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Hearing Screening for Postnatal Hearing Loss in Paediatric Age Groups: CODEPEH Recommendations 2024

Cribado auditivo de la sordera postnatal en edad pediátrica: Recomendaciones CODEPEH 2024

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FIAPAS
CONFEDERACIÓN ESPAÑOLA DE FAMILIAS DE PERSONAS SORDAS
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SUMMARY

The prevalence of permanent hearing loss in childhood increases during the first six years of life. Early detection programmes for neonatal hearing loss are insufficient to detect all hearing loss throughout childhood, and it is necessary to develop further initiatives aimed at the early detection of postnatal hearing loss. Research is also urgently needed to set standardised protocols to promote and improve the quality of early detection, diagnosis and treatment of hearing loss.

School hearing screening programmes are a feasible option, although not yet implemented. Innovative methods are important in the context of inclusive education. Tele-audiology emerges as an innovative solution that, with artificial intelligence, would improve the efficiency and accuracy of detection. These emerging techniques offer advantages such as greater availability, simplicity and accuracy in hearing assessment. And tests can be performed remotely and autonomously, reducing the need for specialised personnel.

Postnatal hearing screening should be included in the public health service portfolio, as with other population-based screening programmes for children.

KEY WORDS

School hearing screening, postnatal hearing loss in children, audiometry, tele-audiology.

RESUMEN

La prevalencia de la hipoacusia permanente en la infancia aumenta durante los seis primeros años de vida. Los programas de detección precoz de hipoacusia neonatal son insuficientes para detectar todas las sorderas en la infancia y es preciso desarrollar otras iniciativas para detectar precozmente pérdidas auditivas postnatales. Es urgente también la investigación para establecer protocolos estandarizados que promuevan y mejoren la calidad de la detección, diagnóstico y tratamiento tempranos de la sordera.

Los programas de cribado auditivo escolar son una opción viable, aunque no están implantados. En el contexto de la educación inclusiva es importante contar con métodos innovadores. La teleaudiología emerge como solución innovadora que, contando con la inteligencia artificial, mejoraría la eficiencia y la precisión de la detección. Estas técnicas emergentes ofrecen ventajas como mayor disponibilidad, sencillez y precisión en la evaluación auditiva. Y se pueden realizar pruebas en remoto y autónomamente, disminuyendo la necesidad de personal especializado.

El cribado auditivo posnatal debe incorporarse en la cartera de servicios de Salud Pública, como otros programas de cribado poblacional infantil.

PALABRAS CLAVE

Cribado auditivo escolar, hipoacusia infantil postnatal, audiometría, teleaudiología.

CONTENTS

All CODEPEH Documents and supplementary information brochures can be consulted in the FIAPAS Virtual Library (http://bit.ly/DocCODEPEH). Free download.

- CODEPEH (Núñez, F. et al.) (2014): "Late Onset and Acquired Hearing Loss in Children: CODEPEH 2014 recommendations". FIAPAS Magazine No. 151: Supplement.
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1. INTRODUCTION

Although there are few publications on the matter, it is known that the prevalence of permanent hearing loss in childhood increases during the first six years of life (Niskar *et al.*, 1998; Mackey *et al*., 2024). Early detection programmes for neonatal hearing loss are not enough to detect all deafness throughout childhood. It is therefore necessary to develop further initiatives aimed at the early detection of postnatal hearing loss, which should be considered an important health problem that needs assessment and treatment (Torrente *et al.*, 2023).

The definition of postnatal childhood hearing loss applies to any hearing impairment that is detected after birth. It can be progressive, late-onset and acquired, and may be due to many other causes, including those attributable to a lack of sensitivity of the diagnostic technology used or lack of compliance with/adherence to established protocols (Núñez-Batalla *et al.*, 2024).

To date, early detection programmes for congenital hearing loss have typically included surveillance until three or four years of age for children at risk of developing delayed or late-onset hearing loss (Joint Committee on Infant Hearing, 2019; Núñez-Batalla *et al.*, 2015). However, studies show that this is not enough, as most postnatal hearing loss occurs after the age of three and in many cases there are no recognisable risk factors at birth (Núñez-Batalla *et al.*, 2024).

Sensory disabilities may go unnoticed in children for a long time due to their high capacity for adaptation. Hence the need and justification for postnatal screening, as the disease to be diagnosed also meets frequency and severity criteria and benefits from early diagnosis, the technology exists to facilitate it, and there are clear socioeconomic savings (Faramarzi, 2022).

