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A systematic review of early hearing detection and intervention (EHDI) programs for infants and young children in low and middle income countries in Asia

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TITLE: A systematic review of early hearing detection and intervention (EHDI) programs for infants and young children in low and middle income countries in Asia

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Abbreviations

EHDI	Early Hearing Detection and Intervention
LMIC	Low Middle Income Countries
HIC	High Income Countries
OAE	Oto Acoustic Emissions
AABR	Automated Auditory Brainstem Response
ABR	Auditory Brainstem Response
TEOAE	Transient Evoked Oto Acoustic Emissions
DPOAE	Distortion Product Oto Acoustic Emissions
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ICT	Information and Communication Technology
ASSR	Auditory Steady State Response
MeSH	Medical Subject Headings
WHO	World Health Organization
NHS	Newborn Hearing Screening
SNHL	Sensori Neural Hearing Loss

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ABSTRACT

Background: Early Hearing Detection and Intervention (EHDI) measures initiated in high incomes countries were attempted in LMICs. However, information regarding the models of EHDI, context specific adaptations made to strategies, and outcomes are not known**. Aim:** The aim of this systematic review was to identify the various models of EHDI used in the Asian LMICs in the published scientific literature, and to describe the their efficacy and validity. **Method**: The studies were eligible if the program was from an Asian LMIC, implemented for children below 6 years of age and published between 2010 - 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 PRISMA 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 OAE(DP/TE) or AABR 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 high-income countries (HICs). However, no uniform protocols were followed within each country. Long term viability of EHDI programs was not known as there was limited information on impact outcomes such as cost-benefit.

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INTRODUCTION

Currently, 34 million children below 15 years are estimated to have hearing loss, with a higher prevalence in low and middle income countries (2.4%) than in high income countries (0.5%) [1]. Early Hearing Detection and Intervention (EHDI) for children with hearing loss is critical to maximize linguistic competence and literacy development. EHDI is a concept that emanated in the United States 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 programs. Subsequently, Joint Committee of Infant Hearing (JCIH) (2007) in the US, recommended that all infants should be screened for hearing by 1 month of age, diagnosed by 3 months and intervened by 6 months of age [2]. It is practiced as a mandatory universal screening in the entire country.

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

The aim of this systematic review is to identify different models of EHDI that have been implemented in the context of Asian LMICs in the published scientific literature, and describe evidence of their efficacy and validity.

METHOD

The protocol for this systematic review was registered in PROSPERO (Reg No: CRD42021240341)

Inclusion criteria

All types of study designs were eligible for this review, including i) Cross-sectional ii) Cohort iii) Case-control iv) Randomized control trials v) Quasi-experimental and vi) 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 programs related to triaging children suspected with hearing loss using methods such as objective or subjective screening, parental questionnaire based screening, implemented in the context of LMICs including hospital, community, school based or any other alternative approach were included.

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

According to World Bank classification, Low and Middle-Income Countries (LMICs) in Asian continent (South East Asia, Central Asia and Western Asia/Middle East) were considered as eligible for the review In the LMICs, 6 years and below was 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 2010-2022.

Exclusion criteria

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

Search strategy

Since EHDI is an interdisciplinary program often implemented by ENT/ Pediatrics/ neonatology/ audiology/ nursing, databases that captured articles from multiple disciplines was preferred. The primary databases used for the search includes; 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 to 2022) and bibliographies of the selected papers based on the eligibility criteria. Grey literature search included ProQuest Dissertations & Theses Global (Interdisciplinary) and first 500 searches for articles/ reports in Google search. We excluded social media articles, newspaper articles, editorials, website information.

A search strategy for each of the above mentioned databases was designed using 2Dsearch online tool[12] . The search strategy included MeSH terms and Boolean operators (Appendix 1). 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 abstract and full texts. Screening was conducted by two reviewers (DJ, VR) and any discrepancies were discussed between the reviewers and decisions were made. Joanna Briggs Quality assessment tools specific to the research design was used to assess the quality of the articles.

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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 LN) and was verified by another author (VR).

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 programs, personnel involved in delivery of the program and reported barriers and facilitators of the program. 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 i) validity and efficacy of the screening programmes. We developed a checklist (Figure 2A & 2B) to assess the validity and efficacy using three criteria each. The items in the validity checklist included; i) the use of a *validated screening tool*, ii) the use of a *validated diagnostic tool,* whether the screening programme reported was in the iii) *design phase* (e.g. pilot/feasibility/validity/only reported coverage rate or referral rate or follow up rate) or *implementation phase* (e.g. scale programme). The efficacy was assessed if the study reported the i) evidence of early identification ii) evidence of early intervention ii) inclusion of an economic analysis.

The secondary outcome of interest was to estimate the incidence & prevalence outcomes of EHDI programs in the LMIC Asian countries. For secondary outcomes analysis, in screening programs for newborns and infants, the prevalence of hearing loss in infants reported in each country was analyzed using the SWIM guidelines. Using a random effect model, Forest plots (Figure 3A-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 one thousand.

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 flow chart (Figure 1). Sixty five (79%), reported on newborn hearing screening, and only seventeen 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), Tajikistan (n=1).

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These studies included 75 cross sectional studies and 7 cohort studies. Results of quality appraisal using appropriate JBI tool is provided in supplementary file 1.

Insert Figure 1: PRISMA flowchart representing the selection of article at each stage

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

Hearing screening programs for newborns and infants (below 2 years) included 65 studies. Most studies (49) reported single-hospital programmes, whereas others (16 studies) reported multiple-center 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 to 17. Fifteen of these studies were school-based hearing screenings, while two were community-based. Of these studies, 9 were undertaken in the private sector and 8 in the public sector. Table 1A to E represent the summary of included studies describing hearing screening programs for newborns and infants in each country.

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Table 1A: Hearing screening programs for newborns and infants in India

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Biswas et al., 2012	[17]	India	2 years	newborns	490	1 stage	DPOAE	Not mentioned	Not mentioned
Paul et al.,2011	[18]	India	7 years	newborns	10165	2 stage	OAE + OAE (not mentioned DP/TE)	Person with basic knowledge in computer with training on NHS.	Diagnostic ABR
Mishra et al., 2013	[19]	India	3 years	0-2 years	1101	<6 months of age- 5 stage; 6m to 1yr-4 stage ; 1 yr to 2 yrs -3 stage	DPOAE	Not mentioned	Diagnostic ABR
Ramesh et al., 2012	[20]	India	2 years	newborns	425	1 stage	Calibrated noise maker based BOA	Trained health workers (30 hours of training)	Diagnostic ABR, OAE & BOA
Rai & Takur et al.,2013	[21]	India	1 year	newborns	500	3 stage	TEOAE +TEOAE +TEOAE	ENT	Diagnostic ABR
Kumar et al.,2015	[22]	India	1 year 8 months	High risk < 2 years of age	500	2 stage	TEOAE+AABR	Audiologist	Not mentioned
Gupta et al., 2015*	[23]	India	1 year	newborns	2265	2 stage	AABR + AABR	Single specialist staff	Not mentioned
Vignesh et al.,2015 *	[24]	India	1.5 years	newborns	1405	2 stage	TEOAE+AABR	Not mentioned	Diagnostic ABR
Vishwakarma et al.,2015	[25]	India	1 year 8 months	newborns	Wellbabies : 2000 high risk :1020	3 stage	TEOAE+TEOAE + AABR	Nurse, Resident doctor/ certified audiologist	Diagnostic ABR
Paul et al.,2016	[26]	India	11 years	newborns	Wellbabies : 84774 High risk: 16,914	2 stage	OAE+ OAE (Not mentioned DP/TE)	Person with basic training in hearing screening	Diagnostic ABR
Sharma et al., 2018	[27]	India	3 years	newborns	2534	2 stage	DPOAE	Not mentioned	Diagnostic ABR
Kumar et al.,2016*	[28]	India	2 years	newborns	1537	2 stage	TEOAE+TEOAE + AABR	Not mentioned	Not mentioned
Sachdeva & Sao et al.,2017	[29]	India	10 months	newborns	2254	2 stage	(HRR + BOA + DPOAE) + DPOAE	Not mentioned	Confirmatory Diagnostic ABR
Kumar et al.,2017	[30]	India	No info	newborns	600	2 stage	TEOAE+DPOAE	Not mentioned	Not mentioned
Swain et al.,2017	[31]	India	1.5 years	newborns	410	2 stage	DPOAE + DPOAE	Not mentioned	Diagnostic ABR
Bhat et al.,2018	[32]	India	1 year	High risk newborns	195	1 stage	TEOAE	Not mentioned	Diagnostic ABR
Bishnoi et al.,2018	[33]	India	No info	newborns	2000	2 stage	(OAE & TYMP) + OAE (not mentioned DP/TE)	Not mentioned	Diagnostic ABR
Parab et al.,2018 *	[34]	India	3 years	newborns	8192	2 stage	TEOAE + TEOAE	Audiologist	Diagnostic ABR
Jacob et al.,2020	[35]	India	2 years	newborns	773	2 stage	TEOAE +TEOAE	Not mentioned	Diagnostic ABR

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Nishad et al.,2020	[36]	India	1 year	newborns	1000	2 stage	OAE+OAE (not mentioned DP/TE)	Not mentioned	Diagnostic ABR
Sija et al., 2022	[37]	India	4 years	Newborns	16265	2 stage	DPOAE +DPOAE	Trained nurse	Diagnostic ABR

Table 1B: Hearing Screening programs for newborns and infants in China

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Zhang et al., 2012 *	[38]	China	1.5 years	newborns	10043	2 stage + genetic screening	TEOAE+ (TEOAE& AABR)	Nurse	Not mentioned
Tobe et al.,2013*	[39]	China	2 years	newborns	Not mentioned	2 stage	OAE+AABR (not mentioned DP/TE)	Trained personnel - no info	Not mentioned
Chen et al.,2012	[40]	China	2 years	newborns	11568	2 stage	TEOAE	Audiologist	Diagnostic ABR, TFT, Impedance, ASSR at hospital
Shang et al.,2016	[41]	China	6 months	newborns	1064	2 stage	1st protocol: TEOAE + TEOAE 2nd protocol: (TEOAE & ABR screen) + TEOAE	Not mentioned	Diagnostic ABR
Wenjin et al., 2018	[42]	China	2 years	newborns	19098	2 stage	Well babies : DPOAE + ABR screening High risk babies: (DPOAE & ABR screening) + (DPOAE & ABR screening)	Nurse	Otoscopy, Diagnostic ABR at 30dBHL, Tympanometry; DPOAEs
Wang et al., 2019	[43]	China	5 years	newborns	55,977	2 stage	OAE+AABR (Non mentioned DP/TE)	Nurse	Comprehensive diagnostic audiometry around three months of age
Dai et al.,2019	[44]	China	1 year	newborns	180469	2 stage + genetic screening	TEOAE + (TEOAE & AABR)	Not mentioned	Diagnostic ABR, ASSR, DPOAE, Immitance
Zeng et al., 2020	[45]	China	1 year	newborns	4205	2 stage + genetic screening	OAE+AABR screening (Not mentioned DP/TE)	Not mentioned	No
Wen et al., 2020 *	[46]	China	2 years	newborns	467980	2 stage	OAE + (OAE & AABR) (not mentioned DP/TE)	Not mentioned	Not mentioned
Guo et al., 2020	[47]	China	2 years 4 months	infants > 3 months	2,87,430	2 stage + genetic	OAE +AABR (Non mentioned DP/TE)	Not mentioned	Diagnostic ABR
Guomei et al.,2022	[48]	China	9 months	Newborns	2174	2 stage + genetic	OAE + OAE (Not mentioned DP/TE)	Not mentioned	Diagnostic ABR

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Table 1C: Hearing Screening Programs for newborns and infants in Southeast Asia

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Ahmad et al.,2011	[49]	Malaysia	5 years	newborns	16000	3 stage	DPOAE +DPOAE + DPOAE	Technician, staff nurse, ward attendants	Diagnostic ABR
Wong et al.,2020	[50]	Malaysia	2 years	newborns	28432	1 and 2 stage	1 stage AABR 2 stage - DPOAE + AABR	Nurses	Diagnostic ABR
Tungvachirakul et al.,2011	[51]	Thailand	1 year 11 months	newborns	4043	2 stage	OAE+ OAE (Not mentioned DP/TE)	Not mentioned	ASSR
Poonual et al.,2016	[52]	Thailand	1 year 7 months	newborns	3120	2 stage	Automated TEOAE + Conventional TEOAE	Not mentioned	Diagnostic ABR
Poonual et al.,2017	[53]	Thailand	Not mentioned	newborns	3120	3 stage	COBRA HRR tool + TEOAE + AABR	Not mentioned	Not mentioned
Poonual et al., 2017b	[54]	Thailand	1 year	newborns	3120	2 stage	TEOAE+ AABR	Not mentioned	ABR at 3 and 8 months
Pitathawatchai et al.,2019	[55]	Thailand	1 year 7 months	newborns	6140	2 stage	TEOAE+TEOAE	Nurses	Not mentioned
Ray et al.,2021	[56]	Nepal	2 years	newborns	540	2 stage	OAE+OAE (Not mentioned DP/TE)	Not mentioned	Diagnostic OAE and Diagnostic ABR
Mazlan et al.,2022	[57]	Malaysia	10 years	newborns	50633	2 stage	TEOAE +AABR	Trained nurses and medical technologists	Diagnostic ABR
Shameem et al., 2022	[58]	Bangladesh	2 years	High risk newborns	426	2 stage	TEOAE + TEOAE	Not mentioned	Diagnostic ABR
Khaimook et al.,2022	[59]	Thailand	6 months	newborns	1696	2 stage	TEOAE + TEOAE	Trained Nurse & audiologist	Diagnostic ABR + Tympanometry

