mHealth applications for hearing loss – a scoping review

Caitlin Frisby, MA[1], Robert Eikelboom, PhD[1,2,3], Faheema Mahomed-Asmail, PhD[1], Hannah Kuper, PhD[4], and De Wet Swanepoel, PhD[1,2,*]

Journal of Telemedicine and E-Health

1 Department of Speech-Language Pathology and Audiology, University of Pretoria, Pretoria, Gauteng, South Africa.
2 Ear Science Institute Australia, Subiaco, Australia.
3 Ear Sciences Centre, Medical School, The University of Western Australia, Nedlands, Australia.
4 International Centre for Evidence in Disability, London School of Hygiene & Tropical Medicine, London, United Kingdom.

*Address for correspondence: De Wet Swanepoel, Department of Speech-Language Pathology and Audiology, University of Pretoria, Lynnwood Rd & Roper Street, Pretoria, South Africa. E-mail: dewet.swanepoel@up.ac.za

ABSTRACT

Background

Mobile health (mHealth) has the potential to improve access and uptake of health services globally. Non-communicable diseases like hearing loss have seen increasing use of mHealth approaches to improve access, scalability, penetration, quality, and convenience of health services. This scoping review describes published research in mHealth supported hearing healthcare services across the continuum of care.

Methods

A search on Scopus, MEDLINE (PubMed), and Web of Science for articles published up to 2 July 2021 was conducted. Articles in which mHealth was used across a continuum of care where the primary focus was hearing healthcare were included. A narrative synthesis was conducted.

Results

146 articles meeting the inclusion criteria were included in data extraction. High- income countries contributed 56% of articles, upper-middle countries 32%, lower-middle countries 8%, and low-income countries 4%. Articles identified included promotion (2%), screening (39%), diagnosis (35%), treatment (10%), and support (14%) for hearing loss. mHealth applications in high-income countries were more represented in diagnosis (62% vs 38%), treatment (67% vs 33%) and support (82% vs 18%) compared to low- and middle-income countries (LMICs) except for screening (64% vs 36%). Few studies focussed on hearing health promotion across all income brackets.

Conclusion

mHealth supported hearing healthcare services are available across a continuum of care and various world regions, although more prevalent in high-income countries. Although great potential is demonstrated, implementation evaluations are important to further validate its widespread use and potential to make services for hearing loss more accessible in LMICs.

Key Words: mHealth, hearing loss, hearing impairment, mobile phone, hearing services.

INTRODUCTION

An estimated five billion people use mobile phones, constituting more than 60% of the global population.[1] This level of penetration is continually increasing as mobile technology becomes more accessible and affordable[2] allowing both young and old in high, middle, and low-income countries to make use of mobile health (mHealth) applications.[3] mHealth, defined as technologies to improve healthcare outcomes, services, and research using mobile and wireless devices[4], is an enabler of improved access and uptake of services, especially in low- and middle-income countries (LMICs).[5-6] mHealth approaches, therefore, demonstrate potential to support more accessible health care for non-communicable diseases[5], given the development of new innovations and the wide availability of mobile phones.

The technologies underlying mHealth often make use of simple user interfaces for digital inclusion, automation, quality control measures and cloud data management that support task-shifting approaches towards more accessible care.[7] Further potential benefits of mHealth include reduced costs[8-9] and reduced time required for appointments,[10-11] which contribute to the expected increased rate of healthcare access and attendance.[11-13] mHealth approaches do, however, present with some limitations. These include concerns regarding the confidentiality and privacy of individuals' data[14]. Furthermore, mHealth approaches may be hindered by poor connectivity and unstable electricity supply that can delay or prevent care especially in rural or remote areas[14]. Individuals with low literacy or previously limited access to digital technologies may also find the use of mHealth approaches challenging[14]. Despite potential limitations mHealth has demonstrated its value to increase quality of care[2,15], lower patient burden[2], promote health awareness[3,16], guide efficient care[3,16], and improve service delivery to underserved and vulnerable populations. [2,,5,6]

Persons with disabilities face additional challenges in accessing healthcare and so may benefit from mHealth in particular.[6,17] There is already evidence that persons with disabilities report that their mobile phones provide them with greater access to basic services in countries where services are scarce and inadequate.[17] Particularly individuals with hearing loss demonstrate a high usage of mobile phones and the internet.[17] Hearing loss is one of the most prevalent disability types affecting close to 500 million persons globally.[18] Estimates indicate that by 2050, disabling hearing loss will increase to affect 900 million people,[18] due to an ageing and growing world population.[19]

Hearing healthcare has traditionally been centralised requiring expensive equipment and trained professionals. Consequently, these services are not accessible for the majority of the world's population due to the costs and shortages of trained professionals.[4,20,21] The lack of basic hearing services faced by the majority of the global population has resulted in a growing interest in innovative solutions, including mHealth approaches, to support the provision of hearing healthcare services.[22-24] Implementing mHealth in hearing healthcare could address critical challenges of limited availability of hearing healthcare professionals, as well as transportation, time, costs, and access to resources.[25-26] Considering that more than 80% of persons with hearing loss reside in LMICs with severely limited access to care[4] mHealth applications could support services across a continuum of hearing healthcare including advocacy, promotion and awareness, detection, diagnosis, treatment, support, and rehabilitation.[27] COVID-19 has further emphasized the importance of decentralised healthcare supported by mHealth in communities to avoid risk of infection and associated morbidity and mortalities.[28]

Several recent studies have used mHealth approaches in decentralised hearing healthcare services across the continuum of care. These services included health promotion, such as monitoring of listening habits.[29] Screening through mobile apps has been conducted at schools, communities and in homes,[30-33] and diagnostic approaches differentiated between types of hearing loss to ensure directed referrals.[34] Treatment has been provided in the form of self-fitting hearing aids[35] with support providing rehabilitation, education, and applications to control device settings.[36-37] However, a comprehensive assessment of the range of mHealth use for hearing healthcare across the care continuum and from a global perspective has not been undertaken. This scoping review, therefore, aimed to identify and describe the published research in mHealth supported hearing healthcare services across the continuum of care.

