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Early hearing detection and intervention (EHDI) programmes for infants and young children in low-income and middle-income countries in Asia: a systematic review

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ABSTRACT

Background Early hearing detection and intervention (EHDI) measures initiated in high-income countries (HICs) were attempted in low-income and middle-income countries (L&MICs). However, information regarding the models of EHDI, context-specific adaptations made to strategies and outcomes are not known.

Aims The aims of this systematic review were to identify the various models of EHDI used in Asian L&MICs in the published scientific literature and to describe their efficacy and validity.

Methods The studies were eligible if the programme was from Asian L&MICs, implemented for children below 6 years of age and published between 2010 and 2021. Google Scholar, PubMed, Web of Science, Scopus, EBSCOHost and EBSCO–CINAHL were used to find articles. Data were extracted from each selected article, and the risk of bias was assessed. The search results were summarised using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram. For primary outcomes, narrative synthesis was used, and forest plots were generated for secondary outcomes.

Results In all, 82 studies were included, and these studies were divided into two categories: newborn and infant screening programmes and screening programmes for older children. Predominantly, a two-stage objective otoacoustic emission (Distortion Product/Transient Evoked) or automated auditory brainstem response screening, followed by a detailed auditory brainstem response to confirm the hearing loss, was used in newborn and infant screening programmes. Audiologists were the most frequent screening personnel. Screening of older children was mostly done by otolaryngologists, school instructors and nurses. They performed a single-stage pure tone audiometry screening followed by a detailed examination.

Conclusion The screening tools and protocols used were similar to those used in HICs. However, no uniform protocols were followed within each country. Long-term viability of EHDI programmes was not known as there was limited information on impact outcomes such as cost–benefit.

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WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Early hearing detection and intervention (EHDI) programmes are mandated in several high-income countries (HICs) for over two decades. These screening programmes are based on guidelines and standards provided by the Joint Committee on Infant Hearing, the American Audiology Association, the Newborn Hearing Screening Programme England, WHO, the European Consensus Statement on Neonatal Hearing Screening, etc. Systematic reviews have documented screening protocols and programme outcomes predominantly in the context of HICs.

WHAT THIS STUDY ADDS

⇒ Unlike several HICs, EHDI programmes are not mandated in many low-income and middle-income countries (L&MICs). In this context, we conducted a systematic review and gathered information on hearing screening programmes mainly to identify different models of EHDI that were implemented in the context of Asian L&MICs. This review provides information on various screening protocols, tools, personnel, diagnostic tools, use of information and communication technology, barriers and facilitators in different EHDI programmes of L&MICs.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ We found that the screening tools and protocols used were similar to those used in HICs, yet no uniform protocols were followed within each country. Long-term viability of EHDI programmes is not known in this context due to limited impact outcome-based studies(eg, cost–benefit, rate of intervention, etc); hence, future research should focus on these aspects. Further, policy makers and programme planners in these countries should build consensus to implement uniform countrywise protocols suited to the context.

INTRODUCTION

Currently, 34 million children below 15 years are estimated to have hearing loss, with a higher prevalence in low-income and middle-income countries (L&MICs) (2.4%) than in

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Citation	Country	Validity of the screening program			Efficacy of the screening program		
		Use of validated screening tools	Valid diagnostic testing tools within the scope of the program	Implementation phase Outcome of HL identification/intervention or Impact evaluation/> 2 years duration	Program's economic analysis	Frequency of identification	Frequency of intervention
Biswas et al., 2012	India						
Paul et al.,2011	India						
Sharma et al., 2013	India						
Ramesh et al., 2012	India						
Rai & Takhur et al.,2013	India						
Kumar et al.,2015	India						
Gupta et al., 2015	India						
Vignesh et al.,2015	India						
Vishwakarma et al.,2015	India						
Paul et al.,2016	India						
Kumar et al., 2016	India						
Bhat et al.,2018	India						
Sachdeva & Sao et al.,2017	India						
Kumar et al.,2017	India						
Swain et al.,2017	India						
Bhat et al.,2018	India						
Bishnoi et al.,2018	India						
Parab et al.,2018	India						
Jacob et al.,2020	India						
Nishad et al.,2020	India						
Sija et al., 2022	India						
Zhang et al., 2012	China						
Huang et al.,2012	China						
Chen et al.,2012	China						
Shang et al.,2016	China						
Wenjin et al., 2018	China						
Wang et al., 2019	China						
Dai et al.,2019	China						
Zeng et al., 2020	China						
Wen et al., 2020	China						
Guo et al., 2020	China						
Guomei et al.,2022	China						
Ahmad et al.,2011	Malaysia						
Wong et al.,2020	Malaysia						
Mazlan et al.,2022	Malaysia						
Tasci et al.,2010	Turkey						
Sennaroglu & Akmese, 2011	Turkey						
Ulusoy et al.,2014	Turkey						
Kemaloğlu et al., 2016	Turkey						
Yorulmaz et al., 2017	Turkey						
Celik et al.,2016	Turkey						
Ozturk et al.,2017	Turkey						
Hamdi, 2018	Turkey						
Yücel et al., 2019	Turkey						
Arslan et al., 2013	Turkey						
Çıkrıkçı et al., 2020	Turkey						
Arjmandi et al., 2012	Iran						
Islami et al.,2013	Iran						
Firoozbakht et al.,2014	Iran						
Zahed et al., 2014	Iran						
Farhat et al., 2014	Iran						
Haghshenas et al., 2014	Iran						
Baradaranfar et al., 2014	Iran						
Azizi et al., 2016	Iran						
Tajik & Ahmadpour-Kacho, 201	Iran						
Saki et al.,2017	Iran						
Rahimi et al.,2018	Iran						
Thungvachirakul et al.,2011	Thailand						
Poonual et al.,2016	Thailand						
Poonual et al., 2017b	Thailand						
Poonual et al.,2017	Thailand						
Pitathawatchai et al.,2019	Thailand						
Ray et al.,2021	Nepal						
Shameem et al.,2022	Bangladesh						
Khaimook et al.,2022	Thailand						

b

Citation	Country	Validity of the screening program			Efficacy of the screening program		
		Use of validated screening tools	Valid diagnostic testing tools within the scope of the program	Implementation phase (Outcome of HL identification/intervention or Impact evaluation/> 2 years duration)	Program's economic analysis	Rate of identification	Rate of intervention
Tuli et al.,2012	India						
Chanda et al.,2012	India						
Shekhar et al., 2020	India						
Verma et al.,2022	India						
Lu et al.,2011	China						
Chen et al.,	China						
Tokgöz-Yilmaz et al.,2013	Turkey						
Kaplama et al.,2020	Turkey						
Mashhad et al.,2012	Iran						
Jalali et al.,2020	Iran						
Skarzyński et al.,2016	Tajikistan						
Alaqrabawi et al.,2016	Jordon						
Al-Obeidy et al.,2019	Iraq						
Wu et al.,2013	China						
Kam et al.,2014	China						
Ramkumar et al.,2018	India						
Ramkumar et al.,2019	India						
Key		Met criteria					
		Not met criteria					

Figure 1 Validity and efficacy of screening programmes (A) for newborns and infants and (B) for older children. HL, hearing loss.

high-income countries (HICs) (0.5%).[1] Early hearing detection and intervention (EHDI) for children with hearing loss is critical to maximise linguistic competence and literacy development. EHDI is a concept that emanated in the USA in the 1990s and is intended as an at-birth hearing screening of newborns prior to hospital discharge. Infants who do not pass the screening are recommended for diagnostic evaluation and, when confirmed to have hearing loss, are enrolled in early intervention programmes. Subsequently, the Joint Committee on Infant Hearing (2007) in the USA recommended that all infants be screened for hearing by 1 month of age and diagnosed by 3 months and receive intervention by 6 months of age.[2] It is practised as a mandatory universal screening in the entire country.