Table 1D: Hearing screening programs for newborns and infants in Turkey

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Tasci et al.,2010	[60]	Turkey	14 months	newborns	16,975	3 steps	TEOAE+ TEOAE+ ABR	Audiology technician	Diagnostic ABR
Sennaroglu & Akmese, 2011	[61]	Turkey	1 year	newborns	1840	2 stage	TEOAE	Audiologist or audiometrist	Diagnostic ABR;
Ulusoy et al.,2014 *	[62]	Turkey	3 years	newborns	11575	3 stage	TEOAE+ AABR	2 audiometrists and 1 nurse	Diagnostic ABR, the level three center
Kemaloğlu et al., 2016	[63]	Turkey	10 years	newborns	19436 (I/P) 2083 (O/P)	3 stage	TEOAE+ TEOAE+ (TEOAE & AABR)	Audiology technicians and audiology students	Diagnostic ABR
Yorulmaz et al., 2017	[64]	Turkey	5 years	newborns	13693	3 stage	TEOAE+TEOAE+AABR	Audiometrist	Diagnostic ABR, Tympanometry, Acoustic

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									reflexes, ASSR
Celik et al.,2016	[65]	Turkey	6 years	newborns	142128	2 stage	TEOAE (twice same day)+ TEOAE	Not mentioned	Diagnostic ABR
Ozturk et al.,2017	[66]	Turkey	2 years	newborns	7502	3 stage	Wellbabies: DPOAE+DPOAE+ABR screening Highrisk babies: Direct ABR	Audiologist	Diagnostic ABR
Hamdi, 2018	[67]	Turkey	2 years	newborns	1808	3 stage	TEOAE+TEOAE+ABR screening	Nurses (Trained)	Diagnostic ABR
Yücel et al., 2019	[68]	Turkey	2 years	newborns	786 syrian & 7230 turkish	3 stage	(TEOAE & Tymp) + TEOAE + ABR	Not mentioned	Detailed testing
Arslan et al., 2013	[69]	Turkey	8 months	newborns	2229	2 stage	TEOAE+ TEOAE	Nurse	Diagnostic ABR
Çıkrıkçı et al., 2020*	[70]	Turkey	1.5 years	newborns	702 turkish 172 syrian	2 stage	AABR + AABR	Not mentioned	Diagnostic ABR

Table 1E: Hearing screening programs for newborns and infants in Iran

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Arjmandi et al., 2012	[71]	Iran	1 year	newborns	1232	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Islami et al.,2013	[72]	Iran	1.5 years	newborns	7250	2 stage	TEOAE+TEOAE	Audiologists	Diagnostic ABR
Firoozbakht et al.,2014	[73]	Iran	8 years	newborns	33,50,995	2 stage	TEOAE+AABR	audiologists, nurses, midwives and trained health technicians.	Comprehensive test
Zahed et al., 2014*	[74]	Iran	8 years	newborns	40930	2 stage	TEOAE+ABR	Audiologists	ABR/ASSR & immittance audiometry,
Farhat et al., 2014	[75]	Iran	2 years	newborns	8987	2 stage	TEOAE+TEOAE	Not mentioned	ASSR
Haghshenas et al., 2014	[76]	Iran	2 years	newborns	15,165	3 stage	OAE + OAE + (OAE & AABR) (Not mentioned DP/TE)	Audiologist	ABR screening
Baradaranfar et al., 2014	[77]	Iran	1 year	newborns	514	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Azizi et al., 2016	[78]	Iran	1.5 years	newborns	3818	2 stage	TEOAE+TEOAE	not mentioned	ABR,
Tajik & Ahmadpour-Kacho, 2016	[79]	Iran	4 years	newborns	3362	2 stage	TEOAE + (TEOAE & ABR)	Not mentioned	Not mentioned
Saki et al.,2017	[80]	Iran	3 years	newborns	92,521	2 stage	1st & 2nd:TEOAE + AABR	Audiologists	Diagnostic OAE and ABR .
Rahimi et al.,2018	[81]	Iran	5 years	newborns	4729	3 stage	TEOAE + TEOAE + AABR	Audiologist	Diagnostic ABR

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Table 2 : Hearing screening programs for older children

Author and year	Citation	Country	Years of Program	Age of screening (years)	Number screened	Screening protocol	Screening test used	Pass/fail criteria	Screening personnel	Diagnostic test	Diagnostic person
Tuli et al.,2012	[82]	India	2 years	5 to 16	111	1 stage	Case history, Audiological & ENT evaluation, Awareness &SIFTER	Not mentioned	Not mentioned	ENT & PTA & Diagnostic ABR	Audiologist
Chadha et al., 2013	[83]	India	3 years	5 to 12	15718	1 stage	Otoscopy, Ten 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	[84]	India	2 years	Birth to 5 years	1335	2 stage	DPOAE +DPOAE	>SNR 3 dB	Trained Village Health Worker	Tele-Diagnostic ABR	Audiologist
Ramkumar et al.,2019	[85]	India	2 years	Birth to 5 years	2815	2 stage	DPOAE + DPOAE	>SNR 3 dB	Trained Village Health Worker	Diagnostic ABR – in person and Tele-diagnostic ABR	Audiologist
Verma et al.,2022	[86]	India	6 months	6 to 17 years	597	1 stage	Tuning fork test	Not mentioned	Not mentioned	PTA and Tympanometry	Audiologist
Shekhar et al., 2020	[87]	India	Not mentioned	5 to 14	474	1 stage	PTA	Not mentioned	ENT specialist	ENT examination	ENT specialist
Lu et al.,2011	[88]	China	1 year	3 to 6	21427	1 stage	PTA	1, 2 and 4KHz > 20dB	Screening person with training (training program with certificate)	PTA (5 to 6 years) VRA or Play PTA (3 to 4 years)	Not mentioned
Chen et al.,2013	[89]	China	1 year 5 months	3 to 6	28546	1 stage	TEOAE	>SNR 3 dB	School nurses & doctors 2 hours of training	Comprehensive test	Not mentioned Audiologist
Wu et al.,2014	[90]	China	Not mentioned	3 to 6	6288	1 stage	Software based new PTA	>30dBHL at 1,2,4KHz	Preschool teachers - minimally trained	Not mentioned	Not mentioned
Kam et al.,2014	[91]	China	Not mentioned	3 to 7	6231	1 stage	Automated PTA	>30dBHL at 1,2 and 4KHz	Automatic test - Nurses with 2 hours training as facilitator	Tympanometry, DPOAE & PTA (0.25 to 8KHz)	Not mentioned
Tokgöz-Yılmaz et al.,2013	[92]	Turkey	3 years	3 to 5	239	1 stage	PTA	Not mentioned	Audiologist and SLP	ENT examination	ENT specialist
Kaplama et al.,2020	[93]	Turkey	1 year	69 to 84 months	23664	2 stage	PTA, Ten questionnaire	500, 1000, 2000 and 4000Hz > 20dB Ten question -	Certified nurses, midwives, health offcers or	ENT examination	ENT specialist

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								Refer in 1 question	audiometrists,		
TarviEslami et al.,2017	[94]	Iran	1 year	6 to 7	2237	Not mentioned	PTA	Not mentioned	Not mentioned	PTA, Weber, Rinne test	Not mentioned
Jalali et al.,2020	[95]	Iran	4 months	6 to 13	2019	1 stage	PTA	0.5KHz to 4KHz >15dBHL	Not mentioned	ENT examination & comprehensive audiological examination	Not mentioned
Pilka et al.,2016	[8]	Tajikistan	Not mentioned	6 to 8	143	1 stage	Questionnaire, PTA using SZOK telemed model	PTA module (500 to 8KHz) >25dB at one frequency,	Medical doctors Other specialists	Detailed PTA	Audiologists
Alaqrabawi et al.,2016	[96]	Jordon	4 years	5 to 15	1649	1 stage	PTA	500Hz, 1KHz, 2KHz & 4KHz > 25dB	Not mentioned	Audiometry Otoscopy Tympanometry	Audiologists
Al-Obeidy et al.,2019	[97]	Iraq	1 year	6	425	1 stage	HR Questionnaire	Not mentioned	Not mentioned	ENT examination, TFT (Weber, Rinne and Absolute bone conduction). HRR children: PTA	Not mentioned

Abbrevations: PTA: Pure Tone Audiometry; ABR-Auditory Brainstem Response; DPOAE-Distortion Product OtoAcoustic Emissions; TEOAE-Transient Evoked Oto Acoustic Emissions; TFT-Tuning Fork Test; HRR-High Risk Register; SNR-Signal to Noise Ratio; SIFTER: Screening Identification For Targeting Educational Risk; Tymp-Tympanometry

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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 5-step hearing screening protocol.

Sixteen studies that reported a two-stage hearing screening protocol, employed otoacoustic emission (OAE) (TE/DP-OAE) or Automated Auditory Brainstem Response (AABR) as screening tests (individually or combined in either stage[22,24,32,42–47,50,53,57,73,74,79]. Other twenty five studies used only OAEs (DP/TE) [19,26,34–37,40,51,55,56,58,59,61,65,69,71,72,78] or AABR screening [23,70]for testing in both stages. Those studies that reported the use of AABR in the initial stage of screening either employed AABR solely for both stages [23] or a combination of AABR and OAE to screen only high-risk newborns [41,42]. Four studies from China used 2 stage screening coupled with genetic hearing screening [43–45,47,48]

When a three-stage protocol was used, generally the first two stages included OAE (DP/TE) screening followed by AABR/ABR screening [25,60,62–64,66,67,76,81] or included OAE(DP/TE) for all three stages [21,49]. Only one study reported combining tympanometry and TEOAE in the initial stage of its three-stage screening protocol [68]. Studies from Turkey (n=7) reported three-stage screening protocol [60,62–64,66–68].

Screening for older children

Fourteen studies for older children employed a single stage screening protocol [8,82,83,87,88,90–92,95–97] with three employing a two stage protocol [85,93]. Ten studies reported using subjective hearing screening tests, two studies used questionnaire or otoscopy for screening [83,97] and another three studies used TEOAE [84,85]. Pure tone audiometry was the most commonly used subjective test for screening older children [87,88,92,94–96]; Two studies reported the use of automated software based PTA [90,91]. Pure tone audiometry was combined with questionnaires [8,93] or otoscopy [83,97]. Only one study reported the use of TEOAE screening [89].

Pass/ refer criteria

In several programs 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 and 6 dB SNR [18,21,25,30,32,37,40,42,47,49,55,59,63,65,78] and for AABR it varied between 30 dB nHL, 35 dB nHL and 40 dB nHL [41,42,62,64,76]. Predominantly, refer results in one ear was considered for follow-up screening.

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For screening older children, the pass criteria for pure tone audiometry ranged from 15dB HL to 30dB HL. All studies used the four frequencies 0.5KHz to 4KHz for pure tone testing. In questionnaire-based studies, failing one item or a family history of hearing loss were the referral criteria [83,87].

Screening personnel:

Audiologists were the primary screening personnel in many newborn and infant programs [22,25,34,39,40,61,66,72,74,76,80,81]; followed by nurses [25,37,42,43,49,50,55,57,59,62,67,69,73].In five studies, the training provided for nurses to perform hearing screening was also briefly mentioned [55,57,67,69,73]. including some certifications [62]. Other than nurses, some studies reported audiometrists [61,62,64] and audiologist technicians [60] as personnel involved in screening. Other non-specialists that were engaged in hearing screening were technicians[49], ward attendants[49], trained health workers [20,73] social workers [39]and midwives [18,26,73]. In a few programmes, otolaryngologists [21] performed the hearing screening. 29 out of 59 studies did not provide any information regarding the screening individual.

Screening for older children was conducted by otorhinolaryngologists [8,83,87]audiologists [92], and audiometrists [93]. Other non-specialists involved in the hearing screening included trained nurses/midwives [40,91,93], trained village health workers or volunteers [84,85] and school teachers with training [90] .

Studies have reported a variety of training programmes. They included hearing screening certification [88,93]; 2 hours of TEOAE training[40]; TEOAE training and tele-diagnostic testing facilitation [85]; and minimal training/2 hours of training for facilitating automated PTA [90,91].

Confirmation of hearing loss:

Diagnostic Auditory Brainstem Response (ABR) was the only testing carried out to confirm the hearing loss in studies in newborns and infants; [19,21,25,27,29,31,33,35–37,47,57,58]. Comprehensive test battery including the diagnostic BERA, OAE, and tympanometry was mentioned only in eleven studies [42,64,73]. Four studies also reported the inclusion of the Auditory Steady State Response (ASSR) in the test battery [64,74].

Two programs utilized solely ASSR [75] [51] and studies also used ABR screening at 30 dB nHL [42] or 35 dB nHL [76] for hearing loss diagnosis.

However, 11 of the 65 programs 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 eighteen 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.

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In studies reporting screening for older children, a test battery approach was used in 3 studies where they included PTA with tympanometry and DPOAE [91] or PTA with otoscopy and tympanometry [96] or PTA and detailed ABR [82]. Two studies reported the use of comprehensive test battery, but did not mention the tests included [40].

Puretone audiometry (PTA) was frequently included in the diagnostic test battery [86,91,96]. While PTA was used as the only diagnostic test in three studies [8]. Apart from these studies, ENT examination was included in five studies [87,92,93,95,97]. The diagnostic testing sites included a hospital [95], a school [87], a speech and hearing centre [91], and a telemedicine platform[8,85].

Utilization of ICT

In studies related to newborn and infant hearing screening, three programs reported the use of ICT for storing and forwarding results [34], database management [39,57], and sending reminders for follow-up screening.

In studies reporting screening of older children, five studies reported using telepractice for screening, diagnosis, or both. Tele-diagnostic ABR [84,85] was reported in India. use of m-health-based automated hearing screening was reported in China by Wu et al. (2013) and Kam et al. (2014) a tele- sensory screening platform including hearing screening (SZOK paradigm) in Tajikistan, where both screening and diagnosis were carried out via telemedicine [8].

Validity and efficacy of the screening programs:

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

Among the studies that reported newborn and infant hearing screening, 48 studies fulfilled all 3 criteria of the validity tool; Eleven studies fulfilled 2 out of 3 criteria; Six studies fulfilled 1 out of 3 criteria (Figure 2A). Validated screening tool was used by sixty three studies and fifty four studies used a validated diagnostic tool. As per the criteria we used, fifty five studies could be classified to be in the implementation phase and ten studies were in design phase.

Economic analysis, frequency of identification and intervention were the 3 criteria included to assess efficacy. Only two studies fulfilled all the three efficacy criteria, seventeen studies fulfilled two out of the three criteria, thirty seven studies fulfilled only one of the three criteria, whereas remaining nine studies did not fulfil any of the criteria. Fifty one studies only reported the frequency of identification, whereas fourteen reported both the frequency of identification and intervention. Twelve percent of the studies did not mention either of these outcomes. Economic analysis was very limited (n=3) and were reported majorly in public programs.