METHODS

This review was conducted in accordance with guidelines in the Joanna Briggs Institute Reviewer Manual.[38] The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) checklist was followed in this scoping review (Online supplementary material).[39]

Eligibility Criteria

The search was limited to papers published up to and including the date of the final search which was conducted on 2 July 2021. Only published articles in peer-reviewed journals were included. Only English empirical studies were included, with no geographic or time restrictions. All publications examining any aspect of mHealth targeting hearing including direct or indirect services between patients and health care providers both professional and non-professional and mHealth monitoring via apps were included. Opinions, viewpoints, reviews, and preprints were excluded. Any articles where mHealth applications were not investigated or hearing loss was not a target condition were excluded. Articles, that only included ear disease but not hearing loss, were excluded. Articles focusing on literacy and education (e.g., articles focused on improving reading or writing abilities of individuals with hearing loss) were also excluded.

Information Sources and Search Strategy

Three electronic databases (Scopus, Web of Science and MEDLINE(PubMed) were systematically searched using keywords. The initial search was conducted on Scopus with two concepts: (1) ("mHealth" OR "mobile health") AND ("hearing loss" OR "hearing impairment"). Extra filters were then applied, and the final search strategy was conducted on all three databases using a combination of two concepts: (1) ("mHealth" OR "mobile health" OR "tablet" OR "smartphone" OR "mobile phone") and (2) ("hearing loss" OR "hearing impairment"). For a comprehensive assessment, reference lists of all the included articles were also checked to identify additional studies that may be relevant to this review.

Data Charting and Data Items

Articles identified by the search strategy were imported into Rayyan QCRI,[40] an online tool for systematic reviews, and duplicates were removed. The first author screened the title, abstracts and full text of the identified articles and extracted data from the included studies. The last author cross-checked the screening of the title, abstracts, and full text of the identified articles, and confirmed exclusion criteria was applied consistently and cross-checked the data extraction. Where discrepancies were identified they were discussed and corrected. A Microsoft Excel spreadsheet (Online supplementary material) was used to tabulate the required information from the included studies such as the name of mHealth approach where applicable, publication date, country in which study was conducted, mHealth approach type (i.e., internet-based or application-based), participant demographics, device type, mode of operation, setting mHealth approach was used in, study design, sample size and mHealth approach availability (Online supplementary material). mHealth approach availability was noted as available from the manufacturer, on a public platform (i.e., app store or via the internet) or designed only for research.

Additionally, for each article, the mHealth approach was categorized into a clinical hearing care continuum of health promotion (including prevention), screening, diagnosis, treatment, and support (Online supplementary material). Health promotion included mHealth approaches promoting hearing healthcare and prevention of adverse hearing activities to individuals, creating awareness and educating individuals. Screening mHealth approaches indicated hearing loss through a pass/fail criterion whereas diagnostic mHealth approaches categorized degree, configuration, or type of hearing loss. Treatment included mHealth approaches aimed at improving hearing ability and speech recognition with either traditional or non-traditional devices. Support included mHealth approaches aimed at providing rehabilitation once a form of treatment had been provided.

Synthesis of Results

A narrative synthesis was conducted. The data extracted was analysed utilizing descriptive statistics with Microsoft Excel and SPSS software (version 27.0; IBM Corp). Data was analysed across the global world regions according to the World Health Organisation (WHO) classification[4] as well as the WHO income classification.[41] The distributions of the articles according to the hearing healthcare continuum of care were analysed. If articles fell within two brackets of the continuum of care they were counted twice, once within each relevant bracket.

RESULTS

This study identified 146 unique articles to be included in the review (Figure 1; Online supplementary material). The primary search was conducted on Scopus and yielded 103 (71%) articles. Subsequent searches of MEDLINE (PubMed) and then Web of Science yielded an additional 14 (10%) and four (3%) articles, respectively. The remaining 25 (17%) were found by reviewing the citations in the papers already included. All included articles were published between 2006 and 2021, and no multiple publications in one year until 2013 (Figure 2).

