Chapter 4

Hearing Screening

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'A healthy start leads to a healthy life'

~Ontario Newborn Screening Program

Introduction

Childhood hearing screening programmes can be grouped into three categories: 1) newborn screening, 2) early childhood development screening and 3) school-based screening. These hearing screening services can be provided through nationalised programmes or via targeted and at-risk based approaches.

Successful Newborn Hearing Screening (NBHS) and Early Hearing Detection and Intervention (EHDI) programmes have been implemented in several countries using a variety of screening methods and protocols. It is estimated that nearly one-third of the world's population, primarily in high-income regions, are fully or nearly fully covered by these programmes (WHO, 2021b). These initiatives have been instrumental in the early detection of congenital hearing loss (HL), reducing the average age of diagnosis from 24 to 30 months, to two to three months in high income countries (Harrison, Roush and Wallace 2003).

Despite the increase of NBHS coverage, approximately 36% of children who refer out on a hearing screening do not receive appropriate follow-up care, with this proportion rising to nearly 50% among higher-risk, urban and underserved populations (Harrison, Roush and Wallace 2003). In low- to middle-income countries (LMICs), the lack of relevant policies or

their implementation as well as the lack of human and financial resources and equipment, limited awareness and the associated stigma of HL make the implementation of NBHS challenging (WHO, 2021b).

By the time children reach school age, the prevalence of HL increases, particularly in areas where ear infections and other risk factors are widespread (Refer to Chapter 2 for more information on risk factors for HL). Furthermore, recent trends suggest that the global increase in childhood HL is partly due to rising levels of environmental noise and the use of digital recreational devices which expose children to potentially harmful noise levels at an early age (WHO 2023). These factors emphasise the need for robust and accessible hearing screening programmes, particularly to identify and address HL and reduce the effects it will have on speech, language and cognitive development. This chapter will describe the components of newborn, early childhood and school-based hearing screening and how these screenings can be practically implemented.

Types of Childhood Hearing Screening Initiatives

Hearing screening was conceptionalised in 1957 and by the end of the 20th century NBHS became the industry standard globally (Fisch 1957; WHO 2013). NBHS can be implemented in all facilities where babies are born and/or receive follow-up care. The primary purpose of NBHS is to identify infants who have HL and need further diagnostic testing. In addition, NBHS aims to identify infants with medical conditions that may cause late-onset or progressive HL and to implement a plan for the continued monitoring of their hearing across various phases of childhood development (JCIH 2019). NBHS is still the most effective way to reduce the prevalence and combat the impact of childhood HL (JCIH 2019; WHO 2021a). The lack of NBHS puts children at risk of impaired or limited language development during the prime language acquisition period, and can also lead to associated social, emotional and academic challenges in later life (WHO 2023; Yoshinaga-Itano et al. 2018).

Early childhood hearing screening can be conducted in various settings, including at general practitioners and paediatric consultations, early childhood development centres, well-infant nurseries or healthcare clinics. According to the Joint Committee of Infant Hearing (2019), a paediatrician or another primary health care professional is responsible for monitoring the general health, development and well-being of a child. Hearing screening in these instances is usually conducted using parental questionnaires, observations of the child's ear canal and tympanic membrane using otoscopy and/or tympanometry, or behavioural observations of the child's response to sound (for example, bell-ringing or hand clapping) (Eiserman et al. 2008). While parental concerns are important, studies have shown that parental questionnaires

are often not accurate indicators of childhood HL (Olusanya 2001). Additionally, although otoscopy and tympanometry can help identify anatomical impairments and middle ear disorders, they are not always available in under-resourced areas and do not assess cochlear or auditory nerve functioning. Informal behavioural observations of a child's response to sound are also unreliable for assessing HL in young children (Eiserman et al. 2008). These subjective techniques have shown poor sensitivity for detecting mild and moderate HL and have low specificity, making them unreliable for screening purposes (Downs and Sterritt 1967; Northern and Downs 2002). The effectiveness of early childhood hearing screenings during wellness visits is further compromised by the fact that a significant proportion of children, particularly in lower-resourced countries, do not attend these visits regularly. Therefore, this more informal method of hearing screening should not primarily be relied upon.