The concept was subsequently adopted in the UK and practised as universal screening since 2006. Subsequently, several other HICs (Australia and Canada, to name a few) adopted this strategy. Alternative strategies for EHDI have been implemented in L&MICs due to financial, human resource and infrastructural challenges.[3] These include high risk-based screening,[4] screening during immunisation,[5] community-based hearing screening by health workers[6 7] and school entry-level screening.[8 9] Several of these programmes have also integrated telepractice to either improve coverage of screening or provide better diagnostic follow-up.[10 11] However, there remains a lack of clarity on the range of strategies implemented in L&MICs and which should be promoted.

The aims of this systematic review were to identify different models of EHDI that have been implemented in the context of Asian L&MICs in the published scientific literature and to describe evidence of their efficacy and validity.

METHOD

The protocol for this systematic review was registered in the International Prospective Register of Systematic Reviews (registration number CRD42021240341).

Patient and public involvement statement

This systematic review did not involve any subject/patient and public directly.

Inclusion criteria

All types of study designs were eligible for this review, including (1) cross-sectional, (2) cohort, (3) case–control, (4) randomised controlled trials, (5) quasi-experimental and (6) field trials. Both qualitative and quantitative types of studies were included.

The EHDI model is operationally defined for the purpose of this systematic review as programmes for identification and referral of young children with hearing loss. Studies that described EHDI programmes related to triaging children suspected with hearing loss using methods such as objective or subjective screening, parental questionnaire-based screening, implemented

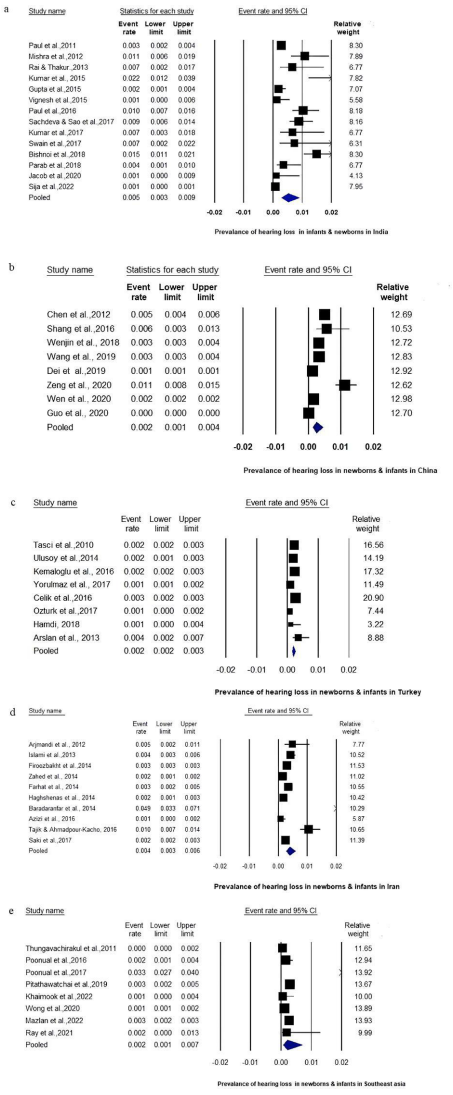

Figure 2 Forest plot of prevalence of hearing loss in (A) newborns and infants in India; (B) newborns and infants in China; (C) newborns and infants in Turkey; (D) newborns and infants in Iran; and (E) newborns and infants in other Asian countries (Thailand, Malaysia and Nepal).

in the context of low-income countries (LICs), lower middle-income countries (LMICs) and upper middle-income countries (UMICs) including hospital, community, school based or any other alternative approach were included.

Studies were eligible regardless of screening strategies (eg, at birthing hospital/community/school), protocol used (eg, single stage/two-stage), provider stakeholder (eg, private/public) involved, tools for screening (eg, checklist, otoacoustic emission (OAE), automated auditory brainstem response (AABR) etc), or personnel involved in screening, diagnosis and intervention (eg, nurse, audiometrists, audiologists and ENT). We also included studies that explored evidence of validity (eg, sensitivity/specificity) and reported implementation barriers and facilitators to EHDI.

According to World Bank classification (2021), LICs, LMICs and UMICs (L&MICs) in the Asian continent (South East Asia, Central Asia and Western Asia/Middle East) were considered as eligible for the review. In the L&MICs, 6 years and below was predominantly considered as the age band for 'early' detection and intervention. Therefore, this review included studies describing EHDI among neonates, infants and children below 6 years of age. Studies were eligible if they had been published from 2010 to 2022.

Exclusion criteria

We excluded studies that described hearing screening programmes for individuals older than 6 years of age or for other disabilities not including hearing. In addition, studies from HICs, studies published in languages other than English and studies published before the year 2010 were excluded.

Search strategy

Since EHDI is an interdisciplinary programme often implemented by ENT/paediatrics/neonatology/audiology/nursing, databases that captured articles from multiple disciplines was preferred. The primary databases used for the search include PubMed, Scopus, Web of science, EBSCOHost, EBSCO–CINAHL (humanities and social sciences) and Google scholar. Hand searching was conducted for the *International Journal of Audiology* (2015–2022) and bibliographies of the selected papers based on the eligibility criteria. Grey literature search included ProQuest Dissertations & Theses Global (nterdisciplinary) and first 500 searches for articles/reports in Google Search. We excluded social media articles, newspaper articles, editorials and website information.

A search strategy for each of the aforementioned databases was designed using 2Dsearch online tool.[12] The search strategy included Medical Subject Headings terms and Boolean operators . A pilot search was conducted in each database to identify the keywords. Synonyms of the keywords were then identified and included in the search strategy.

Screening for eligibility and quality

Title screening was conducted as per the inclusion and exclusion criteria using database search. The Rayyan software[13] was used to screen the abstract and full texts. Screening was conducted by two reviewers (DJ and VR), and any discrepancies were discussed between the reviewers and decisions were made. Joanna Briggs Quality assessment tools specific to the research design were used to assess the quality of the articles.

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart[14] was used to represent the search results.