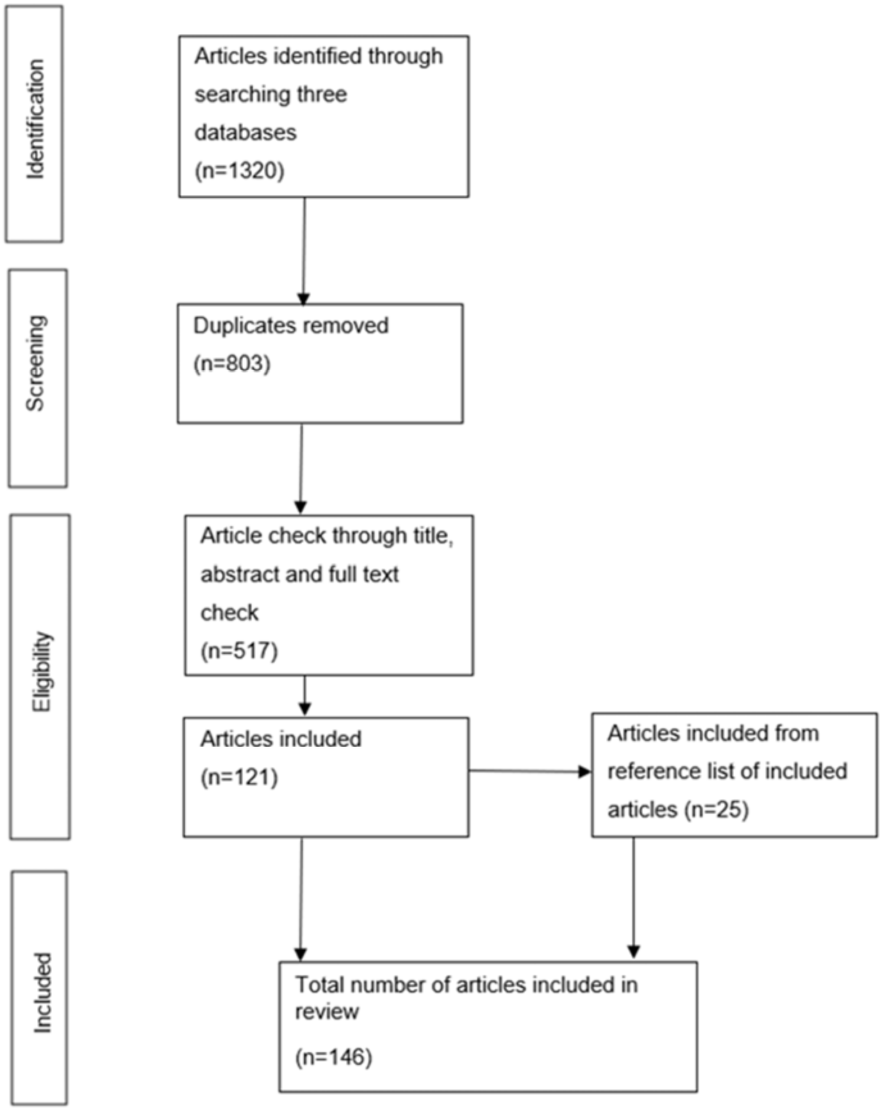

Figure 1: PRISMA flowchart of mHealth and hearing loss article selection process

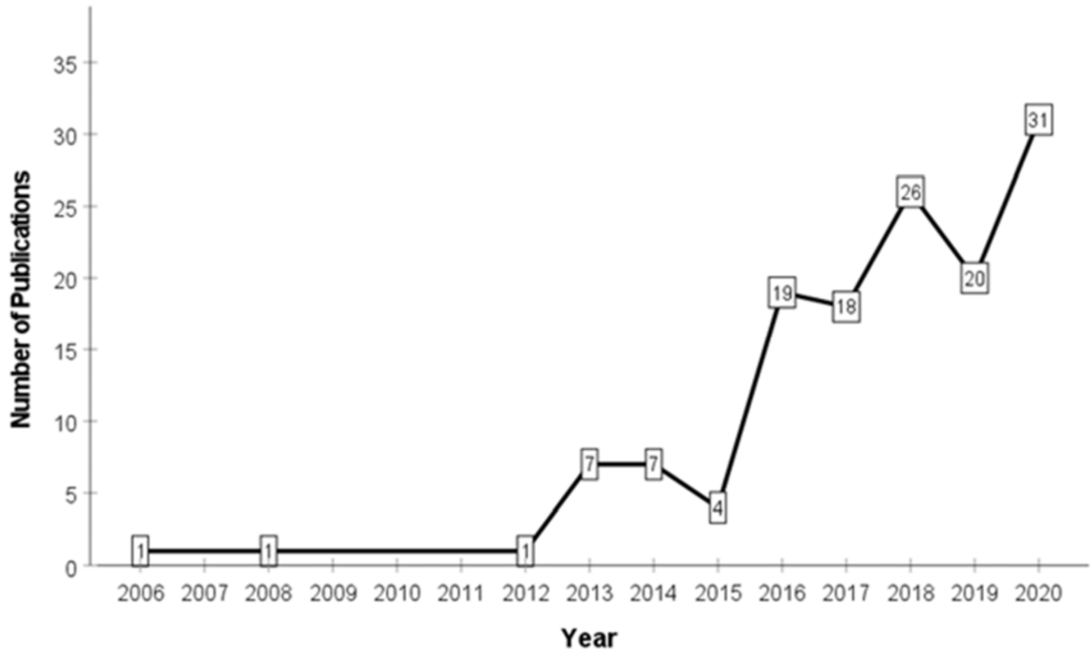

Figure 2: mHealth and hearing loss articles (n=135) published between 2006 and 2020. Articles published in 2021 were not included since the review was until July only.

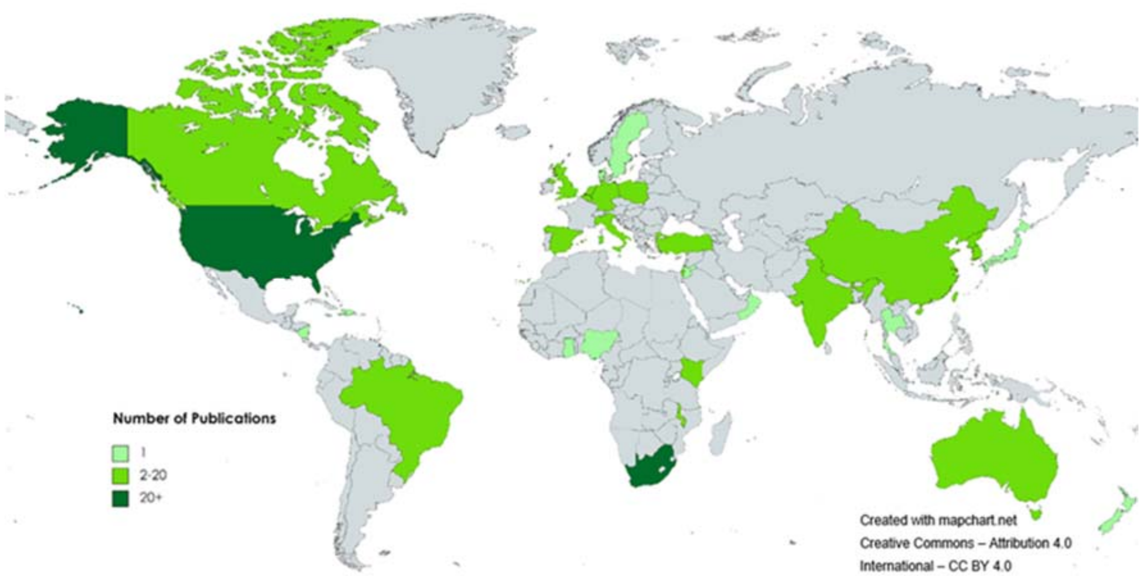

Figure 3: mHealth and hearing loss articles identified globally. Represents 147 articles since one article covered work conducted in two countries.

mHealth approaches were used in 32 unique countries represented across the 146 identified articles (Figure 3; Online supplementary material), with most from the Americas region, and the fewest from the South-east Asia region (Figure 4). The two most prominent contributors across these regions were South Africa (17%) and the United States of America (16%). Represented countries were also grouped into WHO income classifications.[41] High-income countries contributed 56%, upper-middle countries 32%, lower-middle countries 8%, and low-income countries contributed 4% of included articles. 75 unique mHealth approaches were used across the 146 articles (Online supplementary material).