School-based hearing screening programmes aim to evaluate the hearing status of children at various educational levels, typically during school entry and at regular intervals thereafter. School (and pre-school) settings present a unique opportunity to conduct universal hearing screening among children, as most children attend school worldwide (Mahomed-Asmail, Swanepoel and Eikelboom 2016). It also provides an opportunity to educate children and teachers about healthy hearing and safe listening practices (WHO 2021a). In countries like South Africa, where there are disparities in access to healthcare services, implementing school-based hearing screening can help bridge the gap for children who may have missed out on early detection and intervention due to socio-economic barriers (Mahomed-Asmail, Swanepoel and Eikelboom 2016). However, it is essential to note that school-based screening cannot replace early detection through NBHS.

While some countries have national NBHS and early childhood hearing screening programmes (Bussé et al. 2021), resource-constrained settings often rely on targeted or risk-based screening due to limited equipment, shortages of trained personnel and broader infrastructural challenges (WHO, 2021a). Targeted approaches prioritise the identification of children of any age who are at increased risk of HL due to factors such as a family history of HL, neonatal intensive care unit (NICU) admission, congenital infections (for example, cytomegalovirus), craniofacial anomalies, syndromes associated with HL, parental concerns and/or exposure to ototoxic medications (see Chapter 2). By concentrating efforts on higher-risk populations, a targeted approach allows for more efficient use of available resources while maximising the likelihood of early detection. Using risk-based approaches can help prevent HL from progressing by allowing earlier interventions, ultimately improving long-term outcomes for children with identified risk factors.

Establishing a Hearing Screening Programme

Whether hearing screenings are conducted as part of NBHS, in early childhood at Early Communication Development (ECD) centres, during home visits or at school age, there are several considerations to ensure their effectiveness. By following a structured approach, programmes can effectively facilitate early identification and intervention for children with HL (JCIH 2019).

a) Collaboration and quality control

Successful hearing screening programmes require collaboration and quality control measures:

1. Collaboration: Facilitate co-operation between public and private institutions, healthcare agencies and individuals involved in the screening, evaluation and intervention processes (JCIH 2019; WHO 2021a).

2. Advisory board formation: Establish an advisory board to support the planning, execution and evaluation of the programme, adapting roles to local needs and resources.

3. Quality control and continuous improvement: Implement processes to maintain and improve the programme's effectiveness through regular quality checks and updates.

4. Identification of care pathways and follow-up mechanisms: Ensure availability of diagnostic audiology and otology services (including medical and surgical services), hearing technology and rehabilitation.

5. Technology: Evaluate the types, availability and validity of screening devices such as OAE, AABR, immittance and pure tone audiometry equipment. These devices should be regularly calibrated and maintained to ensure accuracy and reliability.

6. Availability of personnel: Train and select screeners based on the service delivery setting, including community health workers (CHWs), ECD practitioners, and paraprofessionals.

7. Timing of screening: In a hospital setting, schedule screenings before the infant is discharged to ensure that the necessary follow-up visits can be planned. In community-based settings, schedule screenings during postnatal visits at Midwife Obstetric Units (MOUs) or during the first immunisation visit at six weeks. In the school setting, screen children at preschool/kindergarten, upon school entry and again where possible in grades one, two, three, seven and eleven.

8. Environments: Ensure that screening environments are quiet and free from visual distractions to prevent interference and to ensure accurate results.

9. Follow-up referral criteria: Set clear guidelines for referring children who do not pass the initial hearing screening for further diagnostic evaluations.

10. Information management: Develop a system for recording and managing screening data to ensure accurate tracking and follow-up. (Appendix 4.1 is an example of a screening form.)

b) Reporting and communication protocols
Effective communication and reporting protocols are crucial.