Data extraction and synthesis

A Google Sheet was used for data extraction, which was undertaken by two authors (DJ and LSN) and verified by another author (VR).

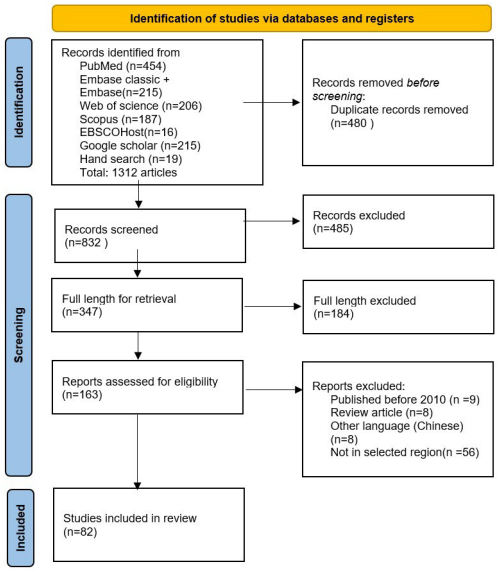

Figure 3 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart representing the selection of article at each stage.

Narrative synthesis of available data was conducted using textual approach to describe strategies adopted for EHDI including screening methods, service delivery points, use of information and communications technology (ICT), the target age groups of such programmes, personnel involved in delivery of the programme, and reported barriers and facilitators of the programme. The Joanna Briggs Institute (JBI) tool for critical appraisal[15] was used for quality assessment. The Synthesis Without Meta-analysis (SWiM) guideline was used for analysis of secondary outcomes.[16] If a country had at least three studies that reported data on children with confirmed hearing loss, then that country was included for estimation of prevalence per 1000 using forest plots.

The primary outcomes of interest were the validity and efficacy of the screening programmes. We developed a checklist (figure 1A,B) to assess the validity and efficacy using three criteria each. The items in the validity checklist included (1) the use of a *validated screening tool*, (2) the use of a *validated diagnostic tool,* whether the screening programme reported was in the (3) *design phase* (eg, pilot/feasibility/validity/only reported coverage rate or referral rate or follow-up rate) or *implementation phase* (eg, scale programme). The efficacy was assessed if the study reported (1) evidence of early identification, (2) evidence of early intervention and (2) inclusion of an economic analysis.

The secondary outcome of interest was to estimate the incidence and prevalence outcomes of EHDI programmes in the Asian L&MICs. For secondary outcomes analysis, in screening programmes for newborns and infants, the prevalence of hearing loss in infants reported in each country was analysed using the SWiM guidelines. Using a random effect model, Forest plots (figure 2A–E) were constructed for each country based on two criteria: if more than five studies in a country reported prevalence outcomes and if the number of children screened was more than 1000.

RESULTS

Our electronic search yielded 1312 citations. Based on the inclusion/exclusion criteria and multiple levels of screening by the two reviewers independently, a total of 82 studies qualified for the current review. The article selection process is presented in the PRISMA flowchart (figure 3). Sixty-five studies (79%) reported on newborn hearing screening (NHS), and only 17 studies (21%) reported hearing screening among older children. Predominantly, studies were conducted in India (n=27), followed by Turkey (n=13), Iran (n=13), China (n=15), Thailand (n=6), Malaysia (n=3), Nepal (n=1), Bangladesh (n=1), Iraq (n=1), Jordan (n=1) and Tajikistan (n=1).

These studies included 75 cross-sectional studies and 7 cohort studies. Results of quality appraisal using appropriate JBI tool are provided in online supplemental file 1.

The screening programmes identified in this review were grouped based on the age group of the children: (1) screening programmes for newborns and infants (0–3 years of age) and (2) screening programmes for older children even beyond 6 years of age.

Hearing screening programmes for newborns and infants (below 2 years) included 65 studies. Most studies (49) reported single-hospital programmes, whereas others (16 studies) reported multiple-centre programmes. Of these studies, 55 were undertaken in the private sector and 10 in the public sector. There were 17 studies of hearing screening programmes for older children aged 3–17. Fifteen of these studies were school-based hearing screenings, while two were community-based. Of these studies, nine were undertaken in the private sector and eight in the public sector. Table 1A–E represents the summary of included studies describing hearing screening programmes for newborns and infants in each country. Table 2 represents the summary of included studies hearing screening programmes for older children.

Screening protocol and tests

Newborn and infant hearing screening

Two-stage hearing screening protocols were employed most frequently for newborn and infant hearing screening (n=47), followed by three-stage protocols (n=13) and one-stage protocols (n=4). One study reported employing a five-step hearing screening protocol.

Sixteen studies that reported a two-stage hearing screening protocol, employed OAE (TE/DP-OAE) or AABR as screening tests (individually or combined in either stage).[17–31] The other 25 studies used only OAEs (DP/TE)[32–49] or AABR screening[50 51] for testing in both stages. Those studies that reported the use of AABR in

Table 1 Hearing screening programmes for (A) newborns and infants in India (LMIC), (B) newborns and infants in China (UMIC), (C) newborns and infants in other Asian countries, (D) newborns and infants in Turkey (UMIC), and (E) newborns and infants in Iran (LMIC)

(A)

Author and year	Citation	Duration of programme	Population screened	Screened (n)	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Biswas *et al* 2012	[104]	2 years	Newborns	490	1 stage	DPOAE	Not mentioned	Not mentioned
Paul 2011	[81]	7 years	Newborns	10 165	2 stage	OAE+OAE (non-mentioned DP/TE)	Person with basic knowledge in computer with training on NHS	Diagnostic ABR
Mishra *et al* 2013	[32]	3 years	0–2 years	1101	<6 months of age, 5 stage; 6 months–1 year, 4 stage; 1–2 years, 3 stage	DPOAE	Not mentioned	Diagnostic ABR
Ramesh *et al* 2012	[85]	2 years	Newborns	425	1 stage	Calibrated noise maker-based Behavioral Observation Audiometry (BOA)	Trained health workers (30 hours of training)	Diagnostic ABR, OAE and BOA
Rai *et al* 2013	[63]	1 year	Newborns	500	3 stage	TEOAE+TEOAE+TEOAE	ENT Specialist (Ear Nose Throat)	Diagnostic ABR
Kumar *et al* 2015	[17]	1 year 8 months	High risk <2 years of age	500	2 stage	TEOAE+AABR	Audiologist	Not mentioned
Gupta *et al* 2015	[50]	1 year	Newborns	2265	2 stage	AABR+AABR	Single specialist staff	Not mentioned
Vignesh *et al* 2015	[18]	1.5 years	Newborns	1405	2 stage	TEOAE+AABR	Not mentioned	Diagnostic ABR
Vishwakarma *et al* 2015	[54]	1 year 8 months	Newborns	Well babies: 2000 High risk:1020	3 stage	TEOAE+TEOAE+AABR	Nurse, resident doctor/ certified audiologist	Diagnostic ABR
Paul *et al* 2016	[33]	11 years	Newborns	Well babies: 84 774 High risk: 16 914	2 stage	OAE+OAE (non-mentioned DP/TE)	Person with basic training in hearing screening	Diagnostic ABR
Sharma *et al* 2018	[86]	3 years	Newborns	2534	2 stage	DPOAE	Not mentioned	Diagnostic ABR
Kumar *et al* 2016	[105]	2 years	Newborns	1537	2 stage	TEOAE+TEOAE+AABR	Not mentioned	Not mentioned
Sachdeva *et al* 2017	[87]	10 months	Newborns	2254	2 stage	(HRR+BOA+DPOAE)+DPOAE	Not mentioned	Confirmatory, diagnostic ABR
Kumar *et al* 2017	[82]	No info	Newborns	600	2 stage	TEOAE+DPOAE	Not mentioned	Not mentioned
Swain *et al* 2017	[88]	1.5 years	Newborns	410	2 stage	DPOAE+DPOAE	Not mentioned	Diagnostic ABR
Bhat *et al* 2018	[19]	1 year	High-risk newborns	195	1 stage	TEOAE	Not mentioned	Diagnostic ABR
Bishnoi *et al* 2018	[89]	No info	Newborns	2000	2 stage	(OAE and Tymp)+OAE (non-mentioned DP/TE)	Not mentioned	Diagnostic ABR
Parab *et al* 2018	[34]	3 years	Newborns	8192	2 stage	TEOAE+TEOAE	Audiologist	Diagnostic ABR
Jacob *et al* 2020	[35]	2 years	Newborns	773	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Nishad *et al* 2020	[36]	1 year	Newborns	1000	2 stage	OAE+OAE (non-mentioned DP/TE)	Not mentioned	Diagnostic ABR