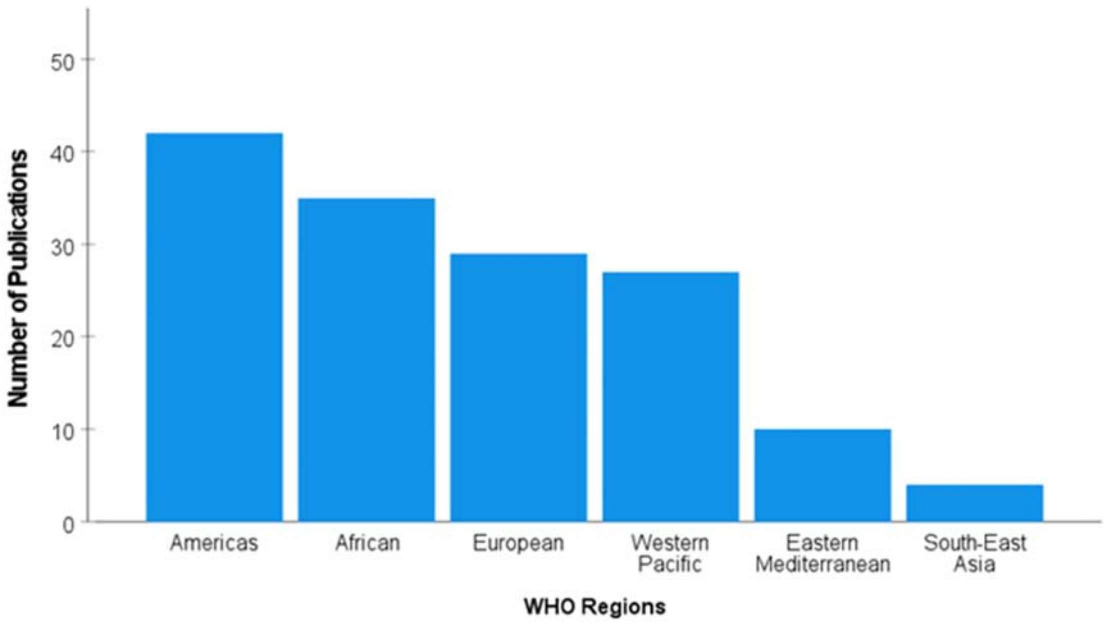

Figure 4: mHealth and hearing loss articles identified across WHO regions. Represents 147 articles since one article covered work conducted in two countries.

A third (31%) of reported mHealth approaches were used in community-based settings (i.e., home and schools) (Table 1). Smartphone applications constituted 95% of the mHealth approaches with the remaining 5% being internet-based mHealth solutions. Overall, 25% of the identified mHealth approaches required a facilitator to operate, of which 65% were healthcare professionals, 19% non-professional healthcare workers and 16% made use of both professional and non-professionals. Healthcare professionals that facilitated mHealth approaches included otolaryngologists, otolaryngology registrars, audiologists, audiology officers, audiology students, audiology research assistants, nurses, and medical doctors. Non-professional healthcare workers included non-governmental organization volunteers and community health workers (CHWs). Identified mHealth approaches were mostly (44%)

available from manufacturers, followed by public platforms (33%) and designated research applications (23%; Online supplementary material).

Table 1: Characteristics of identified mHealth applications (n=152) across area of application, context, devices, mode of use, participants, and study design (HCP – Health care professional; RCT – Randomized controlled trial)

	Health Promotion % (n=3)	Screening % (n=59)	Diagnosis % (n=53)	Treatment % (n=15)	Support % (n=22)	All % (n=152)[1]
Context						
School	-	43	4	-	-	18
Clinic	-	50	75	33	18	52
Daily life	100	-	-	60	59	16
Home	-	7	15	7	23	12
Occupational	-	-	6	-	-	2
Type of device						
Smartphone	100	63	55	93	82	66
Tablet	-	37	45	7	18	34
Mode of use						
Patient self-use	100	58	77	100	95	75
HCP	-	24	17	-	5	16
Non-HCP	-	10	4	-	-	5
HCP and non-HCP	-	7	2	-	-	3
Self-use, HCP, and non-HCP	-	2	-	-	-	1
Type of participants						
Adults	33	34	76	100	100	63
Children	67	49	15	-	-	27
Both	-	17	9	-	-	10
Study design[2]						
Validation	100	73	89	75	44	75
Design and usability	-	5	4	19	20	8
Feasibility	-	16	7	6	36	15
Prevalence	-	5	-	-	-	2
RCT	-	2	-	-	-	1

1. *Total number of articles shown as 152 since five articles included mHealth solutions for both treatment and support and one for both screening and diagnosis. These were counted twice within each of the respective areas of application.*
2. *Total number of articles shown as 162 since several articles included more than one study design or more than one area of application. These were counted twice within each of the respective study design or areas of application.*

Two-thirds of studies (63%) involved adult participants. The median sample size in the reported studies was 65.5 participants (Online supplementary material). Screening and diagnosis article sample size medians were 122 and 63 respectively while promotion, treatment and support medians were 311, 16 and 15.5 participants, respectively (Online supplementary material). Five different study design categories were identified across the articles (Table 1). Seven of the identified articles were however counted within the validation and usability study designs groups and two other articles were included in the validation and feasibility study design groups. Feasibility studies contributed 15% of articles. Four different areas of application were identified across the articles (Table 1). Five of these covered both treatment and support categories and one article covered screening and diagnosis categories. All the health promotion applications were related to sound-level monitoring with 67% of participants younger than 18 years of age. Three in four mHealth approaches (75%) identified were for self-use by patients and 9% were for use by non-professional health workers to facilitate services.