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Among the studies that reported screening programs for older children, ten studies fulfilled all the three criteria, three studies fulfilled two out of three criteria, three studies fulfilled one out of three criteria. Only one study did not meet any of the criteria [83] a questionnaire and an otoscopic examination 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 twelve studies fulfilled only one criterion.

Fourteen studies have reported frequency of identification , but only five studies have reported the frequency of intervention (e.g. medical intervention for conductive pathology). The intervention related screening programs were reported from India, China and Turkey. The economic analysis was only reported in two studies [84,91]. Except for the economic analysis, only two of the 17 studies fulfilled all validity and efficacy criteria [85,88].

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 3 (A to E) shows the forest plots for prevalence of each country.

In screening programs for older children, 11 programs reported percentage of hearing loss including both conductive and sensory neural hearing loss. The outcomes are reported in Table 3.

Table 3: Secondary outcomes: Studies reporting percentage of conductive and sensorineural hearing loss in older children in each country

Country	Author and year	Sample size	No. of CDHL	% of CDHL	No. of SNHL	% of SNHL	Overall HL	% of HL	LB (CI: 95%)	UB (CI: 95%)
India	Chadha et al.,2012	15718	1578	10.03%	NA	NA	1578	10.30%	9.57%	10.52%
	Shekhar et al., 2020	474	146	30.60%	1	0.20%	147	31.01%	26.87%	35.39%
Turkey	Tokgöz-Yılmaz et al.,2013	239	25	10.40%	1	0.40%	26	10.88%	7.23%	15.53%
	Kaplama et al.,2020	23664	186	0.78%	89	0.37%	275	1.16%	1.03%	1.31%
Iran	TarvijEslami et al.,2017	2284	28	1.22%	8	0.35%	36	1.58%	1.11%	2.18%
	Jalali et al.,2020	2019	19	0.94%	8	0.39%	27	1.34%	0.88%	1.94%
Tajikistan	Pilka et al.,2016	143	NA	NA	NA	NA	34	23.70%	17.06%	31.61%
Jordon	Alaqrabawi et al.,2016	1649	54	3.27%	36	2.18%	90	5.46%	4.41%	6.61%
Iraq	Al-Obeidy et al.,2019	425	28	6.59%	2	0.47%	30	7.06%	4.81%	9.92%
China	Lu et al.,2011	21547	285	1.32%	16	0.07%	301	1.40%	1.24%	1.56%
	Chen et al 2012	28546	344	1.21%	22	0.08%	366	1.28%	1.15%	1.42%

Abbreviations: CDHL: Conductive Hearing Loss; SNHL: Sensori Neural Hearing Loss; HL: Hearing Loss; LB: Lower Bound; UB: Upper Bound

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Barriers and facilitators:

Barriers:

Loss to follow-up for second screening and diagnostics [18,25,29,35–37,42,55,58,59,62,64,66,72,73] was reported as a major challenge. Loss to follow up was linked to parental rejection for diagnosis [23,26,59], poor tracking system [42,73], financial burden of parents, low socioeconomic status[70] and travel distance to testing distance. Other major challenges highlighted in relation to outcomes included limited coverage [30,35], and a high referral rate [24,25,37], poor long-term outcomes with respect to coverage and referral rate [46].

Other factors that had an indirect impact on programme outcomes included the lack of dedicated screening personnel [23]; lack of professional resources/audiologists[73,80]; high ambient noise in the testing environment [30]; and the absence of diagnostic facilities [62]. A few studies mentioned challenges affecting programme implementation, such as the use of a three-step protocol only with OAE [60]; the difficulties of centralised programme implementation in remote locations [73] and delay in diagnosis in remote locations due to referral to regional facilities [80].

In screening for older children, children's attention was regarded as a major challenge resulting in poor accuracy [91]. Other key factors influencing programme outcomes included inadequate internet connectivity [8,85]; poor follow-up due to social stigma.

Facilitators:

Use of appropriate tracking or data management systems, were reported to be helpful in minimising lost-to-follow-up[18,26,35,42,57]. Combining hearing screening with other screenings improved follow-up rates [47,81]. Several studies highlighted strategies to minimise false referral rates, including: i) employing a conducive environment and trained individuals [25]; ii) adding AABR in the initial stage of screening protocol [41]; screening between 3 and 5 days of age [81]; and incorporating tympanometry into the screening protocol [33]. Financial assistance in the form of funding [37,39,57]; and centralised hearing screening facilities or grouping more centres [18,26] were strategies reported in studies to improve coverage rates. Multi-centre based or a centralised hearing screening program was reported to be resource efficient with respect to cost, infrastructure and professionals [18].

DISCUSSION

The primary purpose of this review was to describe the models of hearing screening programmes implemented in young children in various Asian LMICs in the published scientific literature. Out of more than one hundred LMICs, only 14 countries in Asia reported hearing screening programs that fit our inclusion criteria. In a recent systematic review, high quality literature with hearing screening programs was

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reported to be primarily in high income countries [98], yet, it is also likely that resources for research and publication is low and hence is also low on priority in the LMIC context. 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 utilised for newborns, infants, and older children were similar to those used in high-income countries [99]. 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. (2018)'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 [20] found good sensitivity and specificity for behavioural hearing assessment for neonates and infants using calibrated noise makers. The use of objective screening in LMICs 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 three. This is comparable to high-income countries where PTA screening is mandatory for children over the age of three [100,101]. In contrast, the current review found a few public initiatives [29,54,97] 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 LMICs. This is in contrast to HICs, where nurses mostly performed hearing screening [102]. While the majority of NHS programmes in Asian LMICs 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 high income countries [102].

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 [103]. Therefore, in HICs the diagnostic test battery approach is mostly preferred [102]. In screening programmes for older children, medical (ENT)

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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 [103]and with the programs from high income countries [102].

Few studies reported the use of ICT to screen, manage data or perform diagnostic tests [8,85]. Lack of utilization of ICT could be due to lack of adequate infrastructure, skills to support use of such tools. Yet, this is not unique to LMICs as evidence on use of ICT is limited even among high income countries [98,99,102,104].

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 [105]. Furthermore, studies predominantly only reported identification but not intervention. The importance of EHDI programs is to intervene children so that the pervasive impact of childhood hearing loss can be mitigated [106,107], 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 (6/1000), followed by Iran (3/1000) and China (2/1000). This is similar to the findings of Busse 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 to other regions [104]. A world report on hearing (WHO, 2021) also stated that prevalence of congenital hearing loss in LMIC is high compared to HICs.

Barriers identified from our review were similar to those previously identified and discussed in various studies including LMICs [102,106,107,109]. 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 LMIC 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 LMICs, yet the risk of bias in many included studies was moderate to high. Furthermore, due to a lack of quantitative data and heterogeneity in the information obtained across studies, no meta-analysis was performed. The generalisability of the findings was limited to Asian LMICs. 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 LMICs were similar to those recommended in HICs. However, there is inadequate evidence related to the intended outcome of early intervention in this

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context. Therefore, program planners and researchers must focus on impact evaluations that demonstrate the long term viability of EHDI programs in the LMIC context.

FIGURES

Figure 1: PRISMA flowchart representing the selection of article at each stage

Figure 2A: Validity and efficacy of screening programs for newborns and infants

Figure 2B: Validity and efficacy of screening programs for older children

Figure 3A: Forest plot of prevalence of hearing loss in newborns and infants in India

Figure 3B: Forest plot of prevalence of hearing loss in newborns and infants in India

Figure 3C: Forest plot of prevalence of hearing loss in newborns and infants in China

Figure 3D: Forest plot of prevalence of hearing loss in newborns and infants in Turkey

Figure 3E: Forest plot of prevalence of hearing loss in newborns and infants in Iran

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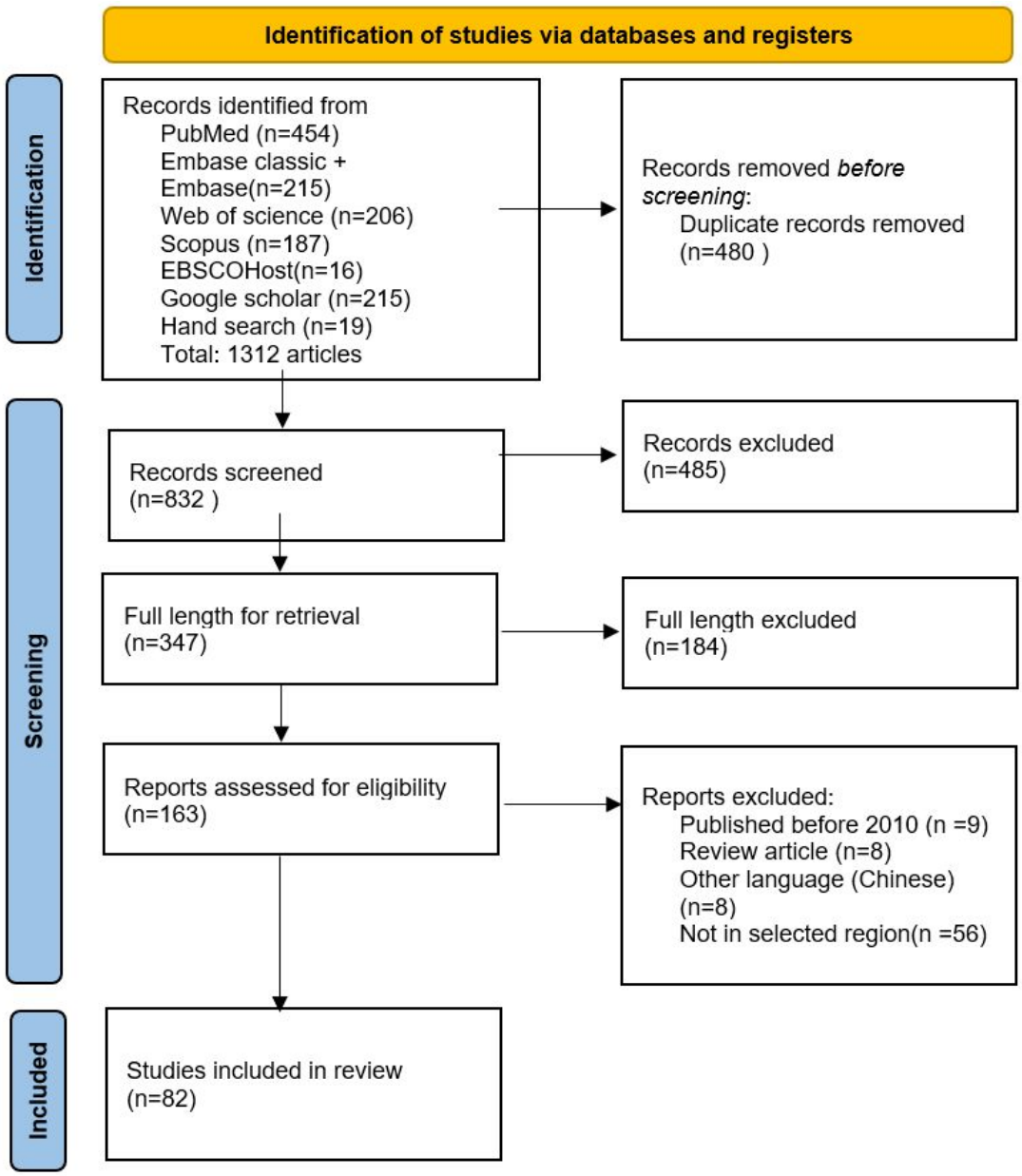
Figure 1 : PRISMA Flowchart representing selection of studies at different levels of screening



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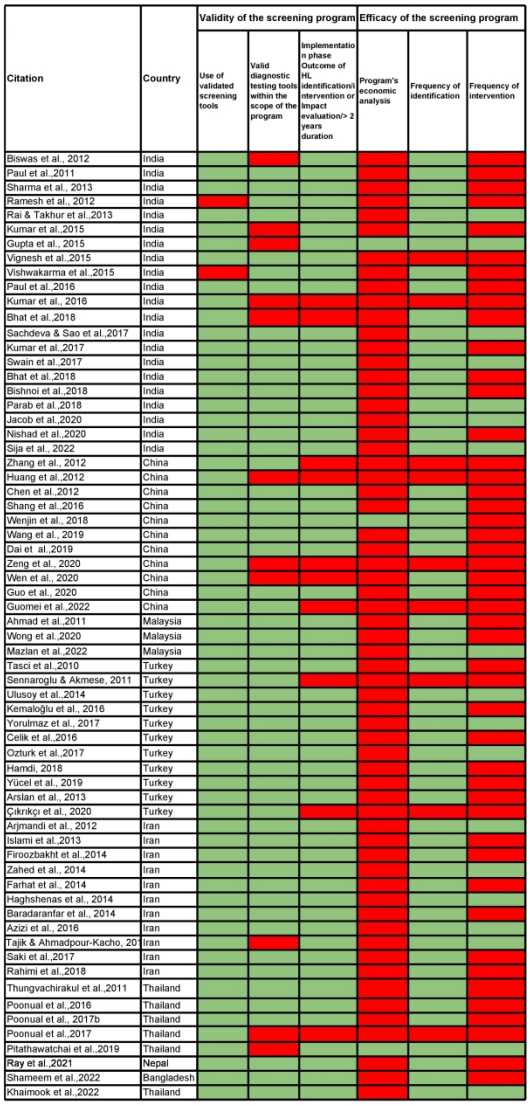
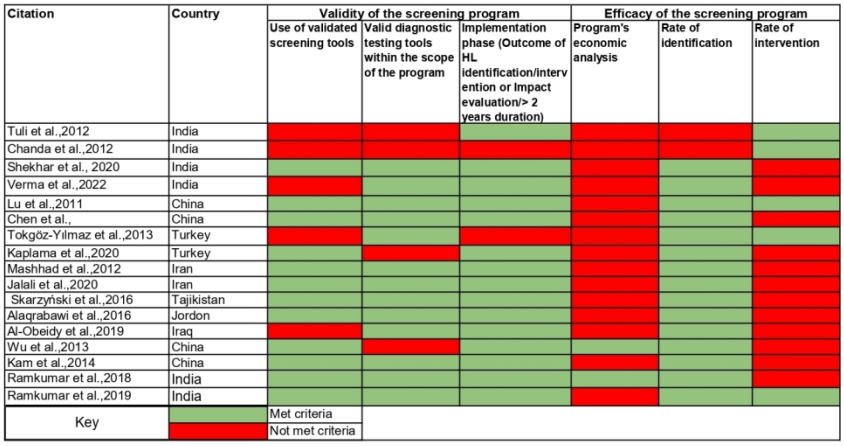