Continued

Table 1 Continued

(A)								
Author and year	**Citation**	**Duration of programme**	**Population screened**	**Screened (n)**	**Screening protocol**	**Screening test used**	**Screening personnel**	**Diagnostic test**
Sija *et al* 2022	[37]	4 years	Newborns	16 265	2 stage	DPOAE+DPOAE	Trained nurse	Diagnostic ABR
(B)								
Author and year	**Citation**	**Duration of programme**	**Population screened**	**Screened (n)**	**Screening protocol**	**Screening test used**	**Screening personnel**	**Diagnostic test**
Zhang *et al* 2012	[106]	1.5 years	Newborns	10 043	2 stage+genetic screening	TEOAE+(TEOAE and AABR)	Nurse	Not mentioned
Tobe *et al* 2013	[83]	2 years	Newborns	Not mentioned	2 stage	OAE+AABR (non-mentioned DP/TE)	Trained personnel, no info	Not mentioned
Chen *et al* 2012	[38]	2 years	Newborns	11 568	2 stage	TEOAE	Audiologist	Diagnostic ABR, TFT, impedance, ASSR at hospital
Shang *et al* 2016	[52]	6 months	Newborns	1064	2 stage	First protocol: TEOAE+TEOAE Second protocol: (TEOAE and ABR screen)+TEOAE	Not mentioned	Diagnostic ABR
Wenjin *et al* 2018	[20]	2 years	Newborns	19 098	2 stage	Well babies: DPOAE+ABR screening High-risk babies: (DPOAE and ABR screening) (DPOAE and ABR screening)	Nurse	Otoscopy, diagnostic ABR at 30 dBHL, Tymp; DPOAEs
Wang *et al* 2019	[21]	5 years	Newborns	55 977	2 stage	OAE+AABR (non-mentioned DP/TE)	Nurse	Comprehensive diagnostic audiometry around 3 months of age
Dai *et al* 2019	[22]	1 year	Newborns	180 469	2 stage+genetic screening	TEOAE+(TEOAE and AABR)	Not mentioned	Diagnostic ABR, ASSR, DPOAE, immitance
Zeng *et al* 2020	[23]	1 year	Newborns	4205	2 stage+genetic screening	OAE+AABR screening (non-mentioned DP/TE)	Not mentioned	No
Wen *et al* 2020	[24]	2 years	Newborns	467 980	2 stage	OAE+(OAE and AABR) (non-mentioned DP/TE)	Not mentioned	Not mentioned
Guo *et al* 2020	[25]	2 years 4 months	Infants >3 months	287 430	2 stage+genetic	OAE+AABR (non-mentioned DP/TE)	Not mentioned	Diagnostic ABR
Guomei *et al* 2022	[53]	9 months	Newborns	2174	2 stage+genetic	OAE+OAE (non-mentioned DP/TE)	Not mentioned	Diagnostic ABR

Continued

Table 1 Continued

(C)

Author and year	Citation	Country	Duration of programme	Population screened	Screened (n)	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Ahmad *et al* 2011	64	Malaysia (MIC)	5 years	Newborns	16 000	3 stage	DPOAE+DPOAE+DPOAE	Technician, staff nurse, ward attendants	Diagnostic ABR
Wong *et al* 2021	26	Malaysia (UMIC)	2 years	Newborns	28 432	1 and 2 stage	1 stage: AABR 2 stage: DPOAE+AABR	Nurses	Diagnostic ABR
Tungvachirakul *et al* 2011	39	Thailand (UMIC)	1 year 11 months	Newborns	4043	2 stage	OAE+OAE (not mentioned DP/TE)	Not mentioned	ASSR
Poonual *et al* 2016	107	Thailand (UMIC)	1 year 7 months	Newborns	3120	2 stage	Automated TEOAE+conventional TEOAE	Not mentioned	Diagnostic ABR
Poonual *et al* 2017	27	Thailand (UMIC)	Not mentioned	Newborns	3120	3 stage	COBRA HRR tool+TEOAE+AABR	Not mentioned	Not mentioned
Poonual *et al* 2017	96	Thailand (UMIC)	1 year	Newborns	3120	2 stage	TEOAE+AABR	Not mentioned	ABR at 3 and 8 months
Pitathawatchai *et al* 2019	40	Thailand (UMIC)	1 year 7 months	Newborns	6140	2 stage	TEOAE+TEOAE	Nurses	Not mentioned
Ray *et al* 2021	41	Nepal (LMIC)	2 years	Newborns	540	2 stage	OAE+OAE (not mentioned DP/TE)	Not mentioned	Diagnostic OAE and diagnostic ABR
Mazlan *et al* 2022	28	Malaysia (UMIC)	10 years	Newborns	50 633	2 stage	TEOAE+AABR	Trained nurses and medical technologists	Diagnostic ABR
Shameem *et al* 2022	42	Bangladesh (LMIC)	2 years	High-risk newborns	426	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Khaimook *et al* 2022	43	Thailand (UMIC)	6 months	Newborns	1696	2 stage	TEOAE+TEOAE	Trained nurse and audiologist	Diagnostic ABR+Tymp

(D)