1. Reports: Provide clear, detailed and timely reports on screening results to both physicians and families.

2. Documentation in medical records: Accurately document results in electronic or paper-based medical records.

3. Reporting of results: Ensure results are reported to the appropriate health authorities and databases.

4. Confidential and culturally sensitive communication: Communicate results to families in a manner that respects their cultural backgrounds and is easy to understand.

5. Referral pathways: Identify and define referral pathways to ensure that infants who do not pass screenings have access to appropriate follow-up care either by an audiologist (for diagnostic audiology services), ear-nose- and throat (ENT) specialist or general practitioner.

Audiologists' role in hearing screening programmes

Audiologists play a crucial role in every stage of a hearing screening programme, from planning and implementation to evaluation and follow-up. Their involvement is essential not only at the local level, such as individual hospitals or community clinics, but also at broader levels, including statewide or national initiatives (Mahomed-Asmail, Swanepoel and Eikelboom 2016). Ideally, audiologists guide the clinical and technical aspects of these programmes, ensuring that protocols are meticulously followed and that best practices are upheld.

According to JCIH (2019), during follow-up visits, audiologists should provide comprehensive diagnostic assessments to confirm the presence and degree of HL. They support parents and caregivers in understanding the significance of HL, guiding them through the next steps with empathy and clarity (Chapter 15). Audiologists also evaluate whether the child is a candidate for amplification devices or other sensory and assistive technologies and oversee the fitting and monitoring of amplification devices (Chapters 10 and 11). Their multifaceted involvement in all aspects of hearing screening and intervention ensures that children with HL receive comprehensive, coordinated care, which is tailored to their unique needs and circumstances.

Screening personnel

Personnel should be assigned in accordance with the setting and available resources for the hearing screening programme. The screening personnel may include healthcare professionals (audiologists, speech-language pathologists, ENT specialists, general practitioners), CHWs, ECD practitioners and paraprofessionals (nurses, medical assistants, technicians). Utilising paraprofessionals, CHW and ECD practitioners from the community can enhance the programme by matching the linguistic and cultural diversity of the population, as well as by fostering trust and better communication during the screening process. All screeners should receive comprehensive training in hearing screening methods and referral pathways which must be supplemented with regular monitoring, quality control and ongoing professional development (WHO 2023). Additionally, they should learn the operational aspects of the hearing screening programme, including reporting processes, the specific role of the screener, screening and referral methods, and setting up screening rooms and calibrating equipment properly. They should also be made aware of the use and maintenance of equipment, troubleshooting issues and background noise measurements. Techniques like otoscopy and tympanometry (when available) should also be included so that personnel are fully prepared for their roles. An audiologist or another qualified individual should facilitate this training and monitoring to ensure that high standards are maintained, by utilising existing

resources such as the WHO (2023) training manuals, available here: *https://www.who.int/teams/noncommunicable-diseases/sensory-functions-disability-and-rehabilitation/primary-ear-and-hearing-care-training-manual*.

Setting up Screening Equipment

When setting up to administer hearing screening, routine checks of the equipment are vital to ascertain that the equipment is in working order, that calibration has not noticeably changed, and that attachments, leads and accessories are not defective. A daily listening check should be performed by the screener to rule out distortion and crosstalk and to ensure that there are no defects in major components. It is recommended that the equipment is calibrated at least once a year according to international and national standards (for example, ISO 389-1).