Citation	Country	Validity of the screening program			Efficacy of the screening program		
		Use of validated screening tools	Valid diagnostic testing tools within the scope of the program	Implementation phase Outcome of HL identification/intervention or impact evaluation/> 2 years duration	Program's economic 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, 20	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						

Figure 2A: Validity and efficacy of hearing screening programs for newborns and infants

221x428mm (300 x 300 DPI)



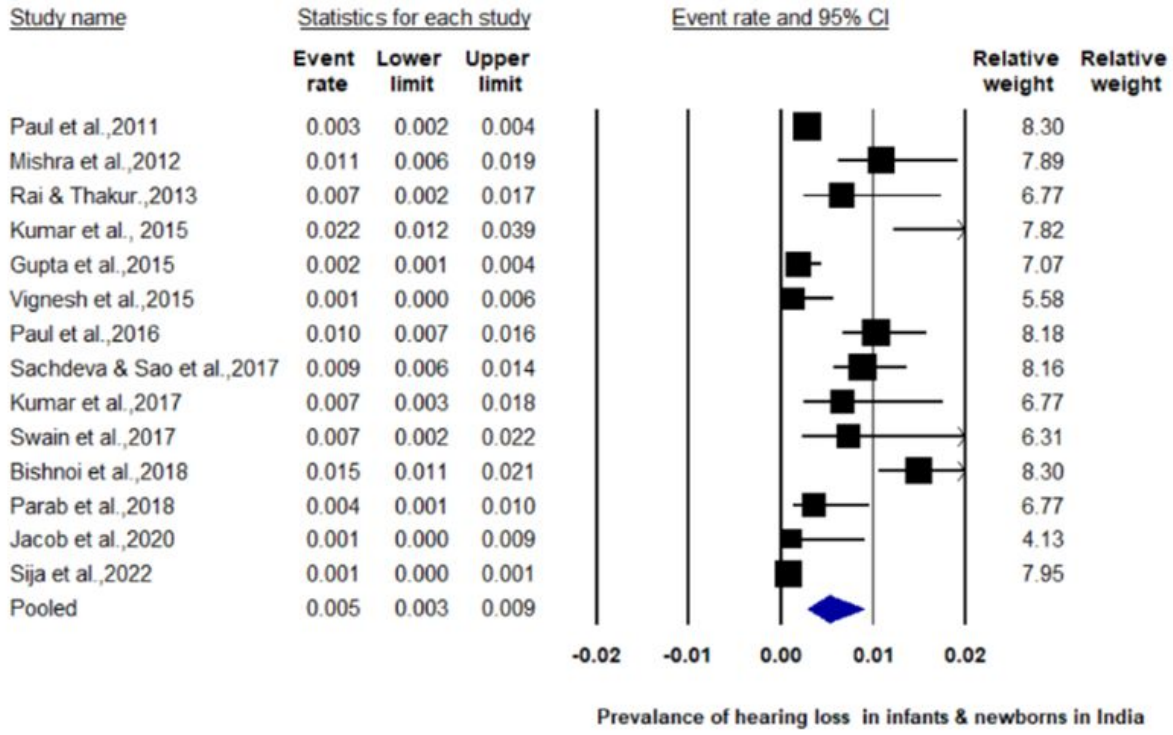
Citation	Country	Validity of the screening program			Efficacy of the screening program		
		Use of validated screening tools	Valid diagnostic testing tools within the scope of the program	Implementation phase (Outcome of HL identification/intervention or Impact evaluation/> 2 years duration)	Program's 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-Yılmaz 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					

Validity and efficacy of hearing screening programs for older children

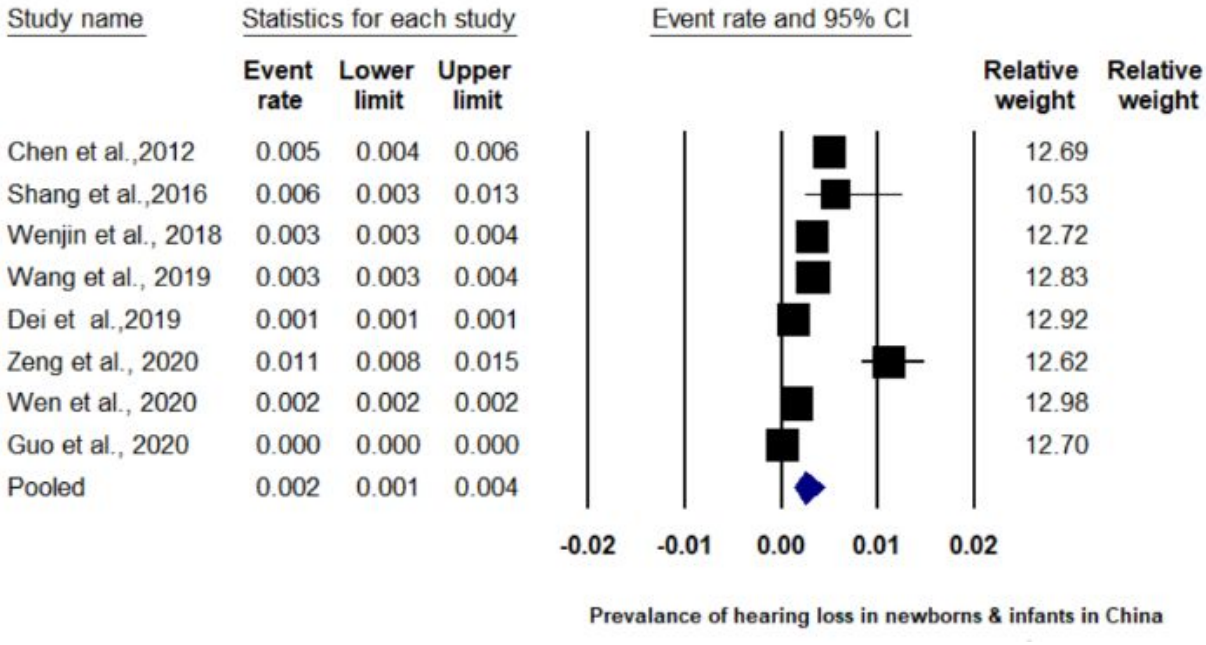
279x215mm (150 x 150 DPI)

Figure 3 (A-E)

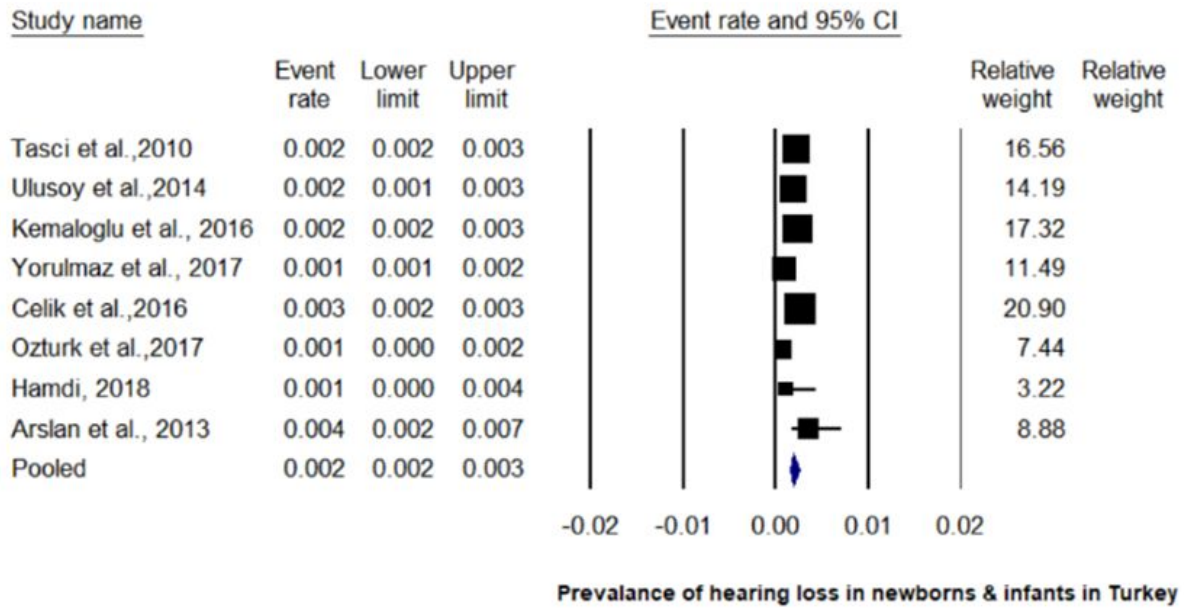
A. Forest plot of prevalence of hearing loss in newborns and infants in India



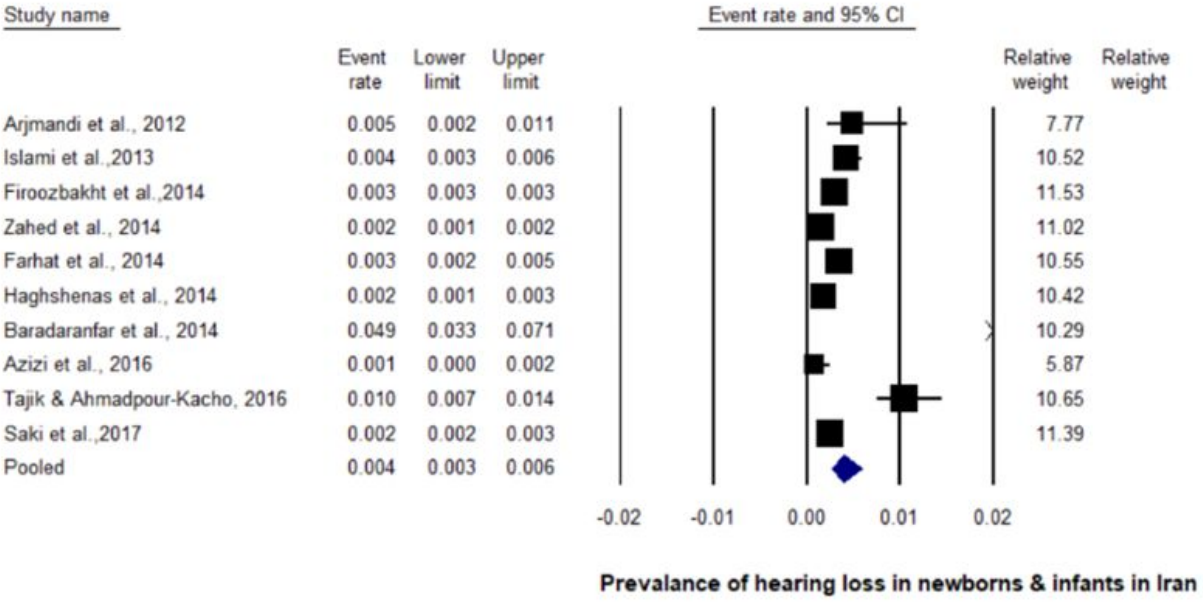
B. Forest plot of prevalence of hearing loss in newborns and infants in China



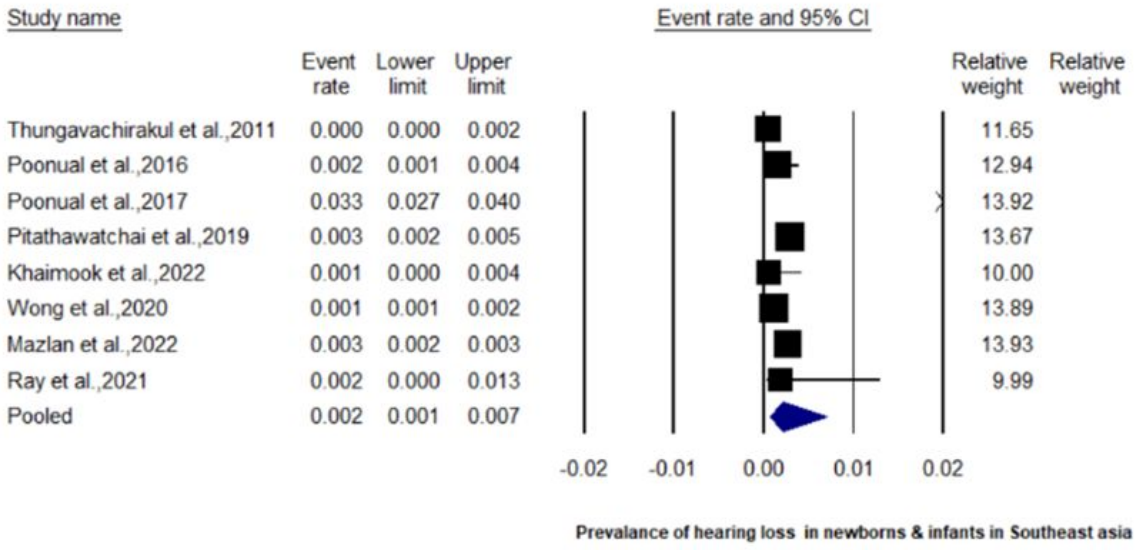
C. Forest plot of prevalence of hearing loss in newborns and infants in Turkey



D. Forest plot of prevalence of hearing loss in newborns and infants in Iran



E. Forest plot of prevalence of hearing loss in newborns and infants in Southeast asia



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Supplementary table 1: Quality appraisal for cross sectional studies using JBI tool for cross sectional studies

Author and Year	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Biswas et al., 2012	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Paul et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Mishra et al., 2013	Yes	Yes	NA	Yes	No	NA	Yes	No
Ramesh et al., 2012	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Kumar et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Gupta et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Vignesh et al.,2015 *	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Vishwakarma et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Paul et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	NA
Sharma et al., 2018	No	Yes	NA	Yes	No	Na	Yes	Yes
Kumar et al.,2016*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Sachdeva & Sao et al.,2017	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Swain et al.,2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Bhat et al.,2018	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Bishnoi et al.,2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Parab et al.,2018 *	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Jacob et al.,2020	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Nishad et al.,2020	Yes	Yes	NA	Yes	No	No	Yes	Yes
Zhang et al., 2012	Yes	Yes	NA	Yes	No	No	No	Yes
Tobe et al.,2013*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Chen et al.,2012	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Shang et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	YEs
Wenjin et al., 2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Dai et al.,2019	Yes	YEs	NA	Yes	No	NA	Yes	Yes