The CODEPEH Document of Recommendations 2023 stated that there is a need for effective protocols for the early detection and early treatment of infant postnatal hearing loss. There is a variety of means that can be used to identify such cases: parental or professional suspicion, age-specific surveillance, targeted screening of children with risk factors, and universal screening throughout school age.

School hearing screening programmes are a viable option for the early detection of postnatal childhood hearing loss and, therefore, have the potential to mitigate its negative effects. Unfortunately, they are not currently as widespread as would be desirable both because of a lack of political and financial commitment and the incorrect belief that all children with hearing loss are detected through universal neonatal screening programmes. Therefore, the debate currently focuses on the feasibility and cost-benefit of this approach (Bamford *et al*., 2007; Kik *et al*., 2023).

This CODEPEH paper continues along the lines of the Document of Recommendations 2023 in order to further study the scientific criteria and new lines of application of the programme for the early detection of postnatal childhood hearing loss, configured as a continuous hearing prevention service throughout childhood, both to follow up cases that “fail” neonatal screening and for children with hearing risk factors or red flags (Table 1), and to detect cases of postnatal childhood hearing loss.

2. CURRENT STATUS OF POSTNATAL SCREENING

For the early detection of postnatal hearing loss, both the Joint Committee (Joint Committee on Infant Hearing, 2019) and CODEPEH (Núñez-Batalla *et al.*, 2015) propose follow-up for children with or without risk factors for hearing loss, even if they have passed neonatal screening, up the age of three years. Hearing skills, middle ear status and developmental milestones should be assessed at each regular visit as part of the “Healthy Child” programme. However, studies show that this is not enough, as most postnatal hearing loss occurs after the age of three and in many cases there are no recognisable risk factors at birth.

Postnatal screening at child health programme check-ups, at the time of starting school and at the beginning or end of each educational stage is therefore highly recommended.

Postnatal hearing screening is considered useful and beneficial because it enables early detection of hearing loss, adequate speech and language development, and consequent improvement in academic performance, thus promoting equal opportunities while having a significant impact and repercussions on public health.

In terms of the cost-benefit of screening, experiments in Australia featured an app that assesses the existence of hearing problems at home. The system is considered to have a 96.2% probability of being cost-effective and enables early identification and intervention, reducing disadvantages in early childhood through cumulative improvements in quality of life, education and economic outcomes (Bussé *et al.*, 2021; Gumbie *et al.*, 2022).

Given that globally the majority of children are in school, the World Health Organisation (WHO) recognises that there is a unique opportunity in this environment for universal screening for hearing loss.

If followed by an appropriate diagnostic process and therapeutic intervention, school screening programmes are an effective tool to mitigate the effects of previously undetected childhood hearing loss. Few parts of the world regulate school screening, so there is little scientific literature on the subject. Even where it is implemented, there are significant differences in protocols, in the tests used for screening, and in the thresholds considered for referral to diagnostic studies and therapeutic interventions.

The principles of school screening provide for accessibility to otology and audiology services prior to its implementation, to which detected cases will be referred. Clinical care pathways and case tracking mechanisms should be clearly defined so that identified children and their families can receive the care, support and follow-up they need. Medical-surgical, audio-prosthetic and rehabilitative treatments must be available for individualised application, respecting the needs of each case as well as their preferences and cultural context. Wherever possible, school hearing screening should be part of routine health checks or combined with other interventions such as general health check-ups, vision screening and dental check-ups.

In terms of the ages of children, the WHO recommends that all children be screened at least at the beginning of school age. In settings with an enabling health system, hearing screening should be established on a regular basis: in addition to the start of schooling (2-3 years), at the equivalent ages of 5-6, 7-8, 11-12 and 15-16 years, although each country decides on the ages depending on the epidemiology of otological conditions and the resources available.

With regard to human resources, the WHO indicates that screening can be performed by medical specialists, general practitioners, nurses, audiologists and even trained teachers. In order to facilitate access for schoolchildren, it is preferable to carry out the screening on the school premises. A quiet room is usually sufficient, however, it is necessary to assess the ambient noise so that it does not exceed the permissible levels for the selected headphones and the screening threshold. The most frequently chosen environment is a quiet space such as an empty classroom. Most countries use supra-aural headphones to suppress the effects of ambient noise.

Globally, there are currently few school-age hearing screening protocols, in place and data on their implementation is inconsistent. In the USA, only 66 % of all states conduct some form of school hearing screening, despite national recommendations to do so at regular intervals (American Speech-Language-Hearing Association, 2019). It is also recommended in South Africa, but there is no data on its implementation. In the UK, approximately 10% of schools do not perform screening, despite recommendations to do so in the first year of primary school (National Screening Committee, 2019). In Spain, the Balearic Islands is the only autonomous region to conduct regulated school screening (Martínez Pacheco *et al.*, 2021). In other countries, there is little published data on current regulations (Yong *et al.,* 2020).