A quiet location should be identified within the hospital or on school or community premises and noise levels should be checked beforehand. Noise levels during hearing screening should not exceed the maximum permissible ambient noise levels (MPANLs) prescribed for the selected tool/headphones. The MPANLs when using TDH39, according to ISO 389-1:1998, are available in Table 4.1 Noise levels can be checked using a sound level meter if available, or by using validated phone applications for noise level measurement (American Academy of Audiology 2011). Examples of phone applications include SLA Lite (iOS), Sound Meter and Noise Detector (Android). If mHealth tools are used for hearing screenings they usually have a built-in noise monitoring system (Swanepoel et al. 2014). Moreover, screening should be paused during transient increases in ambient noise. Ambient noise may occur as a result of ventilation, activity in an adjacent hall or classroom, children moving around in the test room and screening personnel giving instructions. These factors contribute to inaccurate screening and may result in false-positive results. In situations where sound meters are not available, although not ideal, a biologic noise level check can be done by screening personnel, which includes the ability to establish hearing thresholds at least 10 dB HL below the screening level (for example, 15 dB HL for screening conducted at 25 dB HL) at all test frequencies prior to testing. Furthermore, the environment should have minimal visual distractions.

Table 4.1: Maximum permissible ambient noise levels (MPANLs) for TDH 39 headphones in dB SPL according to ISO 389-1: (1998)

Screen intensity	1 kHz	2 kHz	4 kHz
20 dB HL	31.0	37.0	49.7
25 dB HL	36.0	42	54.7

Newborn Hearing Screening (NBHS)

Despite published guidelines from various healthcare bodies in lower-resourced countries (for example, the Health Professions Council of South Africa [2018]) on the importance of EHDI, there is often no standardised implementation of NBHS. Although there is growing awareness of the need for NBHS, clear legislation mandating it is still not fully in effect (de Kock et al. 2016).

The primary goal of EHDI is to make sure that all infants with HL are identified as early as possible and receive timely intervention to optimise speech, language and cognitive outcomes. To guide this approach, the JCIH (2019) established the 1-3-6 rule which outlines three critical and time-sensitive steps: hearing screening by one month of age, a confirmed audiological diagnosis by three months of age, and initiation or appropriate hearing intervention by six months of age. This timeline is based on extensive evidence demonstrating that infants who receive intervention before six months have significantly better language development than those identified later (Yoshinaga-Itano et al. 2018). Consequently, the 1-3-6 rule has become an internationally recognised benchmark for effective infant hearing screening (WHO 2021a; JCIH 2019).

In high-income countries with well-established EHDI programmes, the JCIH now recommends striving towards an even more accelerated 1-2-3 timeline to maximise developmental outcomes (JCIH, 2019). However, in many LMICs, meeting these targets is challenging due to limited equipment, shortages of trained personnel, infrastructure constraints and barriers to follow-up care (WHO, 2021b). As a result, while the 1-3-6 framework remains the global standard, LMICs often adopt a modified or staged implementation.

Types of NBHS

Currently, there are two techniques endorsed for infant hearing screening: OAEs and AABR (HPCSA 2018; JCIH 2019). These tests provide an objective indication of auditory system function but do not estimate frequency-specific behavioural thresholds, and this cannot quantify hearing sensitivity across the hearing spectrum (JCIH 2019). Both screening methods yield a binary result of pass or refer, with an automated decision rule that requires minimal interpretation from the screener (JCIH 2019).

A core component of an effective NBHS protocol is the inclusion of rescreening prior to referral as this reduces false-positive outcomes and unnecessary follow-ups. In larger programmes, using an AABR to rescreen prior to discharge substantially reduces false-positive results (Clemens et al. 2000). This is especially important when screening is performed within the first 24 to 72 hours as there are several transient conductive conditions that can cause an initial refer result. Vernix or debris in the ear canal may interfere with the stimulus delivery and response recording (Shcwarz et al. 2023), while factors such as delivery by caesarean section or vacuum extraction can also lead to higher OAE failure on initial screening (Farlandansky-Gershnabel et al. 2025). Therefore, within the framework, referral for diagnostic testing is indicated when the infant does not pass after the recommended screening attempts (typically two), because indefinite repeat screenings attempts can delay diagnosis and intervention (JCIH 2019).