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Zeng et al., 2020	Yes	Yes	Yes	Yes	NA	NA	Yes	Yes
Wen et al., 2020 *	Yes	Yes	NA	yes	No	NA	Yes	Yes
Guo et al., 2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Guomei et al.,2022	Yes	Yes	NA	Yes	No	NA	No	Yes
Ahmad et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Wong et al.,2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Tungvachirakul et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Poonual et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Poonual et al., 2017b	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Pitathawatchai et al.,2019	Yes	Yes	Yes	Yes	No	Na	Yes	Yes
Ray et al.,2021	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Mazlan et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Shameem et al., 2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Khaimook et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Sennaroglu & Akmese, 2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Ulusoy et al.,2014	yes	Yes	NA	Yes	No	NA	Yes	Yes
Kemaloğlu et al., 2016	Yes	Yes	NA	Yes	No	No	Yes	Yes
Yorulmaz et al., 2017	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Ozturk et al.,2017	Yes	Yes	NA	Yes	No	No	Yes	Yes
Hamdi, 2018	Yes	Yes	NA	Yes	No	No	Yes	Yes
Yücel et al., 2019	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Arslan et al., 2013	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Çıkrıkçı et al., 2020*	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Arjmandi et al., 2012	Yes	Yes	No	Yes	No	NA	Yes	Yes
Islami et al.,2013	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Firoozbakht et al.,2014	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Zahed et al., 2014*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Farhat et al., 2014	Yes	Yes	No	Yes	No	NA	Yes	Yes

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Haghshenas et al., 2014	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Baradaranfar et al., 2014	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Azizi et al., 2016	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Tajik & Ahmadpour-Kacho, 2016	Yes	Yes	NA	Yes	No	NA	Yes	YEs
Saki et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Tuli et al.,2012	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Chadha et al., 2013	Yes	Yes	NA	No	Yes	Yes	Yes	Yes
Ramkumar et al.,2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Ramkumar et al.,2019	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Verma et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Shekhar et al., 2020	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Lu et al.,2011	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Chen et al.,2013	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Wu et al.,2014	Yes	Yes	NA	No	No	NA	Yes	Yes
Kam et al.,2014	Yes	YEs	NA	Yes	NA	NA	YES	YES
Tokgöz-Yılmaz et al.,2013	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Kaplama et al.,2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
TarviEslami et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Jalali et al.,2020	Yes	Yes	Yes	No	No	NA	Yes	Yes
Pilka et al.,2016	No	Yes	NA	Yes	No	NA	Yes	Yes
Alaqrabawi et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Al-Obeidy et al.,2019	No	Yes	NA	No	No	NA	Yes	Yes

Supplementary table 2: Quality appraisal for cohort studies using JBI tool for cohort study

	Were the two groups similar	**Were the exposures**	**Was the exposure**	**Were confounding factors**	**Were strategies to deal with**	**Were the groups/participants free of**	**Were the outcomes**	**Was the follow up**	**Was follow up complet**	**Were strategies to address**	**Was appropriate statistical**

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	and recruited from the same population?	measured similarly to assign people to both exposed and unexposed groups?	measured in a valid and reliable way?	identified?	confounding factors stated?	the outcome at the start of the study (or at the moment of exposure)?	measured in a valid and reliable way?	time reported and sufficient to be long enough for outcomes to occur?	e, and if not, were the reasons to loss to follow up described and explored?	incomplete follow up utilized?	analysis used?
Boonyasopon et al.,2016	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	No	Yes
Sija et al.,2022	Yes	Yes	NA	No	NA	Yes	Yes	Yes	Yes	No	Yes
Rahimi et al.,2018	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	No	No	Yes
Celik et al.,2016	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Tasci et al.,2020	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes
Wang et al., 2019	Yes	Yes	Yes	No	NA	Yes	yes	Yes	Yes	Yes	Yes
Kumar et al.,2017	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes
Rai & Thakur 2013	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes

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5th November 2022

To
The Editor
BMJ Pediatrics Open,

Dear Editor,

We thank you for the opportunity to re-submit our manuscript titled "**A systematic review of early hearing detection and intervention (EHDI) programs for infants and young children in low and middle income countries in Asia**" with all the suggested corrections received during our initial submission (bmjpo-2022-001725). The PRISMA checklist for systematic reviews is filled and provided as enclosure (Enclosure 1).

The following were the suggestions provided and our response;

1. **Justify excluding papers from 2022. Ideally extend your search**
   The search was expanded to include articles till 2022 and seven articles were included (2 India, 1 China, 1 Thailand, 1 Malaysia,1 Nepal and 1 Bangladesh). Based on this inclusion, suitable changes have been made to the entire results section including text, tables and figures.

2. **Supplementary Tables 1A and 1B need to be in the main paper**
   Supplementary Tables 1A (now Tables 1A-1E) and 1B (now Table 2) are included in the main manuscript

3. **Table 1A would be better as 2 -5 separate tables: divided by country of origin.**
   Table 1A has been divided by country of origin (Tables 1A-1E)

4. **Avoid use of % when describing your results - just state number of studies**
   All % are removed and only the numbers are retained

5. **By having your tables in the main paper you should be able to shorten the text**

   We were unable to reduce the text significantly at this juncture as the data in tables and text are considerably exclusive. However, we are open to any specific comments received from reviewers to eliminate certain sections if required.

6. **State the languages of the papers excluded and justify their inclusion**.
   All studies published in languages other than English were excluded as the authors are not competent with other languages. Based on this, eight Chinese language papers were excluded and this has been mentioned now in the PRISMA flow diagram.

Unlike several high income countries, EHDI programs are not mandated in many low and middle income countries (LMICs). In this context, we conducted a systematic review and gathered information on hearing screening programs mainly to identify different models of EHDI that were implemented in the context of Asian LMICs. This is one of the first systematic reviews that highlights the EHDI program models in the context of LMICs.

This review provides information on various screening protocols, tools, personnel, diagnostic tools, use of ICT, barriers and facilitators in different EHDI programs of LMICs. This study also highlights the validity and efficacy of these EHDI programs. We found that the screening tools and protocols used were similar to those used in high-income countries. However, no uniform protocols were followed within each country. Long term viability of EHDI programs was not known as there was limited information on impact outcomes such as cost-benefit.

Truly,

Vidya Ramkumar

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Enclosure 1: PRISMA checklist for systematic reviews

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Yes
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Yes
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Yes
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Yes
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Yes
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Yes
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Yes
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Yes
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Yes
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Yes
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Yes
Synthesis	13a	Describe the processes used to decide which studies	Yes

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Section and Topic	Item #	Checklist item	Location where item is reported
methods		were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Yes
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Yes
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Yes
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Yes
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Yes
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Yes
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	NA
Study characteristics	17	Cite each included study and present its characteristics.	Yes
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Yes
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	No
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Yes
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Yes
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA

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Section and Topic	Item #	Checklist item	Location where item is reported
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	No
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	No
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Yes
	23b	Discuss any limitations of the evidence included in the review.	Yes
	23c	Discuss any limitations of the review processes used.	Yes
	23d	Discuss implications of the results for practice, policy, and future research.	Yes
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Yes
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Yes
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Yes
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Yes
Competing interests	26	Declare any competing interests of review authors.	NA
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Yes. Can be accessed by contacting authors

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A systematic review of early hearing detection and intervention (EHDI) programs for infants and young children in low and middle income countries in Asia

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TITLE: A systematic review of early hearing detection and intervention (EHDI) programs for infants and young children in low and middle income countries in Asia

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New born

Infants

Low Middle Income Countries

Asia

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Abbreviations

EHDI	Early Hearing Detection and Intervention
LMIC	Low Middle Income Countries
LIC	Low Income Countries
MIC	Middle Income Countries
UMIC	Upper Middle Income Countries
HIC	High Income Countries
OAE	Oto Acoustic Emissions
AABR	Automated Auditory Brainstem Response
ABR	Auditory Brainstem Response
TEOAE	Transient Evoked Oto Acoustic Emissions
DPOAE	Distortion Product Oto Acoustic Emissions
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ICT	Information and Communication Technology
ASSR	Auditory Steady State Response
MeSH	Medical Subject Headings
WHO	World Health Organization
NHS	Newborn Hearing Screening
SNHL	Sensori Neural Hearing Loss

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ABSTRACT

Background: Early Hearing Detection and Intervention (EHDI) measures initiated in high incomes countries were attempted in low and middle income countries (L &MIC). However, information regarding the models of EHDI, context specific adaptations made to strategies, and outcomes are not known**. Aim:** The aim of this systematic review was to identify the various models of EHDI used in the Asian L&MICs in the published scientific literature, and to describe the their efficacy and validity. **Method**: The studies were eligible if the program was from an Asian LICs and MICs, implemented for children below 6 years of age and published between 2010 - 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 PRISMA 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 OAE(DP/TE) or AABR 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 high-income countries (HICs). However, no uniform protocols were followed within each country. Long term viability of EHDI programs was not known as there was limited information on impact outcomes such as cost-benefit.

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KEY MESSAGES

What is already known?

Early Hearing Detection and Intervention (EHDI) programs are mandated in several high income countries (HICs) for over two decades. These screening programs are based on guidelines and standards provided by JCIH (Joint Committee for Infant Hearing), AAA (American Audiology Association), NHSP England (Newborn Hearing Screening Program England), WHO (World Health Organization), Europeon Consensus Statement on Neonatal Hearing Screening etc. Systematic reviews have documented screening protocols and program outcomes predominantly in the context of HICs.

What this study adds?

Unlike several HICs, EHDI programs are not mandated in many Low and Middle Income Countries (L&MICs). In this context, we conducted a systematic review and gathered information on hearing screening programs mainly to identify different models of EHDI that were implemented in the context of Asian LICs and MICs. This is the first known review that provides information on various screening protocols, tools, personnel, diagnostic tools, use of information and communication technology, barriers and facilitators in different EHDI programs of L&MICs.

How this study might affect research, practice or policy sections?

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 programs 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 program planners in these countries should build consensus to implement uniform country wise protocols suited to the context.

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INTRODUCTION

Currently, 34 million children below 15 years are estimated to have hearing loss, with a higher prevalence in low and middle income countries (L& MICs)(2.4%) than in high income countries (HICs) (0.5%) [1]. Early Hearing Detection and Intervention (EHDI) for children with hearing loss is critical to maximize linguistic competence and literacy development. EHDI is a concept that emanated in the United States 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 programs. Subsequently, Joint Committee of Infant Hearing (JCIH) (2007) in the US, recommended that all infants should be screened for hearing by 1 month of age, diagnosed by 3 months and intervened by 6 months of age [2]. It is practiced as a mandatory universal screening in the entire country.

The concept was subsequently adopted in UK and practiced as universal screening since 2006. Subsequently, several other high income countries (Australia, 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 immunization [5], community based hearing screening by health workers [6,7] and school entry level screening [8,9]. Several of these programs have also integrated tele-practice to either improve coverage of screening or to 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 aim of this systematic review is to identify different models of EHDI that have been implemented in the context of Asian L&MICs in the published scientific literature, and describe evidence of their efficacy and validity.

METHOD

The protocol for this systematic review was registered in PROSPERO (Reg No: 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 i) Cross-sectional ii) Cohort iii) Case-control iv) Randomized control trials v) Quasi-experimental and vi) field trials. Both qualitative and quantitative types of studies were included

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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 programs related to triaging children suspected with hearing loss using methods such as objective or subjective screening, parental questionnaire based screening, implemented 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 (e.g. at birthing hospital/community/school), protocol used (e.g. single stage/ two-stage), provider stakeholder (e.g. private/ public) involved, tools for screening (e.g. checklist, OAE, AABR etc), or personnel involved in screening, diagnosis and intervention (e.g. nurse, audiometrists, audiologist, ENT). We also included studies that explored evidence of validity (e.g. sensitivity/specificity) and reported implementation barriers and facilitators to EHDI.

According to World Bank classification (2021), LICs, LMICs and UMICs (LICs and MICs) in Asian continent (South East Asia, Central Asia and Western Asia/Middle East) were considered as eligible for the review. In the LICs and 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 2010-2022.

Exclusion criteria

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

Search strategy

Since EHDI is an interdisciplinary program often implemented by ENT/ Pediatrics/ neonatology/ audiology/ nursing, databases that captured articles from multiple disciplines was preferred. The primary databases used for the search includes; 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 to 2022) and bibliographies of the selected papers based on the eligibility criteria. Grey literature search included ProQuest Dissertations & Theses Global (Interdisciplinary) and first 500 searches for articles/ reports in Google search. We excluded social media articles, newspaper articles, editorials, website information.

A search strategy for each of the above mentioned databases was designed using 2Dsearch online tool [12] . The search strategy included MeSH terms and Boolean operators (Appendix 1). 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.

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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 abstract and full texts. Screening was conducted by two reviewers (DJ, VR) and any discrepancies were discussed between the reviewers and decisions were made. Joanna Briggs Quality assessment tools specific to the research design was used to assess the quality of the articles.

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 LN) and was verified by another author (VR).

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 programs, personnel involved in delivery of the program and reported barriers and facilitators of the program. 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 i) validity and efficacy of the screening programmes. We developed a checklist (Figure 2A & 2B) to assess the validity and efficacy using three criteria each. The items in the validity checklist included; i) the use of a *validated screening tool*, ii) the use of a *validated diagnostic tool,* whether the screening programme reported was in the iii) *design phase* (e.g. pilot/feasibility/validity/only reported coverage rate or referral rate or follow up rate) or *implementation phase* (e.g. scale programme). The efficacy was assessed if the study reported the i) evidence of early identification ii) evidence of early intervention ii) inclusion of an economic analysis.

The secondary outcome of interest was to estimate the incidence & prevalence outcomes of EHDI programs in the L&MICs Asian countries. For secondary outcomes analysis, in screening programs for newborns and infants, the prevalence of hearing loss in infants reported in each country was analyzed using the SWIM guidelines. Using a random effect model, Forest plots (Figure 3A-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 one thousand.