Author and year	Citation	Duration of programme	Population screened	Screened (n)	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Tasci *et al* 2010	55	14 months	Newborns	16975	3 steps	TEOAE+TEOAE+ ABR	Audiology technician	Diagnostic ABR
Sennaroglu *et al* 2011	44	1 year	Newborns	1840	2 stage	TEOAE	Audiologist or audiometrist	Diagnostic ABR;
Ulusoy *et al* 2014	56	3 years	Newborns	11575	3 stage	TEOAE+AABR	2 audiometrists and 1 nurse	Diagnostic ABR, the level 3 centre
Kemaloğlu *et al* 2016	57	10 years	Newborns	19436 (I/P) 2083 (O/P)	3 stage	TEOAE+TEOAE+(TEOAE and AABR)	Audiology technicians and audiology students	Diagnostic ABR
Yorulmaz *et al* 2017	58	5 years	Newborns	13693	3 stage	TEOAE+TEOAE+AABR	Audiometrist	Diagnostic ABR, Tymp, acoustic reflexes, ASSR
Çelik *et al* 2016	45	6 years	Newborns	142 128	2 stage	TEOAE (twice same day)+TEOAE	Not mentioned	Diagnostic ABR

Continued

Table 1 Continued

(D)							
Author and year	**Citation**	**Duration of programme**	**Population screened**	**Screened (n)**	**Screening protocol**	**Screening test used**	**Screening personnel**	**Diagnostic test**
Ozturk *et al* 2017	59	2 years	Newborns	7502	3 stage	Wellbabies: DPOAE+DPOAE+ ABR screening Highrisk babies: Direct ABR	Audiologist	Diagnostic ABR
Hamdi 2018	60	2 years	Newborns	1808	3 stage	TEOAE+TEOAE+ABR screening	Nurses (trained)	Diagnostic ABR
Yücel *et al* 2019	65	2 years	Newborns	786 Syrian and 7230 turkish	3 stage	(TEOAE and Tymp)+TEOAE+ABR	Not mentioned	Detailed testing
Arslan *et al* 2013	46	8 months	Newborns	2229	2 stage	TEOAE+TEOAE	Nurse	Diagnostic ABR
Çıkrıkçı *et al* 2020	51	1.5 years	Newborns	702 turkish 172 syrian	2 stage	AABR+AABR	Not mentioned	Diagnostic ABR

(E)								
Author and year	**Citation**	**Duration of programme**	**Population screened**	**Screened (n)**	**Screening protocol**	**Screening test used**	**Screening personnel**	**Diagnostic test**
Arjmandi *et al* 2012	47	1 year	Newborns	1232	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Islami *et al* 2013	48	1.5 years	Newborns	7250	2 stage	TEOAE+TEOAE	Audiologists	Diagnostic ABR
Firoozbakht *et al* 2014	29	8 years	Newborns	3 350 995	2 stage	TEOAE+AABR	Audiologists, nurses, midwives and trained health technicians.	Comprehensive test
Zahed *et al* 2014	30	8 years	Newborns	40 930	2 stage	TEOAE+ABR	Audiologists	ABR/ASSR and immittance audiometry,
Farhat *et al* 2014	90	2 years	Newborns	8987	2 stage	TEOAE+TEOAE	Not mentioned	ASSR
Haghshenas *et al* 2014	61	2 years	Newborns	15 165	3 stage	OAE+OAE+(OAE and AABR) (not mentioned DP/TE)	Audiologist	ABR screening
Baradaranfar *et al* 2014	108	1 year	Newborns	514	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Azizi *et al* 2016	49	1.5 years	Newborns	3818	2 stage	TEOAE+TEOAE	not mentioned	ABR,
Tajik *et al* 2016	31	4 years	Newborns	3362	2 stage	TEOAE+(TEOAE and ABR)	Not mentioned	Not mentioned
Saki *et al* 2017	84	3 years	Newborns	92 521	2 stage	First and second:TEOAE+AABR	Audiologists	Diagnostic OAE and ABR
Rahimi *et al* 2018	62	5 years	Newborns	4729	3 stage	TEOAE+TEOAE+AABR	Audiologist	Diagnostic ABR

AABR, automated auditory brainstem response; ABR, auditory brainstem response; ASSR, auditory steady-state response; BOA, behavioral observation audiometry; DPOAE, distortion product otoacoustic emission; LMIC, lower middle-income country; MIC, middle-income country; NHS, newborn hearing screening; OAE, otoacoustic emission; PTA, pure tone audiometry; TEOAE, transient evoked otoacoustic emission; Tymp, tympanometry; UMIC, upper middle-income country.

Table 2 Hearing screening programmes for older children

Author and year	Citation	Country	Duration of programme	Age of screening (years)	Screened (n)	Screening protocol	Screening test used	Pass/fail criteria	Screening personnel	Diagnostic test	Diagnostic person
Tuli *et al* 2012	[66]	India	2 years	5–16 years	111	1 stage	Case history, audiological and ENT evaluation, awareness and SIFTER	Not mentioned	Not mentioned	ENT and PTA and diagnostic ABR	Audiologist
Chadha *et al* 2013	[67]	India	3 years	5–12 years	15718	1 stage	Otoscopy, 10-Question Screening Index for Disabilities in English and Hindi	Positive history of hearing or speech defects, a positive finding on examination	Proforma: parents, otoscopy: otolaryngologists	Not mentioned	Not mentioned
Ramkumar *et al* 2018	[77]	India	2 years	Birth–5 years	1335	2 stages	DPOAE+DPOAE	>SNR 3 dB	Trained village health worker	Telediagnostic ABR	Audiologist
Ramkumar *et al* 2019	[76]	India	2 years	Birth–5 years	2815	2 stages	DPOAE+DPOAE	>SNR 3 dB	Trained village health Worker	Diagnostic ABR—in person and telediagnostic ABR	Audiologist
Verma *et al* 2022	[91]	India	6 months	6–17 years	597	1 stage	Tuning fork test	Not mentioned	Not mentioned	PTA and Tymp	Audiologist
Shekhar *et al* 2022	[68]	India	Not mentioned	5–14 years	474	1 stage	PTA	Not mentioned	ENT specialist	ENT examination	ENT specialist
Lü *et al* 2011	[69]	China	1 year	3–6 years	21427	1 stage	PTA	1, 2 and 4 kHz >20 dB	Screening person with training (training programme with certificate)	PTA (5–6 years) VRA or play PTA (3–4 years)	Not mentioned
Chen *et al* 2013	[80]	China	1 year 5 months	3–6 years	28546	1 stage	TEOAE	>SNR 3 dB	School nurses and doctors 2 hours of training	Comprehensive test	Not mentioned Audiologist
Wu *et al* 2014	[70]	China	Not mentioned	3–6 years	6288	1 stage	Software-based new PTA	>30 dBHL at 1, 2 and 4 kHz	Preschool teachers—minimally trained	Not mentioned	Not mentioned
Kam *et al* 2014	[71]	China	Not mentioned	3–7 years	6231	1 stage	Automated PTA	>30 dBHL at 1, 2 and 4 kHz	Automatic test: nurses with 2 hours' training as facilitator	Tymp, DPOAE and PTA (0.25–8.0 kHz)	Not mentioned
Tokgöz-Yılmaz *et al* 2013	[72]	Turkey	3 years	3–5 years	239	1 stage	PTA	Not mentioned	Audiologist and SLP	ENT examination	ENT specialist
Kaplama *et al* 2020	[79]	Turkey	1 year	69–84 months	23664	2 stage	PTA, 10 questionnaire	500, 1000, 2000 and 4000 Hz >20 dB 10 questions—refer in 1 question	Certified nurses, midwives, health officers or audiometrists,	ENT examination	ENT specialist
TarvijEslami *et al* 2017	[78]	Iran	1 year	6–7 years	2237	Not mentioned	PTA	Not mentioned	Not mentioned	PTA, Weber, Rinne test	Not mentioned
Jalali *et al* 2020	[73]	Iran	4 months	6–13 years	2019	1 stage	PTA	0.5–4.0 kHz >15 dBHL	Not mentioned	ENT examination and comprehensive audiological examination	Not mentioned
Skarzyński *et al* 2016	[8]	Tajikistan (LMIC)	Not mentioned	6–8 years	143	1 stage	Questionnaire, PTA using SZOK telemed model	PTA module (500–8 kHz) >25 dB at one frequency	Medical doctors Other specialists	Detailed PTA	Audiologists