Otoacoustic Emissions (OAEs)

Otoacoustic emissions (OAEs) (Figure 4.1) are low-intensity sounds generated by the outer hair cells of the cochlea as they actively amplify and fine-tune incoming acoustic signals (HPCSA 2018). This outer hair cell activity produces measurable acoustic energy that travels backward through the middle ear and can be recorded in the ear canal using a sensitive probe microphone. As OAEs reflect the integrity of cochlear outer hair cell function, their presence is a strong indicator of normal peripheral auditory system functioning. There are two primary types of automated OAE measurements used in NBHS: transient-evoked OAEs (TEOAEs) and distortion-product OAEs (DPOAEs). Chapter 6 provides a detailed overview of OAE assessment.

1. TEOAEs: These emissions, also known as cochlear echoes, are produced by the outer hair cells and triggered by response to clicks or tone bursts. These echoes reflect the response of outer hair cells across a broad frequency range and can be recorded quickly and easily without requiring advanced audiological interpretation, making them suitable for NBHS (JCIH 2019). TEOAEs have also been found to have high sensitivity and specificity to identify cochlear dysfunction and can therefore be used as a first stage screen in well-baby programmes (Kemp 2015). However, TEOAEs can be affected by conductive HL, ambient noise and internal noise from the patient.

2. DPOAEs: These emissions are produced when two continuous pure tones are introduced simultaneously into the ear. DPOAEs help predict frequency-specific

hearing sensitivity, particularly in the range of 500 Hz to 8 kHz, allowing more detailed evaluation of cochlear responses in comparison to TEOAEs (JCIH2019). This advantage is not critical for infant hearing screenings. Just as with TEOAEs, DPOAEs are susceptible to vernix, residual middle ear fluid or debris in the external ear canal (Kemp 2015). However, what makes them the preferred choice in NBHS programmes is the fact that DPOAEs perform better in noisy test environments such as NICU, making them a more commonly selected option (HPCSA 2018).

Automated auditory brainstem response (AABR)

The Auditory Brainstem Response test evaluates how sound travels through the auditory system up to the brainstem. It does not rely on behavioural responses and is ideally performed while the baby is naturally asleep. For screening purposes, an automated version, Automated ABR (AABR) is used. This method delivers soft click stimuli to the newborn's ears through earphones connected to a battery-powered device. The electrical responses are recorded using three surface electrodes placed on the head, nape of the neck or shoulder. The device automatically analyses the responses and issues a 'pass' if they match a pre-set response template after a minimum of 1,000 sweeps, or a 'refer' if no match is detected after 15,000 sweeps. If a refer result is obtained, the patient requires further additional diagnostic testing.

AABR devices such as the Vivosonic and Natus screeners are commonly used as they are portable and have simple step-by-step protocols and instructions for use. The Natus in particular is compact and lightweight, easy for use at the bedside and in neonatal wards. Both screeners provide the standard pass or refer results and use disposable electrodes and ear cups that are changed between each patient. The disposable items increase the cost of testing per patient which can be challenging in low-resourced environments.

The MB 11 BERAphone® (Figure 4.1) provides an alternative AABR option to traditional choices (Melagrana et al. 2011). The MB 11 BERAphone® has become increasingly popular as it requires no disposable ear tips or electrodes, reducing the overall cost per screening, which is critical where resources are constrained. This device consists of a handheld headphone with a built-in preamplifier and three fixed electrodes that connects to and are powered by a laptop (Meier et al. 2004). Electrode gel is applied to the electrodes that correlate with the vertex, ground and mastoid sites on a baby's head.

Figure 4.1: (a)



Figure 4.1: (b)



Figure 4.1: (a) A baby undergoing OAE screening
Figure 4.1: (b) A baby undergoing AABR screening

Which screening method should I choose?