RESULTS

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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 flow chart (Figure 1). Sixty five (79%), reported on newborn hearing screening, and only seventeen 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), Tajikistan (n=1). These studies included 75 cross sectional studies and 7 cohort studies. Results of quality appraisal using appropriate JBI tool is provided in supplementary file 1.

Insert Figure 1: PRISMA flowchart representing the selection of article at each stage

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

Hearing screening programs for newborns and infants (below 2 years) included 65 studies. Most studies (49) reported single-hospital programmes, whereas others (16 studies) reported multiple-center 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 to 17. Fifteen of these studies were school-based hearing screenings, while two were community-based. Of these studies, 9 were undertaken in the private sector and 8 in the public sector. Table 1A to E represent the summary of included studies describing hearing screening programs for newborns and infants in each country.

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Table 1A: Hearing screening programs for newborns and infants in India (LMIC)

Author and Year	Citation	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Biswas et al., 2012	[17]	2 years	newborns	490	1 stage	DPOAE	Not mentioned	Not mentioned
Paul et al.,2011	[18]	7 years	newborns	10165	2 stage	OAE + OAE (not mentioned DP/TE)	Person with basic knowledge in computer with training on NHS.	Diagnostic ABR
Mishra et al., 2013	[19]	3 years	0-2 years	1101	<6 months of age- 5 stage; 6m to 1yr-4 stage ; 1 yr to 2 yrs -3 stage	DPOAE	Not mentioned	Diagnostic ABR
Ramesh et al., 2012	[20]	2 years	newborns	425	1 stage	Calibrated noise maker based BOA	Trained health workers (30 hours of training)	Diagnostic ABR, OAE & BOA
Rai & Takur et al.,2013	[21]	1 year	newborns	500	3 stage	TEOAE +TEOAE +TEOAE	ENT	Diagnostic ABR
Kumar et al.,2015	[22]	1 year 8 months	High risk < 2 years of age	500	2 stage	TEOAE+AABR	Audiologist	Not mentioned
Gupta et al., 2015*	[23]	1 year	newborns	2265	2 stage	AABR + AABR	Single specialist staff	Not mentioned
Vignesh et al.,2015 *	[24]	1.5 years	newborns	1405	2 stage	TEOAE+AABR	Not mentioned	Diagnostic ABR
Vishwakarma et al.,2015	[25]	1 year 8 months	newborns	Wellbabies : 2000 high risk :1020	3 stage	TEOAE+TEOAE + AABR	Nurse, Resident doctor/ certified audiologist	Diagnostic ABR
Paul et al.,2016	[26]	11 years	newborns	Wellbabies : 84774 High risk: 16,914	2 stage	OAE+ OAE (Not mentioned DP/TE)	Person with basic training in hearing screening	Diagnostic ABR
Sharma et al., 2018	[27]	3 years	newborns	2534	2 stage	DPOAE	Not mentioned	Diagnostic ABR
Kumar et al.,2016*	[28]	2 years	newborns	1537	2 stage	TEOAE+TEOAE + AABR	Not mentioned	Not mentioned
Sachdeva & Sao et al.,2017	[29]	10 months	newborns	2254	2 stage	(HRR + BOA + DPOAE) + DPOAE	Not mentioned	Confirmatory Diagnostic ABR
Kumar et al.,2017	[30]	No info	newborns	600	2 stage	TEOAE+DPOAE	Not mentioned	Not mentioned
Swain et al.,2017	[31]	1.5 years	newborns	410	2 stage	DPOAE + DPOAE	Not mentioned	Diagnostic ABR
Bhat et al.,2018	[32]	1 year	High risk newborns	195	1 stage	TEOAE	Not mentioned	Diagnostic ABR
Bishnoi et al.,2018	[33]	No info	newborns	2000	2 stage	(OAE & TYMP) + OAE (not mentioned DP/TE)	Not mentioned	Diagnostic ABR
Parab et al.,2018 *	[34]	3 years	newborns	8192	2 stage	TEOAE + TEOAE	Audiologist	Diagnostic ABR

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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 (not mentioned DP/TE)	Not mentioned	Diagnostic ABR
Sija et al., 2022	[37]	4 years	Newborns	16265	2 stage	DPOAE +DPOAE	Trained nurse	Diagnostic ABR

Table 1B: Hearing Screening programs for newborns and infants in China (UMIC)

Author and Year	**Citation**	**Years of program**	**Population screened**	**Number screened**	**Screening protocol**	**Screening test used**	**Screening personnel**	**Diagnostic test**
Zhang et al., 2012	[38]	1.5 years	newborns	10043	2 stage + genetic screening	TEOAE+ (TEOAE& AABR)	Nurse	Not mentioned
Tobe et al.,2013	[39]	2 years	newborns	Not mentioned	2 stage	OAE+AABR (not mentioned DP/TE)	Trained personnel - no info	Not mentioned
Chen et al.,2012	[40]	2 years	newborns	11568	2 stage	TEOAE	Audiologist	Diagnostic ABR, TFT, Impedance, ASSR at hospital
Shang et al.,2016	[41]	6 months	newborns	1064	2 stage	1st protocol: TEOAE + TEOAE 2nd protocol: (TEOAE & ABR screen) + TEOAE	Not mentioned	Diagnostic ABR
Wenjin et al., 2018	[42]	2 years	newborns	19098	2 stage	Well babies : DPOAE + ABR screening High risk babies: (DPOAE & ABR screening) + (DPOAE & ABR screening)	Nurse	Otoscopy, Diagnostic ABR at 30dBHL, Tympanometry; DPOAEs
Wang et al., 2019	[43]	5 years	newborns	55,977	2 stage	OAE+AABR (Non mentioned DP/TE)	Nurse	Comprehensive diagnostic audiometry around three months of age
Dai et al.,2019	[44]	1 year	newborns	180469	2 stage + genetic screening	TEOAE + (TEOAE & AABR)	Not mentioned	Diagnostic ABR, ASSR, DPOAE, Immitance
Zeng et al., 2020	[45]	1 year	newborns	4205	2 stage + genetic screening	OAE+AABR screening (Not mentioned DP/TE)	Not mentioned	No
Wen et al., 2020 *	[46]	2 years	newborns	467980	2 stage	OAE + (OAE & AABR) (not mentioned DP/TE)	Not mentioned	Not mentioned
Guo et al., 2020	[47]	2 years 4 months	infants > 3 months	2,87,430	2 stage + genetic	OAE +AABR (Non mentioned DP/TE)	Not mentioned	Diagnostic ABR
Guomei et al.,2022	[48]	9 months	Newborns	2174	2 stage + genetic	OAE + OAE (Not mentioned DP/TE)	Not mentioned	Diagnostic ABR

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Table 1C: Hearing Screening Programs for newborns and infants in other Asian countries

Author and Year	Citation	Country	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Ahmad et al.,2011	[49]	Malaysia (MIC)	5 years	newborns	16000	3 stage	DPOAE +DPOAE + DPOAE	Technician, staff nurse, ward attendants	Diagnostic ABR
Wong et al.,2020	[50]	Malaysia (UMIC)	2 years	newborns	28432	1 and 2 stage	1 stage AABR 2 stage - DPOAE + AABR	Nurses	Diagnostic ABR
Tungvachirakul et al.,2011	[51]	Thailand (UMIC)	1 year 11 months	newborns	4043	2 stage	OAE+ OAE (Not mentioned DP/TE)	Not mentioned	ASSR
Poonual et al.,2016	[52]	Thailand (UMIC)	1 year 7 months	newborns	3120	2 stage	Automated TEOAE + Conventional TEOAE	Not mentioned	Diagnostic ABR
Poonual et al.,2017	[53]	Thailand (UMIC)	Not mentioned	newborns	3120	3 stage	COBRA HRR tool + TEOAE + AABR	Not mentioned	Not mentioned
Poonual et al., 2017b	[54]	Thailand (UMIC)	1 year	newborns	3120	2 stage	TEOAE+ AABR	Not mentioned	ABR at 3 and 8 months
Pitathawatchai et al.,2019	[55]	Thailand (UMIC)	1 year 7 months	newborns	6140	2 stage	TEOAE+TEOAE	Nurses	Not mentioned
Ray et al.,2021	[56]	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	[57]	Malaysia (UMIC)	10 years	newborns	50633	2 stage	TEOAE +AABR	Trained nurses and medical technologists	Diagnostic ABR
Shameem et al., 2022	[58]	Bangladesh (LMIC)	2 years	High risk newborns	426	2 stage	TEOAE + TEOAE	Not mentioned	Diagnostic ABR
Khaimook et al.,2022	[59]	Thailand (UMIC)	6 months	newborns	1696	2 stage	TEOAE + TEOAE	Trained Nurse & audiologist	Diagnostic ABR + Tympanometry

Table 1D: Hearing screening programs for newborns and infants in Turkey (UMIC)

Author and Year	Citation	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Tasci et al.,2010	[60]	14 months	newborns	16,975	3 steps	TEOAE+ TEOAE+ ABR	Audiology technician	Diagnostic ABR
Sennaroglu & Akmese, 2011	[61]	1 year	newborns	1840	2 stage	TEOAE	Audiologist or audiometrist	Diagnostic ABR;
Ulusoy et al.,2014	[62]	3 years	newborns	11575	3 stage	TEOAE+ AABR	2 audiometrists and 1 nurse	Diagnostic ABR, the level three center
Kemaloğlu et al., 2016	[63]	10 years	newborns	19436 (I/P)	3 stage	TEOAE+ TEOAE+	Audiology technicians and	Diagnostic ABR

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				2083 (O/P)		(TEOAE & AABR)	audiology students	
Yorulmaz et al., 2017	[64]	5 years	newborns	13693	3 stage	TEOAE+TEOAE+AABR	Audiometrist	Diagnostic ABR, Tympanometry, Acoustic reflexes, ASSR
Celik et al.,2016	[65]	6 years	newborns	142128	2 stage	TEOAE (twice same day)+ TEOAE	Not mentioned	Diagnostic ABR
Ozturk et al.,2017	[66]	2 years	newborns	7502	3 stage	Wellbabies: DPOAE+DPOAE+ABR screening Highrisk babies: Direct ABR	Audiologist	Diagnostic ABR
Hamdi, 2018	[67]	2 years	newborns	1808	3 stage	TEOAE+TEOAE+ABR screening	Nurses (Trained)	Diagnostic ABR
Yücel et al., 2019	[68]	2 years	newborns	786 syrian & 7230 turkish	3 stage	(TEOAE & Tymp) + TEOAE + ABR	Not mentioned	Detailed testing
Arslan et al., 2013	[69]	8 months	newborns	2229	2 stage	TEOAE+ TEOAE	Nurse	Diagnostic ABR
Çıkrıkçı et al., 2020	[70]	1.5 years	newborns	702 turkish 172 syrian	2 stage	AABR + AABR	Not mentioned	Diagnostic ABR

Table 1E: Hearing screening programs for newborns and infants in Iran (LMIC)

Author and Year	Citation	Years of program	Population screened	Number screened	Screening protocol	Screening test used	Screening personnel	Diagnostic test
Arjmandi et al., 2012	[71]	1 year	newborns	1232	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Islami et al.,2013	[72]	1.5 years	newborns	7250	2 stage	TEOAE+TEOAE	Audiologists	Diagnostic ABR
Firoozbakht et al.,2014	[73]	8 years	newborns	33,50,995	2 stage	TEOAE+AABR	audiologists, nurses, midwives and trained health technicians.	Comprehensive test
Zahed et al., 2014*	[74]	8 years	newborns	40930	2 stage	TEOAE+ABR	Audiologists	ABR/ASSR & immittance audiometry,
Farhat et al., 2014	[75]	2 years	newborns	8987	2 stage	TEOAE+TEOAE	Not mentioned	ASSR
Haghshenas et al., 2014	[76]	2 years	newborns	15,165	3 stage	OAE + OAE + (OAE & AABR) (Not mentioned DP/TE)	Audiologist	ABR screening
Baradaranfar et al., 2014	[77]	1 year	newborns	514	2 stage	TEOAE+TEOAE	Not mentioned	Diagnostic ABR
Azizi et al., 2016	[78]	1.5 years	newborns	3818	2 stage	TEOAE+TEOAE	not mentioned	ABR,
Tajik & Ahmadpour-Kacho, 2016	[79]	4 years	newborns	3362	2 stage	TEOAE + (TEOAE & ABR)	Not mentioned	Not mentioned
Saki et al.,2017	[80]	3 years	newborns	92,521	2 stage	1st & 2nd:TEOAE + AABR	Audiologists	Diagnostic OAE and ABR .
Rahimi et al.,2018	[81]	5 years	newborns	4729	3 stage	TEOAE + TEOAE + AABR	Audiologist	Diagnostic ABR

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Table 2 : Hearing screening programs for older children

Author and year	Citation	Country	Years of Program	Age of screening (years)	Number screened	Screening protocol	Screening test used	Pass/fail criteria	Screening personnel	Diagnostic test	Diagnostic person
Tuli et al.,2012	[82]	India	2 years	5 to 16	111	1 stage	Case history, Audiological & ENT evaluation, Awareness &SIFTER	Not mentioned	Not mentioned	ENT & PTA & Diagnostic ABR	Audiologist
Chadha et al., 2013	[83]	India	3 years	5 to 12	15718	1 stage	Otoscopy, Ten 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	[84]	India	2 years	Birth to 5 years	1335	2 stage	DPOAE +DPOAE	>SNR 3 dB	Trained Village Health Worker	Tele-Diagnostic ABR	Audiologist
Ramkumar et al.,2019	[85]	India	2 years	Birth to 5 years	2815	2 stage	DPOAE + DPOAE	>SNR 3 dB	Trained Village Health Worker	Diagnostic ABR – in person and Tele-diagnostic ABR	Audiologist
Verma et al.,2022	[86]	India	6 months	6 to 17 years	597	1 stage	Tuning fork test	Not mentioned	Not mentioned	PTA and Tympanometry	Audiologist
Shekhar et al., 2020	[87]	India	Not mentioned	5 to 14	474	1 stage	PTA	Not mentioned	ENT specialist	ENT examination	ENT specialist
Lu et al.,2011	[88]	China	1 year	3 to 6	21427	1 stage	PTA	1, 2 and 4KHz > 20dB	Screening person with training (training program with certificate)	PTA (5 to 6 years) VRA or Play PTA (3 to 4 years)	Not mentioned
Chen et al.,2013	[89]	China	1 year 5 months	3 to 6	28546	1 stage	TEOAE	>SNR 3 dB	School nurses & doctors 2 hours of training	Comprehensive test	Not mentioned Audiologist
Wu et al.,2014	[90]	China	Not mentioned	3 to 6	6288	1 stage	Software based new PTA	>30dBHL at 1,2,4KHz	Preschool teachers - minimally trained	Not mentioned	Not mentioned
Kam et al.,2014	[91]	China	Not mentioned	3 to 7	6231	1 stage	Automated PTA	>30dBHL at 1,2 and 4KHz	Automatic test - Nurses with 2 hours training as facilitator	Tympanometry, DPOAE & PTA (0.25 to 8KHz)	Not mentioned

