of participants attended follow-up audiology services, and one in four participants attended vision follow-up services. Previous studies reported that even though some participants received hearing screening, the follow-up rate remained low (Almani, 2015; Thodi, Parazzini, & Kramer, & Davis, 2013; Yousuf Hussein et al., 2016). Likewise, Zeng et al. (2020) reported poor post-vision screening follow-ups for diagnostic testing (Zeng et al., 2020). It was noted that post-vision screening telephonic follow-ups and the provision of appointments for further testing improved the follow-up rate for vision services (Zeng et al., 2020). Further research is needed to address and identify barriers to attending hearing and vision services.

Older school-aged children may have had little to no access to hearing or vision screening services due to an under-resourced and over-burdened school-health system. A mass hearing and vision screening study focusing on an older school-aged population (>9 years) is recommended as limited information is available on this population. Several studies have found that there is an increasing prevalence rate of hearing loss in older children (Shargorodsky, Curhan, Curhan, & Eavey, 2010; Stenfeldt, 2018).

A standardized mHealth protocol is needed for hearing and vision screening in low-resourced communities. This would improve the reliability and, consistency of results obtained, it would also allow various community-based programmes to be compared and to identify any limitations of such programmes so they can be adequately addressed to ensure sustainability.

Various studies have reported different gender effects on school hearing screening, and more research is needed to investigate the potential underlying causes for these gender differences (Mahomed-Asmail et al., 2016; North-Matthiassen & Singh, 2007; Osei et al., 2018; Rao et al., 2002).

4.5 Conclusion

Using clinically validated mHealth technology products to screen hearing and vision has shown promise. The results obtained have demonstrated that task shifting of essential hearing and vision services can increase the accessibility at a community level. The use of smartphone-based technology facilitated by LHWs improved the cost-effectiveness of the dual sensory screening services. The identification of sensory deficits before school entry and throughout the school-aged period is imperative as they negatively impact on academic abilities. Dual hearing and vision screening of school-aged children can be implemented at a community level, and it is easily integrated into the school health program. The utilisation of mHealth technologies has the potential to improve access to essential hearing and vision services in low-income communities.

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6. APPENDICES

Appendix A: Ethical Clearance certificate for the hearX group to a conduct hearing and vision screening program

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

4 December 2017

Dear Prof Swanepoel

Project:	**Hearing and vision screening for preschool children using mHealth technologies: a community-based service-delivery model**
Researcher:	**Prof DCDW Swanepoel**
Department:	**Speech-Language Pathology and Audiology**
Reference numbers:	**GW20171104HS (Staff research)**

Thank you for the application that was submitted for ethical consideration.

I am pleased to inform you that the above application was **approved** by the Research Ethics Committee at an ad hoc meeting held on 30 November 2017, conditional to the submission of the following information:

- Written permission from the ECD schools

Please note that data collection **may not** commence prior to the above permissions being submitted and subject to final approval by this committee. To facilitate the administrative process, please respond to Ms Tracey Andrew at tracey.andrew@up.ac.za or Room HB 7-27, at your earliest possible convenience.

Sincerely

Prof Maxi Schoeman
Deputy Dean: Postgraduate Studies and Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail:tracey.andrew@up.ac.za

Appendix B: Letter to hearX CEO requesting utilisation of data as part of a master's dissertation

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

08 August 2018

Dear Mr. Klopper,

REQUEST TO UTILISE HEARING & VISION SCREENING DATA

I, Michelle Manus, a masters student at the Department of Speech Language Therapy and Audiology, University of Pretoria. I would like to request permission to use the hearing and vision screening data that has been collected by your organisation, hearX Group, in a hearing and vision screening program, carried out in the Tembisa and Ivory Park area. This data will be used as basis for a master's dissertation research study, entitled: *Community-based smartphone-based hearing and vision screening at schools in a low-resourced community: an evaluation study*. The rationale of this study is to evaluate a community-based mHealth hearing and vision screening programme and to determine the efficacy in a low-resourced community. All research outputs will be shared with hearX Group, and the organisation will be acknowledged as the original data collector in any subsequent research publications. If permission is granted, the data as per university regulations will be required to be stored for a period of 15 years. To protect the confidentiality of the participants in your hearing and vision screening program, we ask that data is provided to us anonymised.

Ethical clearance will be obtained prior to analysing the data. If consent is given, please provide us with a letter on your organisation's letterhead, acknowledging that permission is granted to utilise this data in the aforementioned research study.

Should you require any further information, you can contact me on michellemanus0@gmail.com or on (012) 3140477.

Yours Sincerely,

Mrs Michelle Manus

Primary researcher

Dr Jeannie van der Linde

Co-supervisor

Prof. De Wet Swanepoel

Supervisor

Room 3-4, Level 3, Building Communication Pathology
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 1234

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix C: Letter granting permission to utilise the hearing and vision screening programme data

hearX group

28 September 2018

Att: Cpt. Michelle Manus
1 Military Hospital
1026 Voortrekker Rd
Thaba Tshwane
0157

Dear Cpt. Manus,

PERMISSION FOR USE OF ANONYMISED RESEARCH DATA

We refer to your letter dated 8 August 2018, requesting permission for the use of anonymised participant and test result data from our Diageo Tembisa Project.

We hereby grant permission for use of this data in your research project. Data will be provided to you anonymised, so as to protect the privacy and identifying information of the children who participated in this community-based project in Tembisa that we managed.

Should you require any further information regarding the project or this data, you can contact Mrs. Renate le Roux on renate@hearxgroup.com or 074 996 9692.