AABR screening, although generally more expensive than OAE due to initial capital costs, is recommended for screening infants at risk of auditory neuropathy spectrum disorder (ANSD) before discharge from the hospital (Kezirian et al. 2001). AABR screening can test up to the level of the brainstem, whereas OAE screening only tests up to the level of the cochlea. AABR screening is particularly important for the NICU population, which has a higher prevalence of ANSD due to increased exposure to multiple risk factors for HL. ANSD can only be detected with a neural-based test like the AABR (Sininger 2002). AABR is also suitable for infants who are small for their gestational age or have low birth weight.

However, for infants without risk factors for ANSD, OAE screening is typically recommended. When conducting OAE screening, it is essential to consider ambient noise levels to minimise false-positive results. Additionally, the noise reduction capabilities and signal processing techniques of OAE equipment should be evaluated for different settings, as not all OAE instruments may be suitable for NBHS programmes (Olusanya 2010). Appendix 4.2 can be used when choosing an appropriate screening method. The following steps should be adhered to when conducting OAE and AABR screening:

a) Schedule and environment

- Where possible, post a sign letting others know that hearing screening is in progress.
- Speak to staff and find out if there are quiet times in the wards when screening would be optimal.
- Try to complete screening prior to discharge; if not possible, try and coincide with an immunisation follow-up.

b) Behavioural state of baby

- Speak to caregivers about the baby's next sleep or feeding time; a quiet or sleeping baby is in the optimal state for screening.
- A baby with a clean diaper is a happy, calm baby.
- Swaddle the baby as this keeps it calm and contained. It will also prevent the baby from pulling the OAE probe tip out of the ear during testing.

c) Technique

- For a good probe tip fit on OAE, gently pull the earlobe back to insert the probe. The probe should remain in the ear without support.
- Opt for a slightly larger probe tip as it allows for a tight seal, improving the test accuracy.

- When conducting AABR, put a small amount of electrode gel on each electrode site on the skin so that the baby can get used to the temperature and consistency.

Early Childhood and School-Based Hearing Screening

Early childhood screening is aimed at children post newborn to eight years old and can be conducted in various settings. In resource-constrained countries like South Africa hearing screenings are often conducted in ECD centres (Department of Social Development 2009). ECD centres are established to support the emotional, cognitive and physical growth of children from birth until school age (Department of Social Development 2009). These centres play a role in providing initial access to preventive hearing healthcare for children from underserved communities (Hussein et al. 2018). Research from the US and South Africa have shown that incorporating hearing screenings within early childhood programmes can detect various hearing health issues that may affect language development, literacy, social skills and school readiness (Hussein et al. 2018).

Childhood hearing screenings are generally aimed at children aged four years and older and are primarily conducted within school settings, including pre-school. These hearing screenings may occur as part of an entry assessment or may be risk-based and prompted by concerns raised by caregivers or teachers. In certain high-income countries, school-based hearing screening is mandatory; however, significant variability exists in the protocols, testing methods, threshold criteria and referral guidelines used (Yong et al. 2020).

Early and childhood hearing screenings are recommended on an annual basis; however, the feasibility of implementing annual screening depends on the local epidemiology of ear and hearing disorders, as well as the availability of resources and intervention services within a specific area or country. At a minimum, all children should receive hearing screening in pre-school or kindergarten, at school entry and again where possible in grades one, two, three, seven and eleven (WHO 2023). In addition, targeted screening should be conducted whenever teachers or caregivers express concerns regarding a child's hearing.

The screening should focus on identifying sensorineural, conductive or mixed HL in one or both ears (WHO 2023). The screening referral criteria should be determined based on environmental limitations or health system capacity for referrals. It may include a referral criterion of 20 dB HL for one or both ears, otoscopic examination or tympanometry revealing chronic or acute otitis media, otitis media with effusion, impacted wax, malformations of the ear or

foreign bodies in the ear. The WHO (2023) recommends that early and childhood hearing screening include ear examinations, tympanometry and pure tone air conduction screening.