Continued

Table 2 Continued

Author and year	Citation	Country	Duration of programme	Age of screening (years)	Screened (n)	Screening protocol	Screening test used	Pass/fail criteria	Screening personnel	Diagnostic test	Diagnostic person
Alaqrabawi *et al* 2016	[74]	Jordan (UMIC)	4 years	5–15 years	1649	1 stage	PTA	500 Hz, 1, 2 and 4 kHz >25 dB	Not mentioned	Audiometry, otoscopy and Tymp	Audiologists
Al-Obeidy *et al* 2019	[75]	Iraq (UMIC)	1 year	6 years	425	1 stage	HR questionnaire	Not mentioned	Not mentioned	ENT examination, TFT (Weber, Rinne and absolute bone conductio). HRR children: PTA	Not mentioned

ABR, auditory brainstem response; BOA, behavioral observation audiometry; DPOAE, distortion product otoacoustic emission; HRR, high-risk register; LMIC, lower middle-income country; PTA, pure tone audiometry; SIFTER, Screening Identification For Targeting Educational Risk; SNR, signal-to-noise ratio; TEOAE, transient evoked otoacoustic emission; TFT, Tuning Fork Test; Tymp, tympanometry; UMIC, upper middle-income country.

the initial stage of screening either employed AABR solely for both stages[50] or a combination of AABR and OAE to screen only high-risk newborns.[20 52] Four studies from China used two-stage screening coupled with genetic hearing screening.[21–23 25 53]

When a three-stage protocol was used, generally the first two stages included OAE (DP/TE) screening followed by AABR/auditory brainstem response (ABR) screening[54–62] or included OAE (DP/TE) for all three stages.[63 64] Only one study reported combining tympanometry and TEOAE in the initial stage of its three-stage screening protocol.[65] Studies from Turkey (n=7) reported a three-stage screening protocol.[55–60 65]

Screening for older children

Fourteen studies for older children employed a single-stage screening protocol[8 66–75] with three employing a two-stage protocol.[3 76] Ten studies reported using subjective hearing screening tests, two studies used questionnaire or otoscopy for screening[67 75] and another three studies used TEOAE.[76 77] Pure tone audiometry (PTA) was the most commonly used subjective test for screening older children.[68 69 72–74 78] Two studies reported the use of automated software-based PTA.[70 71] PTA was combined with questionnaires[8 79] or otoscopy.[67 75] Only one study reported the use of TEOAE screening.[80]

Pass/refer criteria

In several programmes for newborn and infant screening, screening results were based on data generated from the screening instrument automatically. The pass criteria for DP/TEOAE was between 3 dB and 6 dB signal-to-noise ratio,[19 20 25 37 38 40 43 45 49 54 57 63 64 81 82] and for AABR, it varied between 30, 35 and 40 dB neural hearing loss (NHL).[20 52 56 58 61] Predominantly, refer results in one ear was considered for follow-up screening.

For screening older children, the pass criteria for PTA ranged from 15 dB HL to 30 dB HL. All studies used the four frequencies from 0.5 kHz to 4.0 kHz for pure tone testing. In questionnaire-based studies, failing one item or a family history of hearing loss was the referral criterion.[67 68]

Screening personnel

Audiologists were the primary screening personnel in many newborn and infant programmes,[17 30 34 38 44 48 54 59 61 62 83 84] followed by nurses.[20 21 26 28 29 37 40 43 46 54 56 60 64] In five studies, the training provided for nurses to perform hearing screening was also briefly mentioned,[28 29 40 46 60] including some certifications.[56] Other than nurses, some studies reported audiometrists[44 56 58] and audiologist technicians[55] as personnel involved in screening. Other non-specialists that were engaged in hearing screening were technicians,[64] ward attendants,[64] trained health workers[29 85] social workers[83] and midwives.[29 33 81] In a few programmes, otolaryngologists[63] performed the hearing screening. Out of 59 studies, 29 did not provide any information regarding the screening individual.

Screening for older children was conducted by otorhinolaryngologists[8 67 68] audiologists[72] and audiometrists.[79] Other non-specialists involved in the hearing screening included trained nurses/midwives,[38 71 79] trained village health workers or volunteers,[76 77] and school teachers with training.[70]

Studies have reported a variety of training programmes. They included hearing screening certification,[67 79] 2 hours of TEOAE training,[38] TEOAE training and telediagnostic testing facilitation,[76] and minimal training/2 hours of training for facilitating automated PTA.[70 71]

Confirmation of hearing loss

Diagnostic ABR was the only testing carried out to confirm the hearing loss in studies in newborns and infants.[25 28 32 35–37 42 54 63 86–89] Comprehensive test battery including the diagnostic BERA, OAE, and tympanometry was mentioned only in 11 studies.[20 29 58] Four studies also reported the inclusion of the auditory steady-state response (ASSR) in the test battery.[30 58]

Two programmes used solely ASSR,[39 90] and studies also used ABR screening at 30[20] or 35 dB NHL[61] for hearing loss diagnosis.

However, 11 of the 65 programmes made no mention of the diagnostic confirmatory test used for confirmation of hearing loss. More than half of the studies (n=37), reported that the diagnostic confirmatory test was performed at the same hospital where screening was conducted. In another 18 studies, children were referred to more specialist or tertiary care facilities for diagnostic confirmatory tests. The diagnostic site was not mentioned or could not be inferred in 10 studies.