Table 2: Characteristics of mHealth applications (n=112) across screening (n=59) and diagnosis (n=53) for hearing loss.

	Screening **% (n=59)**	**Diagnosis** **% (n=53)**
Age		
Over 18 years	*34*	*76*
Under 18 years	*49*	*15*
Both	*17*	*9*
Type of audiometry		
Pure tone	*85*	*83*
Speech	*12*[a]	*11*[b]
Both	*3*	*6*
Type of transducer		
Air Conduction	*90*	*98*
Bone Conduction	*3*	*2*
Both	*7*	-

a) Speech testing in screening included speech-in-noise (56%), speech-in-quiet (10%) and both speech-in-noise and speech-in-quiet (33%) testing.
b) Speech testing in diagnosis included speech-in-noise (78%), speech-in-quiet (22%) testing.

The majority of mHealth approaches used were for screening and diagnosis (74%; Table 2). For screening categories, the youngest participants were two years of age using pure tone audiometry screening applications on an Android platform[33,42,43] and iPad devices.[42] In diagnosis, the youngest participants were three years of age using a pure tone audiometry application on an iPad.[44-45] Digits-in-noise testing made up 44% of the speech-in-noise approaches for screening and diagnosis categories.

10% and 14% of articles were focused on treatment and support respectively. All participants involved in both treatment and support were over the age of 18 years. The types of treatment provided were mHealth approaches used with (56%) and without (44%) traditional amplification devices. mHealth approaches with traditional amplification devices were smartphone applications linked to hearing aids (56%), linked to self-fitting hearing aids (33%), and linked to cochlear implants (11%). The applications were used to control device gain across frequencies for hearing aids or electrodes for cochlear implants. mHealth approaches used without traditional amplification devices were smartphone applications that increased gain of phone signals (29%), applications coupled to wireless earphones (29%), microphone applications (14%), smartphone applications linked to handsets and earphones (14%) and non-traditional body-worn hearing aids linked to earphones (14%). These mHealth approaches were all used to improve speech recognition.

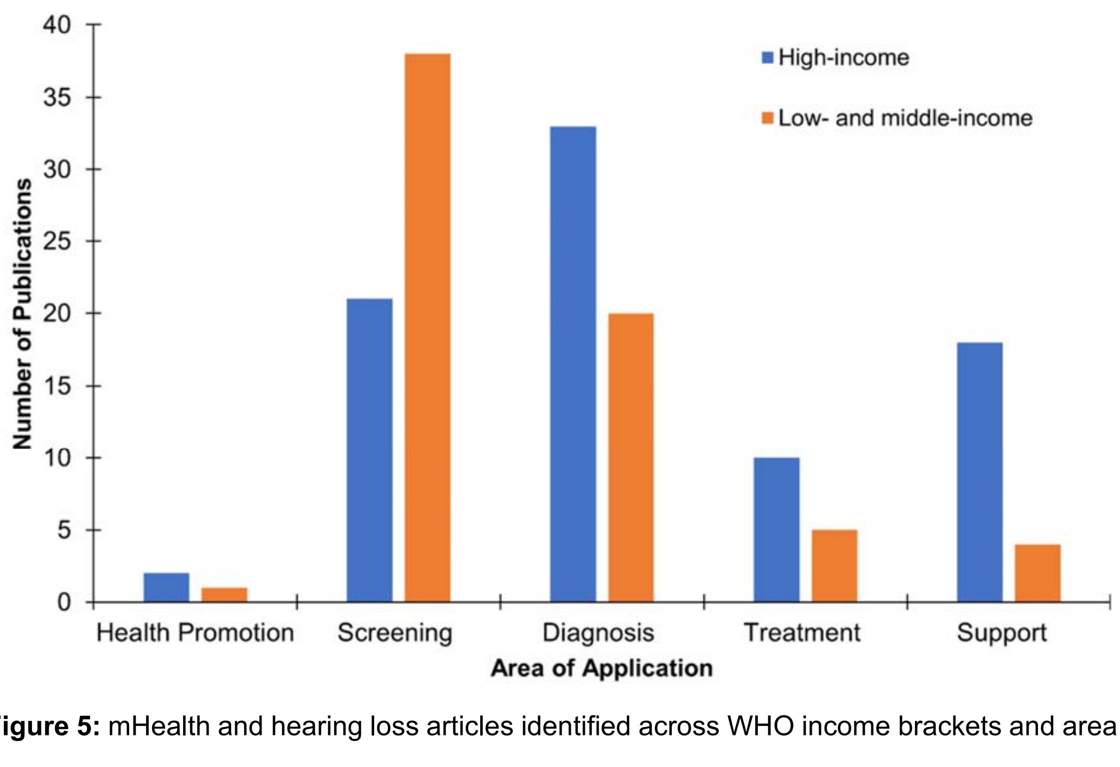

Figure 5: mHealth and hearing loss articles identified across WHO income brackets and area of application. Represents 152 articles as several covered work conducted across more than one area of application.

Types of support provided through mHealth means included rehabilitation and education (46%), ecological momentary assessment (27%), application to control device settings such as microphone directionality, volume, and programme selection (14%), real-time speech-to-sign translation (9%) and text to speech translation (5%). The majority of studies on health promotion, diagnosis, treatment and support were conducted in high-income countries compared to the majority of studies focused on screening conducted in LMICs (Figure 5; Online supplementary material).

DISCUSSION

This scoping review aimed to identify and describe globally reported research in mHealth for hearing healthcare services across the continuum of care. There has been a dramatic annual increase in the publication of mHealth research from no more than one per year until 2013 when there was seven to 31 during 2020. The 146 identified research articles cover the continuum of hearing healthcare including health promotion (2%), screening (39%), diagnosis (35%), treatment (10%), and support (14%). The majority of studies were conducted in high-income countries (56%), while the data from LMICs was sparser (44%). Studies made use of smartphones (65%) and tablets (34%) to facilitate the mHealth services without any mobile or feature phones.