Ear examinations

Ear examinations include a visual inspection of the outer ear and ear canal (American Academy of Audiology 2011). If any malformations of the outer ear are observed, it should be recorded and a referral to an ENT specialist should be made. Otoscopic examination should be undertaken only where trained staff and decision support for examination and diagnosis of ear diseases are available, either on the spot or asynchronously. Asynchronous otoscopic examinations can be provided using video otoscopy, which necessitates task shifting. There are several available technology options for mobile video-otoscopy, such as HearScope, Firefly, Teslong, Dino-Lite, Otocam and Tyto. Chapter 5 provides details on how otoscopic examination should be performed and interpreted.

Tympanometry

Tympanometry is conducted to determine the middle ear status. As with otoscopic examination, it may only be conducted by trained personnel and interpreted by a clinician either on the spot or at a later time. Chapter 5 provides a detailed overview of how this test should be conducted and results interpreted. Research is underway to create affordable versions of smartphone tympanometers that implement machine-learning algorithms to guide facilitators and layperson screeners to make an accurate diagnosis. Furthermore, in situations where test equipment or clinical support is unavailable, otoscopy and tympanometry may be excluded from the screening protocol (WHO 2023).

Air conduction pure tone screening

Pure tone air conduction hearing screening is used to identify if a child can hear the target threshold across certain test frequencies. This test can only be administered from age four onwards and depends on the child's developmental level and ability to follow instructions. Testing can be conducted manually or using automated sweep tests with mHealth tools (for example, uHear, HearScreen) and should be conducted by trained screening personnel. The target threshold is the intensity at which the tone should be presented and ranges between 20-30 dB HL at frequencies 1-4 kHz. The target threshold selected is based on the test environment and the resources available across the intervention pathway. Using the stricter

criterion of 20 dB HL will identify milder losses but will also result in a significant increase in referrals, with an accompanying increase in healthcare resources. In countries where health resources are limited, alternative screening levels may be necessary to ensure that referral rates do not overwhelm an already burdened health system. A cut-off of 25- or 30-dB HL may provide a reasonable trade-off in terms of identifying HL that is educationally significant. While there is risk of missing some milder losses, this ensures acceptably low referral rates (for example, < 4%) (WHO 2023).

Once the test environment has been selected and MPANLs measured, the equipment should be set up with the child facing the direction of a non-visually distracting space (preferably a wall) and the screening personnel seated behind the child, out of view (Figure 4.2). This set-up ensures that the child does not receive any visual cues during the testing. The child should be instructed to raise his or her hand or place a block into a box (play audiometry, Chapter 5) every time they hear a predetermined tone. The testing should start with a practice round which uses a loud or easily audible tone (for example, 50 dB HL) to condition the child to the screening procedure. Once conditioned, pure tone signals are then presented across the different frequencies, first in the one ear and then in the other. Presentations can occur automatically or manually depending on the device that is being utilised. If a child does not respond at the target threshold at one or more frequencies in either ear, the tester should reinstruct the child, reposition the earphones, and conduct a re-screening within the same screening session in which the initial referral occurred. The presence or absence of a child's response should be recorded for each tone. Children who do not pass the rescreen should be referred for further diagnostic hearing evaluation by an audiologist.



Figure 4.2: Seating position while conducting manual pure tone audiometry screening

Speech-in-noise screening

Speech-in-noise (SIN) screening is recommended for children aged four and older, as younger children typically find speech recognition in noise challenging (Koopmans et al. 2018). The SIN screening test measures the speech reception threshold (SRT), which is the signal-to-noise ratio (SNR) that is required to have a probability of 50% for correct word identification. The SRT is compared to a predetermined age-dependent pass/fail criterion, and a test is either passed (SRT is better than pass/fail criterion) or failed (SRT is worse than pass/fail criterion) (De Sousa et al. 2018). SIN test applications are available, for example the hearing-in-noise test (HINT), QuickSIN Test and HearDigits test. However, for screening purposes and in countries where cultural and linguistic diversity is prevalent, a digit-in-noise test (DIN) may be better suited for example, hearWHO application.