In studies reporting screening for older children, a test battery approach was used in three studies where they included PTA with tympanometry and DPOAE[71] or PTA with otoscopy and tympanometry[74] or PTA and detailed ABR.[66] Two studies reported the use of comprehensive test battery but did not mention the tests included.[38]

PTA was frequently included in the diagnostic test battery,[71 74 91] but in three studies, PTA was the only diagnostic test used.[8 73 78] Of the studies that reported the use of PTA for diagnosis, only four studies[72–74 78] mentioned information related to bone conduction testing. Apart from these studies, ENT examination was included in five studies.[68 72 73 75 79] The diagnostic testing sites included a hospital,[73] a school,[68] a speech and hearing centre,[71] and a telemedicine platform.[8 76]

Use of ICT

In studies related to newborn and infant hearing screening, three programmes reported the use of ICT for storing and forwarding results,[34] database management[28 83] and sending reminders for follow-up screening.

In studies reporting screening of older children, five studies reported using telepractice for screening, diagnosis or both. Telediagnostic ABR[76 77] was reported in India. Use of m-health-based automated hearing screening was reported in China.[70 71] .A telesensory screening platform including hearing screening was reported (SZOK - (Sense Examination Platform) paradigm) in Tajikistan, where both screening and diagnosis were carried out via telemedicine.[8]

Validity and efficacy of the screening programmes

Validity of screening programmes as reported in the studies was evaluated based on three criteria: use of a validated screening tool, use of a validated diagnostic tool, and whether the programme was in the design phase or in the implementation phase.

Among the studies that reported newborn and infant hearing screening, 48 studies fulfilled all three criteria of the validity tool; 11 studies fulfilled two out of three criteria; and 6 studies fulfilled one out of three criteria (figure 1A). The validated screening tool was used by 63 studies and 54 studies used a validated diagnostic tool. As per the criteria we used, 55 studies could be classified to be in the implementation phase and 10 studies were in the design phase.

Economic analysis, frequency of identification and intervention were the three criteria included to assess efficacy. Only 2 studies fulfilled all the three efficacy criteria; 17 studies fulfilled two out of the three criteria; and 37 studies fulfilled only one of the three criteria, whereas the remaining 9 studies did not fulfil any of the criteria. Fifty-one studies reported only the frequency of identification, whereas 14 reported both the frequency of identification and intervention. Twelve per cent of the studies did not mention either of these outcomes. Economic analysis was very limited (n=3) and was reported majorly in public programmes.

Among the studies that reported screening programmes for older children, 10 studies fulfilled all the three criteria; 3 studies fulfilled two out of three criteria; and 3 studies fulfilled one out of three criteria. Only one study did not meet any of the criteria[67] since only a questionnaire and an otoscopic examination were used to estimate the incidence of conductive hearing loss in older children.

With respect to efficacy, it was observed that none of the studies among older children fulfilled all the three criteria. Only five studies fulfilled two out of three criteria, whereas the remaining 12 studies fulfilled only one criterion.

Fourteen studies have reported frequency of identification, but only five studies have reported the frequency of intervention (eg, medical intervention for conductive pathology). The intervention-related screening programmes were reported from India, China and Turkey. The economic analysis was reported in only two studies.[71 77] Except for the economic analysis, only 2 of the 17 studies fulfilled all validity and efficacy criteria.[69 76]

Prevalence of hearing loss

Across 48 studies, the mean prevalence of hearing loss among newborns and infants was 5/1000 in India, 2/1000 in China, 2/1000 in other Southeast Asian nations (Thailand, Malaysia and Nepal), 2/1000 in Turkey, and 4/1000

in Iran. Figure 2A–E shows the forest plots for prevalence of each country.

In screening programmes for older children, 11 studies reported number of cases with hearing loss including conductive and sensori neural hearing losses. However, in four studies,[67 68 79 80] the specific audiological tests conducted to diagnose were not mentioned, and in seven studies,[69 72–75 78] details of diagnostic audiometry were provided. In this age group, the percentage of conductive hearing loss reported was higher compared with sensori neural hearing loss across all the studies. In two studies, the type of loss was not differentiated.[8 67] The percentage of children identified with a certain type of hearing loss was calculated based on the information on the number of children diagnosed that was provided in each of the studies. The study outcomes are reported in table 3.

Barriers and facilitators

Barriers

Loss to follow-up for second screening and diagnostics[20 29 35–37 40 43 48 54 56 59 81 87] was reported as a major challenge. Loss to follow-up was linked to parental rejection for diagnosis,[33 43 50] poor tracking system,[20 29] financial burden of parents, low socioeconomic status[51] and travel distance to testing distance. Other major challenges highlighted in relation to outcomes included limited coverage[35 82] and a high referral rate,[18 37 54] poor long-term outcomes with respect to coverage and referral rate.[24]

Other factors that had an indirect impact on programme outcomes included the lack of dedicated screening personnel,[50] lack of professional resources/audiologists,[29 84] high ambient noise in the testing environment[82] and the absence of diagnostic facilities.[56] A few studies mentioned challenges affecting programme implementation, such as the use of a three-step protocol only with OAE,[55] the difficulties of centralised programme implementation in remote locations[29] and delay in diagnosis in remote locations due to referral to regional facilities.[84]

In screening for older children, children's attention was regarded as a major challenge resulting in poor accuracy.[71] Other key factors influencing programme outcomes included inadequate internet connectivity[8 76] and poor follow-up due to social stigma.

Facilitators

Use of appropriate tracking or data management systems, were reported to be helpful in minimising loss to follow-up.[20 28 33 35 81] Combining hearing screening with other screenings improved follow-up rates.[25 62] Several studies highlighted strategies to minimise false referral rates, including (1) employing a conducive environment and trained individuals,[54] (2) adding AABR in the initial stage of screening protocol,[52] (3) screening between 3 days and 5 days of age[62] and (4) incorporating tympanometry into the screening protocol.[89] Financial assistance in the form of funding[28 37 83] and centralised hearing screening facilities or grouping more centres[33 81] were

Table 3 Secondary outcomes: studies reporting number of cases identified with CDHL/SNHL in older children in each country

Country	Author and year	Screened (n)	CDHL identified (n)	% of CDHL	NHL identified (n)	% of SNHL	Overall HL identified (n)	% of HL	95% CI (LB to UP)
India	Chadha *et al*.[67] 2013	15 718	NA	NA	NA	NA	1578	10.30	9.57 to 10.52
	Shekhar *et al*.[68] 2020	474	146	30.80	1	0.21	147	31.01	26.87 to 35.39
Turkey	Tokgöz-Yılmaz *et al*.[72] 2013	239	25	10.46	1	0.42	26	10.88	7.23 to 15.53
	Kaplama *et al*.[79] 2020	23 664	186	0.79	89	0.37	275	1.16	1.03 to 1.31
Iran	TarvijEslami *et al*.[78] 2017	2284	28	1.23	8	0.35	36	1.58	1.11 to 2.18
	Jalali *et al*.[73] 2020	2019	19	0.94	8	0.39	27	1.33	0.88 to 1.94
Tajikistan	Skarzyński et al. 2016	143	NA	NA	NA	NA	34	23.70	17.06 to 31.61
Jordan	Alaqrabawi *et al*.[74] 2016	1649	54	3.27	36	2.18	90	5.45	4.41 to 6.61
Iraq	Al-Obeidy *et al*.[75] 2019	425	28	6.59	2	0.47	30	7.06	4.81 to 9.92
China	Lu *et al*.[44] 2011	21 547	285	1.32	16	0.07	301	1.39	1.24 to 1.56
	Chen *et al*.[38] 2012	28 546	344	1.21	22	0.08	366	1.29	1.15 to 1.42