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Tokgöz-Yılmaz et al.,2013	[92]	Turkey	3 years	3 to 5	239	1 stage	PTA	Not mentioned	Audiologist and SLP	ENT examination	ENT specialist
Kaplama et al.,2020	[93]	Turkey	1 year	69 to 84 months	23664	2 stage	PTA, Ten questionnaire	500, 1000, 2000 and 4000Hz > 20dB Ten question - Refer in 1 question	Certified nurses, midwives, health officers or audiometrists,	ENT examination	ENT specialist
TarviEslami et al.,2017	[94]	Iran	1 year	6 to 7	2237	Not mentioned	PTA	Not mentioned	Not mentioned	PTA, Weber, Rinne test	Not mentioned
Jalali et al.,2020	[95]	Iran	4 months	6 to 13	2019	1 stage	PTA	0.5KHz to 4KHz >15dBHL	Not mentioned	ENT examination & comprehensive audiological examination	Not mentioned
Pilka et al.,2016	[8]	Tajikistan (LMIC)	Not mentioned	6 to 8	143	1 stage	Questionnaire, PTA using SZOK telemed model	PTA module (500 to 8KHz) >25dB at one frequency,	Medical doctors Other specialists	Detailed PTA	Audiologists
Alaqrabawi et al.,2016	[96]	Jordan (UMIC)	4 years	5 to 15	1649	1 stage	PTA	500Hz, 1KHz, 2KHz & 4KHz > 25dB	Not mentioned	Audiometry Otoscopy Tympanometry	Audiologists
Al-Obeidy et al.,2019	[97]	Iraq (UMIC)	1 year	6	425	1 stage	HR Questionnaire	Not mentioned	Not mentioned	ENT examination, TFT (Weber, Rinne and Absolute bone conductio). HRR children: PTA	Not mentioned

Abbrevations: PTA: Pure Tone Audiometry; ABR-Auditory Brainstem Response; DPOAE-Distortion Product OtoAcoustic Emissions; TEOAE-Transient Evoked Oto Acoustic Emissions; TFT-Tuning Fork Test; HRR-High Risk Register; SNR-Signal to Noise Ratio; SIFTER: Screening Identification For Targeting Educational Risk; Tymp-Tympanometry; UMIC: Upper Middle Income Country; LMIC: Lower Middle Income Country

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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 5-step hearing screening protocol.

Sixteen studies that reported a two-stage hearing screening protocol, employed otoacoustic emission (OAE) (TE/DP-OAE) or Automated Auditory Brainstem Response (AABR) as screening tests (individually or combined in either stage[22,24,32,42-47,50,53,57,73,74,79]. Other twenty five studies used only OAEs (DP/TE) [19,26,34-37,40,51,55,56,58,59,61,65,69,71,72,78] or AABR screening [23,70] for testing in both stages. Those studies that reported the use of AABR in the initial stage of screening either employed AABR solely for both stages [23] or a combination of AABR and OAE to screen only high-risk newborns [41,42]. Four studies from China used 2 stage screening coupled with genetic hearing screening [43-45,47,48].

When a three-stage protocol was used, generally the first two stages included OAE (DP/TE) screening followed by AABR/ABR screening [25,60,62-64,66,67,76,81] or included OAE(DP/TE) for all three stages [21,49]. Only one study reported combining tympanometry and TEOAE in the initial stage of its three-stage screening protocol [68]. Studies from Turkey (n=7) reported three-stage screening protocol [60,62-64,66-68].

Screening for older children

Fourteen studies for older children employed a single stage screening protocol [8,82,83,87,88,90-92,95-97] with three employing a two stage protocol [85,3]. Ten studies reported using subjective hearing screening tests, two studies used questionnaire or otoscopy for screening [83,97] and another three studies used TEOAE [84,85]. Pure tone audiometry was the most commonly used subjective test for screening older children [87,88,92,94-96]; Two studies reported the use of automated software based PTA [90,91]. Pure tone audiometry was combined with questionnaires [8,93] or otoscopy [83,97]. Only one study reported the use of TEOAE screening [89].

Pass/ refer criteria

In several programs 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 and 6 dB SNR [18,21,25,30,32,37,40,42,47,49,55,59,63,65,78] and for AABR it varied between 30 dB nHL, 35 dB nHL and 40 dB nHL [41,42,62,64,76]. Predominantly, refer results in one ear was considered for follow-up screening.

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For screening older children, the pass criteria for pure tone audiometry ranged from 15dB HL to 30dB HL. All studies used the four frequencies 0.5KHz to 4KHz for pure tone testing. In questionnaire-based studies, failing one item or a family history of hearing loss were the referral criteria [83,87].

Screening personnel:

Audiologists were the primary screening personnel in many newborn and infant programs [22,25,34,39,40,61,66,72,74,76,80,81]; followed by nurses [25,37,42,43,49,50,55,57,59,62,67,69,73]. In five studies, the training provided for nurses to perform hearing screening was also briefly mentioned [55,57,67,69,73]. including some certifications [62]. Other than nurses, some studies reported audiometrists [61,62,64] and audiologist technicians [60] as personnel involved in screening. Other non-specialists that were engaged in hearing screening were technicians [49], ward attendants [49], trained health workers [20,73] social workers [39] and midwives [18,26,73]. In a few programmes, otolaryngologists [21] performed the hearing screening. 29 out of 59 studies did not provide any information regarding the screening individual.

Screening for older children was conducted by otorhinolaryngologists [8,83,87] audiologists [92], and audiometrists [93]. Other non-specialists involved in the hearing screening included trained nurses/midwives [40,91,93], trained village health workers or volunteers [84,85] and school teachers with training [90].

Studies have reported a variety of training programmes. They included hearing screening certification [83,93]; 2 hours of TEOAE training [40]; TEOAE training and tele-diagnostic testing facilitation [85]; and minimal training/2 hours of training for facilitating automated PTA [90,91].

Confirmation of hearing loss:

Diagnostic Auditory Brainstem Response (ABR) was the only testing carried out to confirm the hearing loss in studies in newborns and infants [19,21,25,27,29,31,33,35-37,47,57,58]. Comprehensive test battery including the diagnostic BERA, OAE, and tympanometry was mentioned only in eleven studies [42,64,73]. Four studies also reported the inclusion of the Auditory Steady State Response (ASSR) in the test battery [64,74].

Two programs utilized solely ASSR [51,75] and studies also used ABR screening at 30 dB nHL [42] or 35 dB nHL [76] for hearing loss diagnosis.

However, 11 of the 65 programs 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 eighteen 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.

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In studies reporting screening for older children, a test battery approach was used in 3 studies where they included PTA with tympanometry and DPOAE [91] or PTA with otoscopy and tympanometry [96] or PTA and detailed ABR [82]. Two studies reported the use of comprehensive test battery, but did not mention the tests included [40].

Puretone audiometry (PTA) was frequently included in the diagnostic test battery [86,91,96], but in three studies PTA was the only diagnostic test used [8,94,95]. Of the studies that reported the use of PTA for diagnosis, only four studies [92,94,95,96] mentioned information related to bone conduction testing. . Apart from these studies, ENT examination was included in five studies [87,92,93,95,97]. The diagnostic testing sites included a hospital [95], a school [87], a speech and hearing centre [91], and a telemedicine platform [8,85].

Utilization of ICT

In studies related to newborn and infant hearing screening, three programs reported the use of ICT for storing and forwarding results [34], database management [39,57], and sending reminders for follow-up screening.

In studies reporting screening of older children, five studies reported using telepractice for screening, diagnosis, or both. Tele-diagnostic ABR [84,85] was reported in India. use of m-health-based automated hearing screening was reported in China by Wu et al. (2013) and Kam et al. (2014) a tele- sensory screening platform including hearing screening (SZOK paradigm) in Tajikistan, where both screening and diagnosis were carried out via telemedicine [8].

Validity and efficacy of the screening programs:

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

Among the studies that reported newborn and infant hearing screening, 48 studies fulfilled all 3 criteria of the validity tool; Eleven studies fulfilled 2 out of 3 criteria; Six studies fulfilled 1 out of 3 criteria (Figure 2A). Validated screening tool was used by sixty three studies and fifty four studies used a validated diagnostic tool. As per the criteria we used, fifty five studies could be classified to be in the implementation phase and ten studies were in design phase.

Economic analysis, frequency of identification and intervention were the 3 criteria included to assess efficacy. Only two studies fulfilled all the three efficacy criteria, seventeen studies fulfilled two out of the three criteria, thirty seven studies fulfilled only one of the three criteria, whereas remaining nine studies did not fulfil any of the criteria. Fifty one studies only reported the frequency of identification, whereas fourteen reported both the

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frequency of identification and intervention. Twelve percent of the studies did not mention either of these outcomes. Economic analysis was very limited (n=3) and were reported majorly in public programs.

Among the studies that reported screening programs for older children, ten studies fulfilled all the three criteria, three studies fulfilled two out of three criteria, three studies fulfilled one out of three criteria. Only one study did not meet any of the criteria [83] a questionnaire and an otoscopic examination 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 twelve studies fulfilled only one criterion.

Fourteen studies have reported frequency of identification , but only five studies have reported the frequency of intervention (e.g. medical intervention for conductive pathology). The intervention related screening programs were reported from India, China and Turkey. The economic analysis was only reported in two studies [84,91]. Except for the economic analysis, only two of the 17 studies fulfilled all validity and efficacy criteria [85,88].

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 3 (A to E) shows the forest plots for prevalence of each country.

In screening programs for older children, 11 studies reported number of cases with hearing loss including conductive and sensori neural hearing losses. However, in four studies [83,87,89,93] the specific audiological tests conducted to diagnose was not mentioned, and in seven studies [88,92,94-97] details of diagnostic audiometry was provided. In this age group, the percentage of conductive hearing loss reported was higher compared to sensori neural hearing loss across all the studies. In two studies, the type of loss was not differentiated [8,83]. The percentage of children identified with a certain type of hearing loss was calculated based on the information on number of children s diagnosed was providedin each of the studies . The study outcomes are reported in Table 3.

Table 3: Secondary outcomes: Studies reporting number of cases identified with conductive/sensorineural hearing loss in older children in each country

Country	Author and year	Number screened	Number of CDHL identified	% of CDHL	Number of SNHL identified	% of SNHL	Overall number of HL identified	% of HL	LB (CI: 95%)	UB (CI: 95%)
India	Chadha et al.,2013	15718	NA	NA	NA	NA	1578	10.30%	9.57%	10.52%
	Shekhar et al.,	474	146	30.80%	1	0.21%	147	31.01%	26.87%	35.39%

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	2020									
	Tokgöz-Yılmaz et al.,2013	239	25	10.46%	1	0.42%	26	10.88%	7.23%	15.53%
Turkey	Kaplama et al.,2020	23664	186	0.79%	89	0.37%	275	1.16%	1.03%	1.31%
	TarvijEslami et al.,2017	2284	28	1.23%	8	0.35%	36	1.58%	1.11%	2.18%
Iran	Jalali et al.,2020	2019	19	0.94%	8	0.39%	27	1.33%	0.88%	1.94%
Tajikistan	Pilka et al.,2016	143	NA	NA	NA	NA	34	23.70%	17.06%	31.61%
Jordan	Alaqrabawi et al.,2016	1649	54	3.27%	36	2.18%	90	5.45%	4.41%	6.61%
Iraq	Al-Obeidy et al.,2019	425	28	6.59%	2	0.47%	30	7.06%	4.81%	9.92%
	Lu et al.,2011	21547	285	1.32%	16	0.07%	301	1.39%	1.24%	1.56%
China	Chen et al 2012	28546	344	1.21%	22	0.08%	366	1.29%	1.15%	1.42%

Abbreviations: CDHL: Conductive Hearing Loss; SNHL: Sensori Neural Hearing Loss; HL: Hearing Loss; LB: Lower Bound; UB: Upper Bound

Barriers and facilitators:

Barriers:

Loss to follow-up for second screening and diagnostics [18,25,29,35-37,42,55,59,62,66,72,73] was reported as a major challenge. Loss to follow up was linked to parental rejection for diagnosis [23,26,59], poor tracking system [42,73], financial burden of parents, low socioeconomic status [70] and travel distance to testing distance. Other major challenges highlighted in relation to outcomes included limited coverage [30,35], and a high referral rate [24,25,37], poor long-term outcomes with respect to coverage and referral rate [46].

Other factors that had an indirect impact on programme outcomes included the lack of dedicated screening personnel [23]; lack of professional resources/audiologists [73,80]; high ambient noise in the testing environment [30]; and the absence of diagnostic facilities [62]. A few studies mentioned challenges affecting programme implementation, such as the use of a three-step protocol only with OAE [60]; the difficulties of centralised programme implementation in remote locations [73] and delay in diagnosis in remote locations due to referral to regional facilities [80].

In screening for older children, children's attention was regarded as a major challenge resulting in poor accuracy [91]. Other key factors influencing programme outcomes included inadequate internet connectivity [8,85]; poor follow-up due to social stigma.

Facilitators:

Use of appropriate tracking or data management systems, were reported to be helpful in minimising lost-to-follow-up [18,26,35,42,57]. Combining hearing screening with other screenings improved follow-up rates

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[47,81]. Several studies highlighted strategies to minimise false referral rates, including: i) employing a conducive environment and trained individuals [25]; ii) adding AABR in the initial stage of screening protocol [41]; screening between 3 and 5 days of age [81]; and incorporating tympanometry into the screening protocol [33]. Financial assistance in the form of funding [37,39,57]; and centralised hearing screening facilities or grouping more centres [18,26] were strategies reported in studies to improve coverage rates. Multi-centre based or a centralised hearing screening program was reported to be resource efficient with respect to cost, infrastructure and professionals [18].