The two most prominent areas of application were screening and diagnosis. Each of these areas contributed almost 40% of the articles. Screening articles were mostly conducted in LMICs, whereas most diagnosis focused articles were conducted in high-income countries. This is likely due to LMICs typically having a limited or total dearth of established screening programs because of challenges including a shortage of human resources and prohibitive cost of equipment[4,20,21]. High-income countries typically have more established screening programs in place such as newborn hearing screening and school-based screening programs. mHealth approaches that can enable the initial step in hearing healthcare in terms of detection, is an important point of departure to utilise mHealth approaches in LMICs to initiate hearing care.

Two thirds (66%) of all screening articles involved children, while almost one in four (25%) diagnosis focused articles involved children. Screening followed by a diagnosis is crucial for early intervention to reduce the negative impact that hearing loss has on both language and cognitive development.[4] The limited number of articles focused on diagnosis in children using mHealth approaches likely reflects the requirement for advanced technologies like auditory brainstem responses and otoacoustic emissions to objectively test very young children unable to provide behavioural responses.[4,46] There were also limited articles (10% and 2%) on screening and diagnosis in children using speech testing. Speech testing provides holistic information on an individual's everyday hearing ability and future research should consider more mHealth approaches in children.[47]

Several (19%) screening articles demonstrate that mHealth supports task-shifting whereby minimally trained individuals such as community healthcare workers (CHWs) made use of mHealth screening technologies. mHealth hearing screening technologies have the potential to be used in combination with vision screenings by CHWs to provide cost-effective and efficient services in communities.[48] This task-shifting allows for decentralized screening services with centralized surveillance through cloud-based data management.[48] Additionally, since 2019 there has been an increase in the number of studies involving diagnostic testing (5%) that utilise mHealth technologies facilitated by minimally trained CHWs. CHWs were able to successfully facilitate diagnostic testing, using a mHealth supported automated pure-tone test, with sensitivity and specificity equivalent to results obtained by professionals.[49] These studies did not include an artificial intelligence (AI) algorithm but utilized automated test protocols, automated ambient noise monitoring as well as quality indices for test operators which could explain sensitivity and specificity results that are comparable to professionals. mHealth supported and automated diagnostic assessments make task-shifting possible through reduced demands on CHWs interpretation and limiting tester errors.[49-50] This demonstrates significant potential since task-shifting, according to the WHO's World Report on Hearing, is an important strategy to make hearing healthcare more accessible.[4,46]

More than half (59%) of screening articles and more than three in four (77%) of the diagnosis articles made use of mHealth technologies that were self-operated by the patient. Low- or no-touch services enabled by patient-operated mHealth technologies show great potential and are especially applicable in the COVID-19 pandemic because they enable remote service delivery.[28,51]

Support, treatment, and health promotion were less common, contributing to only 15%, 10% and 2% respectively, mostly undertaken in high-income countries. No support or treatment articles were identified for the WHO region of Africa, where 39.9 million individuals with hearing losses ranging from moderate to profound degrees reside.[4] All support and treatment articles involved adults, reflecting a dearth of mHealth options to support rehabilitation in children with hearing loss. Nearly half (46%) of support articles involved rehabilitation and education. The use of mHealth in support can assist to improve treatment acceptance, management, and benefits.[4,52,53] Reported mHealth approaches were able to successfully support the management of hearing aids by providing education to older adults on hearing aid tasks.[54-55]

Almost two in three (56%) articles provided treatment through a mHealth approach used in conjunction with traditional hearing devices (i.e., hearing aids and cochlear implants). The use of mHealth to support self-fitting hearing aids shows great potential to provide more accessible and low-cost treatment options.[56] Self-fitting hearing aids have been used successfully, provided sufficient information was given.[35] The use of mHealth can provide greater control over device settings and enable more positive outcomes in the hearing aid fitting process with troubleshooting resources available on a phone.[54,56,57] This approach shows potential for implementation in areas such as in LMICs where approximately 270 million people need hearing aids but are not using hearing aids due to costs and severely limited hearing healthcare professionals and services.[4]

Only three articles focused on health promotion and all involved sound-level monitoring for awareness of the risk of hearing loss due to personal listening devices. Health promotion seems to be a relatively recent area with increasing interest as all three articles on promotion were published in 2021. Hearing health promotion is one of the measures WHO recommends to encourage safe listening to individuals, professionals and policy-makers.[58] A mHealth approach could be used to bring about promotion to safe listening habits.[59]

Feasibility studies, constituting 15% of articles, provided information about mHealth service-delivery rollout initiatives. More than half (58%) of feasibility studies were conducted in high-income countries with 42% being conducted in LMICs. Screening (40%) and support (40%) were the focus of most feasibility studies with diagnosis (16%) and treatment (4%) receiving less attention. These articles demonstrated mHealth approaches potential in service-delivery rollout. More research on feasibility studies for mHealth implementation globally is essential.

This review had some limitations. Only English articles were included which means articles published in other languages may potentially have been excluded. A strict mHealth device selection criteria means some articles that made use of mHealth solutions operated on devices other than phones, smartphones or tablets may have been excluded. This review highlighted strengths and gaps in current literature, however, the quality, effectiveness, or validity of mHealth approaches were not assessed since it was a scoping review. Only published research was used in this review therefore the use of mHealth in the grey literature was not reported.

CONCLUSION

This review highlights a range of mHealth approaches developed and implemented across various ages, settings, countries and along the entire hearing healthcare continuum. mHealth is enabling innovative hearing healthcare service-delivery models through mobile technologies that can be used by patients themselves or facilitated by minimally trained CHWs. Despite a breadth of potential across hearing health services more implementation evaluations are required to strengthen the body of supporting evidence. Future investigations should be focussed especially on LMICs, treatment and support in children and health promotion across regions.

Acknowledgements:

Not applicable.

Authorship Confirmation Statement:

The authors confirm their contribution to the scoping review as follows:

Study conception and design: Caitlin Frisby and De Wet Swanepoel
Data collection: Caitlin Frisby
Analysis and interpretation of results: Caitlin Frisby and De Wet Swanepoel
Draft manuscript preparation: Caitlin Frisby
Revising the manuscript critically for important intellectual content: Caitlin Frisby, Robert Eikelboom, Faheema Mahomed-Asmail, Hannah Kuper, and De Wet Swanepoel
Approval of the version of the manuscript to be published: Caitlin Frisby, Robert Eikelboom, Faheema Mahomed-Asmail, Hannah Kuper, and De Wet Swanepoel

Authors Disclosure Statement:

The authors declare no conflicts of interest.