CDHL, conductive hearing loss; HL, hearing loss; LB, lower bound; NA, not mentioned; NHL, neural hearing loss; SNHL, sensorineural hearing loss; UB, upper bound.

strategies reported in studies to improve coverage rates. Multicentre-based or a centralised hearing screening programme was reported to be resource efficient with respect to cost, infrastructure and professionals.[81]

DISCUSSION

The primary purpose of this review was to describe the models of hearing screening programmes implemented in young children in various Asian L&MICs in the published scientific literature. The inclusion of countries was based on the World bank classification rather than culturally defined regions; this led to a heterogenous inclusion with central Asian and middle eastern countries as well. Out of 61 L&MICs in Asia, only 14 countries reported hearing screening programmes that fit our inclusion criteria. In a recent systematic review, high-quality literature with hearing screening programmes was reported to be primarily in HICs[92]; yet, it is also likely that resources for research and publication are low and hence are also low on priority in the L&MICs context. Though studies from both L&MICs were included, our results show that most of the studies reporting on hearing screening were from the middle-income countries and more specifically from UMICs. This suggests greater adoption of EHDI measures in UMICs, possibly due to greater availability of resources in comparison to LMICs and LICs.

Our review gathered evidence on hearing screening programmes in general, including screening protocols, screening tests, pass/fail criteria, screening personnel, diagnostic tests, use of ICT, and programme validity and efficacy. The hearing screening tools and protocols used for newborns, infants and older children were similar to those used in HICs.[93] Despite the fact that the majority of programmes used a two-stage OAE (DP/TE) and ABR screening as preferred screening tools across countries, there was no consistency in protocol stages or screening tests undertaken. This was consistent with Kanji *et al* 's assessment of NHS protocols, which revealed non-uniformity in the protocols followed.

It was also noted that objective hearing screening was most commonly reported over subjective hearing screening for newborns and infants. Only one study[85] found good sensitivity and specificity for behavioural hearing assessment for neonates and infants using calibrated noise makers. The use of objective screening in L&MICs implies a preference for international best practices based on Western contexts and guidelines.[2] However, it is important to assess the sustainability and long-term outcomes of these efforts. Subjective single-stage PTA screening, on the other hand, was extensively used in various screening programmes for older children above the age of 3. This is comparable to HICs where PTA screening is mandatory for children over the age of 3.[94 95] In contrast, the current review found a few public initiatives[75 87 96] that used questionnaire methods, and this implies that mass screening was being done by low-cost tools like questionnaires where resources were limited.

Audiologists were the most common screening personnel in newborn screening programmes across Asian L&MICs. This is in contrast to HICs, where nurses mostly performed hearing screening.[97] While the majority of NHS programmes in Asian L&MICs were started by audiologists or otolaryngologists in private hospitals, in most HICs, the screening programmes were generally universal and followed as a part of other normal newborns screening before discharge. Screening of older children was mostly done by otolaryngologists, school instructors and nurses. This could be because many of the screening programmes for older children were conducted in schools or community settings in the absence of audiologists on site. In contrast, hearing screenings are carried out at child health clinics by a dedicated school nurse/audiologist in HICs.[97]

Use of the test battery was limited in diagnostic confirmation of hearing loss. Detailed ABR testing was considered as the standard diagnostic tool in many countries as it examines the entire peripheral auditory pathway responsible for hearing. Apart from this, studies from China employed a test battery containing a variety of tests altogether (eg, ASSR, ABR and tympanometry) to confirm hearing loss. In WHO guidelines for hearing screening, diagnostic test battery including ABR/ASSR, tympanometry, acoustic reflex, otoscopic examination and medical evaluation was suggested.[98] Therefore, in HICs, the diagnostic test battery approach is mostly preferred.[97] In screening programmes for older children, medical (ENT) examination in cases of conductive pathology and routine PTA with or without tympanometry were prioritised as tests to confirm hearing loss. This is inconsistent with the WHO guidelines[98] and with the programmes from HICs[97] It is important to note that PTA is a crucial test to differentiate CDHL and sensorineural hearing loss. However information on bone conduction testing was was limited.

Few studies reported the use of ICT to screen, manage data or perform diagnostic tests.[8 76] Lack of use of ICT could be due to lack of adequate infrastructure, skills to support use of such tools. Yet, this is not unique to L&MICs as evidence on use of ICT is limited even among HICs.[92 93 97 99]

We assessed the validity and efficacy of the screening programme for infants and older children using a purposively developed tool. None of the programmes reported met all of the criteria. The majority of programmes made use of validated screening and diagnostic tools and reported the rate of hearing loss identification. However, information on economic analysis was scarce, even though cost effectiveness is a key variable for determining programme success.[100] Furthermore, studies predominantly reported only identification but not intervention. The importance of EHDI programmes is to intervene children so that the pervasive impact of childhood hearing loss can be mitigated[101 102]; therefore, it is

pertinent to know whether such programmes resulted in early intervention.

Mean prevalence of hearing loss in newborns and infants was identified to be high in India (5/1000), followed by Iran (3/1000) and China (2/1000). This is similar to the findings of Bussé and colleagues (2021) where the highest prevalence was found in India and Nigeria, followed by Iran. In another review, prevalence was found to be highest in Asian countries compared with other regions.[99] A world report on hearing also stated that prevalence of congenital hearing loss in L&MICs is high compared with HICs.

Barriers identified from our review were similar to those previously identified and discussed in various studies including L&MICs.[97 101–103] However, a recent study in HICs found that when hearing screening programmes were integrated as part of national screening with a dedicated screening person, database management system and appropriate guidelines, they were more successful. Therefore, EHDI in L&MICs is also likely to be more successful when implemented through the government.

There were some limitations to the review which must be considered. No article was excluded based on quality assessment owing to the limited literature available from L&MICs, yet the risk of bias in many included studies was moderate to high. Furthermore, due to heterogeneity in the information obtained across studies, no meta-analysis was performed. The generalisability of the findings was limited to Asian L&MICs. Further, there were potential for publication bias as not all programmes would have published their results. The coverage of EHDI in these countries was not assessed.

From this study, it is evident that strategies for EHDI in Asian L&MICs were similar to those recommended in HICs. However, there is inadequate evidence related to the intended outcome of early intervention in this context. Therefore, programme planners and researchers must focus on impact evaluations that demonstrate the long-term viability of EHDI programmes in the L&MI context.

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