DISCUSSION

The primary purpose of this review was to describe the models of hearing screening programmes implemented in young children in various Asian LICs and 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 61L&MICs in Asia, only 14 countries reported hearing screening programs that fit our inclusion criteria. In a recent systematic review, high quality literature with hearing screening programs was reported to be primarily in high income countries [98], yet, it is also likely that resources for research and publication is low and hence is also low on priority in the L&MICs context. Though studies from both LICs and MICs were included, our results shows that most of the studies reporting on hearing screening were from the MICs, 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 utilised for newborns, infants, and older children were similar to those used in high-income countries [99]. 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. (2018)'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 [20] found good sensitivity and specificity for behavioural hearing assessment for neonates and infants using calibrated noise makers. The use of objective screening in LICs and MICsimplies 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 three. This is comparable to high-income countries where

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PTA screening is mandatory for children over the age of three [100,101]. In contrast, the current review found a few public initiatives [29,54,97] 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 LICs and MICs. This is in contrast to HICs, where nurses mostly performed hearing screening [102]. While the majority of NHS programmes in Asian LICs and 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 high income countries [102].

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 [103]. Therefore, in HICs the diagnostic test battery approach is mostly preferred [102]. 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 [103] and with the programs from high income countries [102] It is important to note that PTA is a crucial test to differentiate CDHL and SNHL. However information on bone conduction testing was was limited.

Few studies reported the use of ICT to screen, manage data or perform diagnostic tests [8,85]. Lack of utilization of ICT could be due to lack of adequate infrastructure, skills to support use of such tools. Yet, this is not unique to LICs and MICsas evidence on use of ICT is limited even among high income countries [98,99,102,104].

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 [105]. Furthermore, studies predominantly only reported identification but not intervention. The importance of EHDI programs is to intervene children so that the

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pervasive impact of childhood hearing loss can be mitigated [106,107], 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 (6/1000), followed by Iran (3/1000) and China (2/1000). This is similar to the findings of Busse 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 to other regions [104]. A world report on hearing (WHO, 2021) also stated that prevalence of congenital hearing loss in LICs and MICs is high compared to HICs.

Barriers identified from our review were similar to those previously identified and discussed in various studies including LICs and MICs [102,106,107,109]. 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 LICs and MICsis 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&MICswere similar to those recommended in HICs. However, there is inadequate evidence related to the intended outcome of early intervention in this context. Therefore, program planners and researchers must focus on impact evaluations that demonstrate the long term viability of EHDI programs in the L&MICscontext.

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FIGURES

Figure 1: PRISMA flowchart representing the selection of article at each stage

Figure 2: a) Validity and efficacy of screening programs for newborns and infants; b) Validity and efficacy of screening programs for older children

Figure 3: a) Forest plot of prevalence of hearing loss in newborns and infants in India; b) Forest plot of prevalence of hearing loss in newborns and infants in China ; c) Forest plot of prevalence of hearing loss in newborns and infants in Turkey; d) Forest plot of prevalence of hearing loss in newborns and infants in Iran; e) Forest plot of prevalence of hearing loss in newborns and infants in other Asian countries (Thailand, Malaysia, Nepal)

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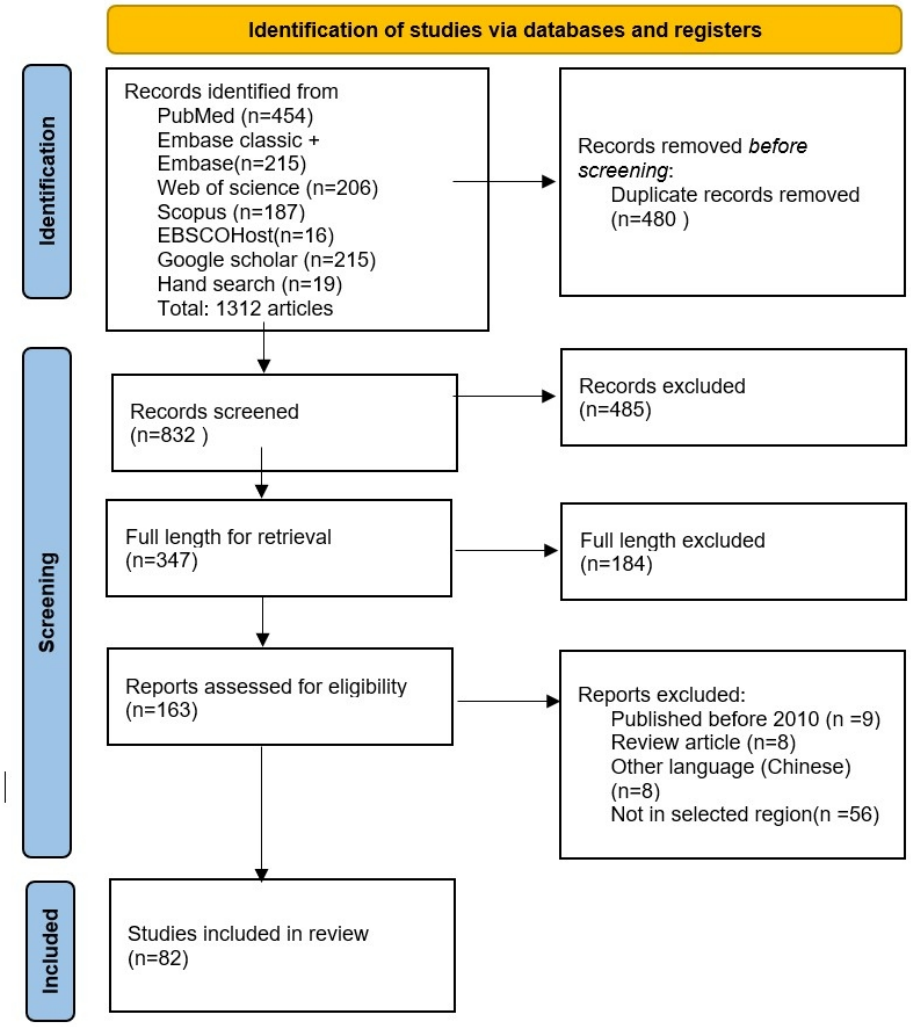

Mono Figure 1: PRISMA Flowchart representing selection of studies at different levels of screening

72x75mm (300 x 300 DPI)

a

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						
Çekiriçi 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, 20	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						
Khamnok 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.,2018	Tajikistan						
Alaqrabawi et al.,2016	Jordon						
Al-Obaidy et al.,2019	Iraq						
Wu et al.,2013	China						
Kain et al.,2014	China						
Ramkumar et al.,2018	India						
Ramkumar et al.,2019	India						
Key		Met criteria					
		Not met criteria					

Figure 2: a) Validity and efficacy of screening programs for newborns and infants; b) Validity and efficacy of screening programs for older children

296x575mm (300 x 300 DPI)

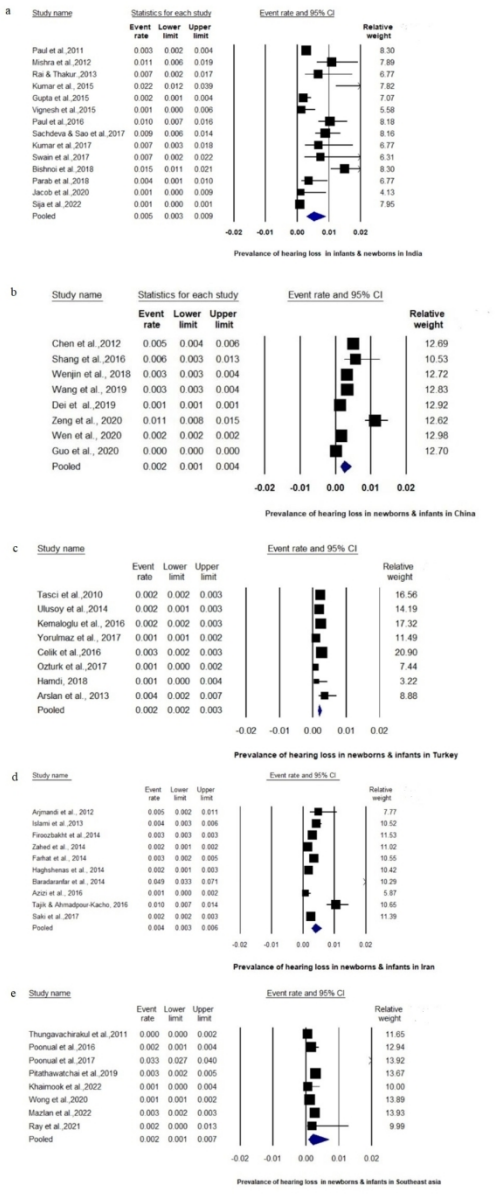

Figure 3: a) Forest plot of prevalence of hearing loss in newborns and infants in India; b) Forest plot of prevalence of hearing loss in newborns and infants in China ; c) Forest plot of prevalence of hearing loss in newborns and infants in Turkey; d) Forest plot of prevalence of hearing loss in newborns and infants in Iran; e) Forest plot of prevalence of hearing loss in newborns and infants in other Asian countries (Thailand, Malaysia, Nepal)

89x194mm (300 x 300 DPI)

Supplementary table 1A: Quality appraisal for cross sectional studies using JBI tool for cross sectional studies

Author and Year	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Biswas et al., 2012	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Paul et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Mishra et al., 2013	Yes	Yes	NA	Yes	No	NA	Yes	No
Ramesh et al., 2012	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Kumar et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Gupta et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Vignesh et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Vishwakarma et al.,2015	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Paul et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	NA
Sharma et al., 2018	No	Yes	NA	Yes	No	Na	Yes	Yes
Kumar et al.,2016*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Sachdeva & Sao et al.,2017	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Swain et al.,2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Bhat et al.,2018	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Bishnoi et al.,2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes

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Parab et al.,2018 *	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Jacob et al.,2020	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Nishad et al.,2020	Yes	Yes	NA	Yes	No	No	Yes	Yes
Zhang et al., 2012	Yes	Yes	NA	Yes	No	No	No	Yes
Tobe et al.,2013*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Chen et al.,2012	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Shang et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	YEs
Wenjin et al., 2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Dai et al.,2019	Yes	YEs	NA	Yes	No	NA	Yes	Yes
Zeng et al., 2020	Yes	Yes	Yes	Yes	NA	NA	Yes	Yes
Wen et al., 2020 *	Yes	Yes	NA	yes	No	NA	Yes	Yes
Guo et al., 2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Guomei et al.,2022	Yes	Yes	NA	Yes	No	NA	No	Yes
Ahmad et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Wong et al.,2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Tungvachirakul et al.,2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Poonual et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Poonual et al., 2017b	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Pitathawatchai et al.,2019	Yes	Yes	Yes	Yes	No	Na	Yes	Yes
Ray et al.,2021	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Mazlan et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes

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Shameem et al., 2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Khaimook et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Sennaroglu & Akmese, 2011	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Ulusoy et al.,2014	yes	Yes	NA	Yes	No	NA	Yes	Yes
Kemaloğlu et al., 2016	Yes	Yes	NA	Yes	No	No	Yes	Yes
Yorulmaz et al., 2017	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Ozturk et al.,2017	Yes	Yes	NA	Yes	No	No	Yes	Yes
Hamdi, 2018	Yes	Yes	NA	Yes	No	No	Yes	Yes
Yücel et al., 2019	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Arslan et al., 2013	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Çıkrıkçı et al., 2020*	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Arjmandi et al., 2012	Yes	Yes	No	Yes	No	NA	Yes	Yes
Islami et al.,2013	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Firoozbakht et al.,2014	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Zahed et al., 2014*	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Farhat et al., 2014	Yes	Yes	No	Yes	No	NA	Yes	Yes
Haghshenas et al., 2014	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Baradaranfar et al., 2014	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Azizi et al., 2016	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Tajik & Ahmadpour-Kacho, 2016	Yes	Yes	NA	Yes	No	NA	Yes	YEs
Saki et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes

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Tuli et al.,2012	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Chadha et al., 2013	Yes	Yes	NA	No	Yes	Yes	Yes	Yes
Ramkumar et al.,2018	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Ramkumar et al.,2019	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Verma et al.,2022	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Shekhar et al., 2020	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Lu et al.,2011	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Chen et al.,2013	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Wu et al.,2014	Yes	Yes	NA	No	No	NA	Yes	Yes
Kam et al.,2014	Yes	YEs	NA	Yes	NA	NA	YES	YES
Tokgöz-Yılmaz et al.,2013	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Kaplama et al.,2020	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
TarviEslami et al.,2017	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Jalali et al.,2020	Yes	Yes	Yes	No	No	NA	Yes	Yes
Pilka et al.,2016	No	Yes	NA	Yes	No	NA	Yes	Yes
Alaqrabawi et al.,2016	Yes	Yes	NA	Yes	No	NA	Yes	Yes
Al-Obeidy et al.,2019	No	Yes	NA	No	No	NA	Yes	Yes

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Supplementary table 1B: Quality appraisal for cohort studies using JBI tool for cohort study

Author & year	Were the two groups similar and recruited from the same population?	Were the exposures measured similarly to assign people to both exposed and unexposed groups?	Was the exposure measured in a valid and reliable way?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	Were the outcomes measured in a valid and reliable way?	Was the follow up time reported and sufficient to be long enough for outcomes to occur?	Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	Were strategies to address incomplete follow up utilized?	Was appropriate statistical analysis used?
Poonual et al.,2016	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	No	Yes
Sija et al.,2022	Yes	Yes	NA	No	NA	Yes	Yes	Yes	Yes	No	Yes
Rahimi et al.,2018	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	No	No	Yes
Celik et al.,2016	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Tasci et al.,2010	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes
Wang et al., 2019	Yes	Yes	Yes	No	NA	Yes	yes	Yes	Yes	Yes	Yes
Kumar et al.,2017	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes
Rai & Thakur 2013	Yes	Yes	Yes	No	NA	Yes	Yes	Yes	Yes	Yes	Yes

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