Funding

This scoping review was financially supported by the Newton Advanced Fellowship Award (NP2020PA\100013, awarded to De Wet Swanepoel and Hannah Kuper).

REFERENCES

1. O'Dea S. Number of smartphone users from 2016 to 2021. [online] Statista. 2021; Available at: <https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/> [Accessed 5 July 2021].
2. Cvrkel T. The ethics of mHealth: Moving forward. J Dent 2018; 74: pp. S15-S20.
3. Valenzuela PL, Morales JS, Santos-Lozano A, Serra-Rexach JA, Izquierdo M, & Lucia A. mHealth and Aging. J Am Med Dir Assoc 2018; 19(9): 810-811.
4. World Health Organization. World report on hearing. 2021.
5. Mantena S, Celi LA, Keshavjee S, & Beratarrechea A. Improving community health-care screenings with smartphone-based AI technologies. Lancet Digital Health 2021; 3(5): https://doi.org/10.1016/S2589-7500(21)00054-6
6. Rono H, Bastawrous A, Macleod D, et al. Effectiveness of an mHealth system on access to eye health services in Kenya: a cluster-randomised controlled trial. Lancet Digital Health 2021; 3(7): https://doi.org/10.1016/S2589-7500(21)00083-2
7. Yousuf Hussein SD, Swanepoel D, Biagio de Jager L, Myburgh HC, Eikelboom RH, & Hugo J. Community-Based Hearing and Vision Screening in Schools in Low-Income Communities Using Mobile Health Technologies. J Telemed Telecare 2016; 22 (27): 405–412.
8. Kim J, Marcusson-Clavertz D, Yoshiuchi K, & Smyth JM. Potential benefits of integrating ecological momentary assessment data into mHealth care systems. BioPsychoSoc Med 2019; 13(1): https://doi.org/10.1186/s13030-019-0160-5
9. Nguyen KH, Smith AC, Armfield NR, Bensink M, & Scuffham PA. Cost-effectiveness analysis of a mobile ear screening and surveillance service versus an outreach screening, surveillance and surgical service for indigenous children in Australia. PLoS One 2015; 10(9): e0138369.
10. Mars M. Telemedicine and advances in urban and rural healthcare delivery in Africa. Prog Cardiovasc Dis 2013; 56: 326–335.

11. Pankomera R, & Greunen D. A model for implementing sustainable mHealth applications in a resource-constrained setting: A case of Malawi. EJISDC 2018; 84(2): https://doi.org/10.1002/isd2.12019
12. Hamine S, Gerth-Guyette E, Faulx D, Green BB, & Ginsburg AS. Impact of mHealth chronic disease management on treatment adherence and patient outcomes: a systematic review. J Med Internet Res 2015; 17(2): e3951.
13. While A. Identifying hearing loss in older people. Br J Community Nursing 2016; 21: 318–318.
14. World Health Organization. WHO Guidelines: Recommendations on Digital Interventions for Health System Strengthening. 2019. https://apps.who.int/iris/bitstream/handle/10665/311941/9789241550505-eng.pdf?ua=1
15. Fortuin J, Salie F, Abdullahi LH, & Douglas TS. The impact of mHealth interventions on health systems: a systematic review protocol. Syst rev 2016; 5(1): 200.
16. Wootton R. The future use of telehealth in the developing world. In: Wootton R, Patil NG, Scott RE, Ho K, eds. Telehealth in the Developing World. London: Royal Society of Medicine Press Ltd 2009; pp. 299–308.
17. Aranda-Jan C, Tech GA, Nique M, et al. The Mobile Disability Gap Report 2020. London: GSMA. The Mobile Disability Gap Report 2020; 4:4.
18. World Health Organization. Deafness and Hearing loss. 2020.
19. World Health Organization. Addressing the rising prevalence of hearing loss. 2018.
20. Mulwafu W, Ensink R, Kuper H, & Fagan J. Survey of ENT services in Sub Saharan Africa: Little Progress Between 2009 and 2015. Glob Health Action 2017; 10(1): 1289736–1289736. https://doi.org/1289710.1281080/16549716.16542017.11289736.
21. World Health Organization. Multi-country assessment of national capacity to provide hearing care. 2013.
22. Clark JL, & Swanepoel DW. Technology for hearing loss–as we know it, and as we dream it. Disabil Rehabil Assist Technol 2014; 9(5): 408-413.

23. Mandavia R, Lapa T, Smith M, & Bhutta M. A cross-sectional evaluation of the validity of a smartphone otoscopy device in screening for ear disease in Nepal. Clin Otolaryngol 2018; 43(41):31-38.
24. Swanepoel. eHealth technologies enable more accessible hearing care. Semin Hear 2020; 41(02): 133-140.
25. Braun R, Catalani C, Wimbush J, & Israelski D. Community health workers and mobile technology: a systematic review of the literature. PLoS One 2013; 8(6): https://doi.org/10.1371/journal.pone.0065772
26. Maidment DW, Coulson NS, Wharrad H, Taylor M, & Ferguson MA. The development of an mHealth educational intervention for first-time hearing aid users: combining theoretical and ecologically valid approaches. Int J Audiol 2020; 59(7): 492-500.
27. Kay M, Santos J, Takane M. mHealth: New horizons for health through mobile technologies. World Health Organization. 2011; 64(7):66-71.
28. Swanepoel DW, & Hall JW. Making Audiology Work During COVID-19 and Beyond. Hear J 2020; 73(6): https://doi.org/10.1097/01.HJ.0000669852.90548.75
29. Paping DE, Vroegop JL, Koenraads SPC, et al. A smartphone application to objectively monitor music listening habits in adolescents. J Otolaryngol Head Neck Surg 2021; 50(1): https://doi.org/10.1186/s40463-020-00488-5
30. Emmett S, Robler S, Gallo J, et al. Hearing Norton Sound: mixed methods protocol of a community randomised trial to address childhood hearing loss in rural Alaska. BMJ Open 2019; 22;29(21): e023081.
31. Medtronic. Shruti. [online] Medtronic.com.2021; Available at: <https://www.medtronic.com/in-en/about/shruti.html>.
32. Van Wyk T, Mahomed-Asmail F, & Swanepoel DW. Supporting hearing health in vulnerable populations through community care workers using mHealth technologies. Int J Audiol 2019;58(11): 790-797.