As with pure tone screening, the environment should be quiet with the child facing a non-visually distracting space with the tester seated behind the child. When using an application like hearWHO, the screening personnel should instruct the child to listen to the digits and repeat aloud what they have heard If they are unsure, they should guess the digit they think they may have heard (De Sousa et al. 2018). The headphones are then placed on the child's ears and the screening personnel should start the test, entering the digits provided by the child on the smartphone application to proceed to the next level of presentation. Once the test is completed the application will provide a pass/fail score, with a failure requiring a referral to an audiologist for further evaluation.

Conclusion

The success of hearing screening programmes relies heavily on the collaboration among healthcare professionals, the availability of appropriate technology, and the establishment of clear referral pathways and follow-up mechanisms. In resource-constrained settings, targeted and risk-based screening approaches are essential to maximise the use of limited resources while ensuring that children at higher risk of HL receive timely intervention. Ultimately, the goal of hearing screening programmes is to reduce the prevalence and impact of HL on speech, language and cognitive development, thereby improving the overall quality of life for affected children. Continuous efforts to enhance screening protocols in various contexts, train personnel and raise awareness about the importance of early hearing detection are vital for the success of these initiatives.

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Appendices

Appendix 4.1: Sample Screening Forms

Background information:

Name of school:	**Grade:**
Name of student:	DOB:
Age: _____years_____months	Gender:
First language:	Race:

Otoscopic Examination:

Left ear	**Normal**	**>75% wax in canal**	**Perforation**	**Discharge**	**Other**
Right ear	Normal	>75% wax in canal	Perforation	Discharge	Other

Tympanograms:

	Type	Volume	Pressure	Compliance
Right ear				
Left ear				

Pure tone screening:

	1000 Hz	2000 Hz	4000 Hz	Overall result
Right ear	pass / refer	pass / refer	pass / refer	pass / refer
Left ear	pass/refer	pass / refer	pass / refer	pass / refer

Retest:

	1000 Hz	2000 Hz	4000 Hz	Overall result
Right ear	pass / refer	pass / refer	pass / refer	pass / refer
Left ear	pass / refer	pass / refer	pass / refer	pass / refer

Overall results: Pass/Refer

Refer to: ENT/Audiologist/ Other:_____

Appendix 4.2: Guide: OAE vs AABR

Risk factors for hearing loss	Type of screening	Action
Bacterial meningitis / meningococcal septicaemia	OAE (include extended high frequencies where possible) and AABR	Initial assessment within four weeks of diagnosis. If normal at baseline, follow-up screen at three months, telephonic follow-up at six months. If abnormal at baseline, emergency referral for diagnostic testing, imaging, and ENT referral.
NICU > 5 days	AABR	
Moderate-Severe HIE*	AABR	
Severe Jaundice, NNJ^	AABR	
ECMO**	AABR	
Extremely low birth weight (<1000g) Low/very low birth weight (>1000g-2500g)	AABR	
Maternal infections during pregnancy: Toxoplasmosis, Rubella, Syphilis, CMV	OAE	CMV: Every three months (birth – one year). Every six months (one – three years). Annually (three years and older). Rubella: once-off assessment if normal.

Risk factors for hearing loss	Type of screening	Action
Maternal/child ototoxic medication"	OAE (include extended high frequencies where possible)	Will need diagnostic assessment if the child is old enough (OAE will not pick up high-frequency HL). Monitoring needed depends on length and duration of ototoxic exposure.
Craniofacial abnormalities: cleft palate, Goldenhar, etc.	OAE and AABR	Audiology services with ENT input on a case-by-case basis.
Syndrome related to HL	OAE and AABR	Audiology services with ENT input on a case-by-case basis. If syndrome is related to progressive HL, it will require annual monitoring.
Family history permanent childhood HL	OAE	Once off unless history of progressive HL, then monitor every six months.

***HIE=hypoxic ischemic event; ^NNJ=neonatal jaundice; **ECMO=extracorporeal membrane oxygenation**