Kind Regards,

Nic Klopper
CEO: hearX Group

Renate le Roux
Audiologist & Project Manager

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Ground Floor, Building 2, Ashlea Gardens Office Park, 180 Garsfontein Road, Ashlea Gardens, 0081, Pretoria, South Africa
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info@hearxgroup.com

hearX Group (Pty) Ltd | Reg No 2016/198519/07
Directors NJ Klopper, J Lim Fung Yen, DCD Swanepoel | Independent Director IM Rademeyer

Appendix D: ECD Preschool/ Primary School consent form

CHILD EAR AND EYE SCREENING PROGRAMME	FORM

Dear Principal

Sihlangene ECD Forum has entered into an agreement with Pheme Consulting and HearX Group which is currently rolling out a free hearing and vision screening for children between the ages 4 and 6 years in and around Tembisa.

In order for our trained screeners to conduct the screening process at your center, we need your consent. The screening will take approximately 10 minutes per child and it is 100% harm free to the child. It is conducted without any use of medication or chemicals.

Research has shown that children will have difficulties learning or associating when they have either a hearing or vision problem and it is for this very reason that Sihlangene is delighted to be a part of this program. We believe it will eliminate so many of the challenges we experience as teachers and principals in ECD centers particularly with parents who do not want to take responsibility for the health of their children.

This opportunity for centers is only available to members of Sihlangene ECD Forums and as thus, we advise that you take advantage of it whilst it is still freely available.

Below is a consent form, kindly give permission for our screener to come screen children at your center. Only children whose parent consent forms have been returned will be screened. This will eliminate any possible fall-out with the parent against your center.

CONSENT (Kindly complete consent 1 or 2 depending on your decision)

(1) I ____________________________________ (full names of Principal/Duly authorised Representative) DO hereby grant permission for the criteria-appropriate children in my school/centre ____ (name of centre/school) to be screened.

(2) I ____ (Full names of principal/duly authorised representative) DO NOT give permission for children in my school/centre ____ (name of school/centre) to be screened.

And thus, completed at ______________________________________ on the____ day of _________________20_____

Signature ____________________ Time __________

SCHOOL DETAILS

Tel Number	
Street Address	
E-mail Address	

Diageo Project Tembisa Partners:

Appendix E: Parent Consent Form

CHILD EAR AND EYE SCREENING PARENT CONSENT FORM

Dear Parent(s)/Legal Guardian

Hearing and seeing are both very important physical birth rights for your child which are also key to his/her success in learning and associating with other children. When NOT screened/tested, treated when necessary and/or known to teachers and care givers, a child's ability to hear and see can prevent him/her from receiving appropriate care.

Our center through its membership to **Sihlangene ECD Forum** has entered into an agreement with HearX Group and its partners to provide free hearing and vision screening for our children. The programme is called Diageo Project – Tembisa and Surrounding. The screening is fun for children and 100% harm free with no chemicals or medical induction to the child. Trained and Identifiable screeners will visit our center on the date to be specified and upon arrival, children whose eye and ear screening consent form is signed by the parent or legal guardian will be screened. Should a child need further medical treatment, a referral letter will be issued and with this letter, that child will be given preference at the nearest clinic or hospital.

In order for your child to be screened for hearing and vision, we need you to give us permission. This screening is not compulsory however, you will be giving your child the added advantage for him/her to be screened and be provided with the necessary medical care if needed.

The information collected during the screening be used for further research by HearX Group and Pretoria University. The research is 100% confidential and your child's personal information will never be known to any third parties or be made public. The screening results will be communicated directly to you via SMS. If the results reflect "referral", your child will be issued with a referral letter. A referral does not mean that your child has failed but simply gives you an opportunity to intervene in your child's hearing and vision ability in the early stages of his/her life.

CONSENT (Kindly complete consent 1 or 2 depending on your decision)

(1) I ______________________________ (full names) in my capacity as: (mother/father/legal guardian – *cancel whichever not applicable*) of ______________________________________ (full names of child) who was born on the ____ day of __________________ 2____ (Child Date of Birth) DO hereby give permission to ____ (name of school/centre) that my child can be screened for hearing and vision by the certified screeners. AND that the information may be used for further research _________(Yes/No).

(2) I ___________________________________ (Full names of parent/legal guardian – *cancel whichever not applicable*) DO NOT give permission for my child ________________________________ (full names of child) to be screened.

And thus, completed at _________________________________ on the____ day of ________________20___

Signature ___________________ Time _________

Cell No:		Cell No:		E-mail:	

Diageo Project Tembisa Partners:

Appendix F: Ethical clearance certificate for study entitled community-based hearing and vision screening in low-income schools using smartphones

ERSITEIT VAN PRETORIA
/ERSITY OF PRETORIA
IBESITHI YA PRETORIA

Faculty of Humanities

Research Ethics Committee

30 October 2018

Dear Ms Manus

Project: Community based hearing and vision screening at schools in a low —resourced community: An evaluation study

Researcher: M Manus

Supervisor: Prof DCDW Swanepoel

Department: speech-Language Pathology and Audiology Reference number: 183375864 (GW20181007HS)

Thank you for the application that was submitted for ethical consideration.

The Research Ethics Committee notes that this is a literature-based study and no human subjects are involved. The application has been approved on 25 October 2018 with the assumption that the document(s) are in the public domain. Data collection may therefore commence, along these guidelines.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. However, should the actual research depart significantly from the proposed research, a new research proposal and application for ethical clearance will have to be submitted for approval.

We wish you success with the project.

Sincerely

Prof Maxi Schoeman
Deputy Dean: Postgraduate Studies and Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail:PGHumanities@up.ac.za

cc Prof DCDW Swanepoel (Supervisor) Prof J van der Linde (Acting-HoD)

Fakulteit Geesteswetenskappe
Lefapha la Bomotho