33. Yousuf Hussein S, Swanepoel DW, Biagio de Jager L, Myburgh HC, Eikelboom RH, & Hugo J. Smartphone hearing screening in mHealth assisted community-based primary care. J Telemed Telecare 2016;22(7): 405-412.
34. De Sousa K, Smits C, Moore D, Myburgh H, & Swanepoel D. Pure-tone audiometry without bone-conduction thresholds: using the digits-in-noise test to detect conductive hearing loss. Int J Audiol 2020; 59(10): 801-808.
35. Keidser G, & Convery E. Outcomes With a Self-Fitting Hearing Aid. Trends Hear 2018; 22: https://doi.org/10.1177/2331216518768958
36. da Rosa Tavares JOE, & Victória Barbosa JL. Apollo SignSound: an intelligent system applied to ubiquitous healthcare of deaf people. J ReliabIntell Environ 2020; 7(2): https://doi.org/10.1007/s40860-020-00119-w
37. Jethanamest D, Azadpour M, Zeman AM, Sagi E, & Svirsky MA. A Smartphone Application for Customized Frequency Table Selection in Cochlear Implants. Oto Neuroto 2017; 38(8): e253
38. Peters MD, Godfrey C, McInerney P, Baldini Soares C, Khalil H, & Parker D. Scoping reviews. Joanna Briggs Institute reviewer's manual 2017; 408-446.
39. Tricco A, Lillie E, Zarin W, O'Brien K, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018: 467.
40. Ouzzani M, Hammady H, Fedorowicz Z, & Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst rev 2016; 5(1): 1-10.
41. Serajuddin U, & Hamadeh N. New World Bank country classifications by income level: 2020-2021. World Bank 2020; Retrieved July 01, from https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2020-2021
42. Shinn JR, Jayawardena AD, Patro A, Zuniga MG, & Netterville JL. Teacher prescreening for hearing loss in the developing world. Ear, Nose Throat J 2021; 100(3_suppl): 259S-262S.

43. Shinn JR, Zuniga MG, Macharia I, Reppart J, Netterville JL, & Jayawardena AD. Community health workers obtain similar results using cell-phone based hearing screening tools compared to otolaryngologists in low resourced settings. Int J Pediatr Otorhinolaryngol 2019; 127: 109670.
44. Larsen-Reindorf R, Otupiri E, Anomah J, Edwards B, Frimpong B, Waller B, Prince M, & Basura G. Paediatric hearing loss: a community-based survey in peri-urban Kumasi, Ghana. J Laryngol Otol 2019; 133(9): 796-804.
45. Yeung J, Javidnia H, Heley S, Beauregard Y, Champagne S, & Bromwich M. The new age of play audiometry: prospective validation testing of an iPad-based play audiometer. J Otolaryngol Head Neck Surg 2013; 42(1): 1-7.
46. World Health Organization. Hearing screening: considerations for implementation. 2021.
47. National Academies of Sciences, Engineering, and Medicine. Hearing health care for adults: Priorities for improving access and affordability. National Academies Press. 2016.
48. Eksteen S, Launer S, Kuper H, Eikelboom R, Bastawrous A, & Swanepoel D. Hearing and vision screening for preschool children using mobile technology, South Africa. Bull World Health Organ 2019; 97(10):672–680.
49. Bright T, Mulwafu W, Phiri M, et al. Diagnostic accuracy of non-specialist versus specialist health workers in diagnosing hearing loss and ear disease in Malawi. Trop. Med. Int. Health 2019;24(7): 817–828.
50. American Academy of Pediatrics JCoIH. Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs. Pediatr2017; 120(4): 898-921.
51. Monaghesh E, & Hajizadeh A. The role of telehealth during COVID-19 outbreak: a systematic review based on current evidence. BMC Public Health 2020; 20(1): https://doi.org/10.1186/s12889-020-09301-4
52. Boothroyd A. Adult aural rehabilitation: what is it and does it work? Trends Amplif 2007; 11(2): 63-71.

53. Timmer BHB, Launer S, & Hickson L. Using smartphone technology to support the adult audiologic rehabilitation journey. Int J Audiol 2020; 60(sup1): https://doi.org/10.1080/14992027.2020.1854483
54. Ferguson MA, Maidment DW, Gomez R, Coulson N, & Wharrad H. The feasibility of an m-health educational programme (m2Hear) to improve outcomes in first-time hearing aid users. Int J Audio 2021; 60(sup1): https://doi.org/10.1080/14992027.2020.1825839
55. Timmer BHB, Hickson L, & Launer S. Ecological Momentary Assessment: Feasibility, Construct Validity, and Future Applications. Am J Audiol 2017; 26(3s): https://doi.org/10.1044/2017_aja-16-0126
56. Keidser G, Matthews N, & Convery E. A Qualitative Examination of User Perceptions of User-Driven and App-Controlled Hearing Technologies. Am J Audiol (Online) 2019; 28(4): https://doi.org/http://dx.doi.org/10.1044/2019_AJA-19-0022
57. Ross F. Hearing aid accompanying smartphone apps in hearing healthcare. a systematic review. App Med Inform 2020; 42(4): 189–199.
58. World Health Organization. Making listening safe. 2019.
59. Knoetze M, Mahomed-Asmail F, Manchaiah V, & Swanepoel DW. Sound-level Monitoring Earphones With Smartphone Feedback as an Intervention to Promote Healthy Listening Behaviors in Young Adults. Ear Hear 2021 42(5): https://doi.org/10.1097/AUD.0000000000001029