Regarding the technology used for screening, the WHO reports that the recommended tests are conventional or automated scanning audiometry, listening to digits in noise using the WHO application (hearWHO app), otoscopy and tympanometry, although tonal audiometry is preferably recommended to study different frequencies at 20, 25, 30 and 35 dBHL.

Most studies use conventional audiometers for screening, others use portable audiometers without booths or tele-audiometry (Botasso *et al*., 2015; Skarzynski *et al.,* 2016; Monica *et al*., 2017; Bussé *et al*., 2021). These alternative means can improve access to hearing screening in remote areas.

In all regions of the world, screening by tone audiometry was considered an indispensable aspect of school hearing screening protocols, and the gold standard for confirmatory diagnostic testing for hearing loss. At European level, school screening is universally carried out in 17 countries or regions, using audiometry (Bussé *et al*.,2021). However, audiometric frequencies and referral criteria vary greatly from study to study. Even in countries such as the USA, the range of frequencies logged is from 0.25 to 8 kHz, although the frequencies typically tested are 0.5, 1, 2 and 4 kHz. Articles assessing hearing loss in adolescents pay greater attention to the importance of extending testing to high frequencies (6 and 8 kHz), as these are the frequencies most affected by exposure to intense noise (Sekhar *et al*., 2011). The criteria for referral in almost all studies are defined by the failure of auditory responses at any one frequency presented to one ear, although the thresholds considered to be borderline differ widely. As an objective of screening, the WHO specifies that uni- or bilateral hearing loss, including transmissive, mixed or sensorineural hearing loss, should be identified. Ideally, all losses above 20 dBHL should be detected, although if there are limitations in terms of the quietness of the test environment (noise above 40 dBA) or the capacity of the health system to cope with referred cases, one can start with a cut-off point of 30-35 dBHL and, once established, gradually move down to 20 dBHL.

There are differences in the complementary tests recommended to be associated with the school screening protocol such as otoscopy, tympanometry and otoacoustic emissions, as chronic ear diseases such as secretory otitis, chronic otitis media, impacted cerumen, malformations and foreign bodies should also be detected. Most protocols incorporate a combination of otoscopy and tympanometry into pure tone screening.

Associated otoscopy is important because of its usefulness in detecting pathology of the outer and middle ear. It is particularly important in regions where ear canal obstruction by cerumen or otitis is more frequent (Jacob *et al*., 1997). However, in general, it is not specified which professional should perform the otoscopic screening (Beals *et al*., 2016). Most studies involve a wide range of professionals, limiting the generalisation of this recommendation in resource-poor settings.

Tympanometry is recommended due to its great utility in the evaluation of middle ear pathology, particularly in the evaluation of secretory otitis (Winston-Gerson and Sabo, 2016). There is much variability regarding the decision as to whether to include it as a first-line screening tool or whether it is better reserved as a second-line test, after initial screening by tone audiometry or otoacoustic emissions (OAE) (Chen *et al*., 2014). Some authors advocate immediate referral to an ear, nose and throat specialist following an abnormal tympanometry result. Others recommend repeating it one month later to check the resolution of the problem (Govender *et al*., 2015).

OAEs are part of routine school hearing screening in few protocols. Current evidence indicates that screening with this technology is less sensitive and produces a higher number of false positives than screening with audiometry (Krueger and Ferguson, 2002). However, many authors argue that otoemissions are more relevant in situations in which children are unable to follow screening instructions, such as in the case of very young children or children with special needs (American Academy of Audiology, 2011; Chen *et al*., 2014).

In reference to the use of automatic auditory potentials, there are also experiments to demonstrate their usefulness, such as that of Soares who concludes that the results demonstrated two important issues (Soares *et al.*, 2014). On one hand, the reliability of the devices, which also show a specificity and sensitivity of 95.1% and 96.3%. The same reliability was observed in groups, with pre-school children and with school-age children. On the other hand, it is a short test that requires only about 20 seconds per normal ear to reach the result from the onset of the stimulus. This is especially important when the subject is not sedated. The points described suggest a high possibility of using screening devices not only for newborns but also for older children, both in developed and developing countries.

A major problem with school hearing screening is the high false positive rate that worsens the cost-benefit ratio (Govender *et al.*, 2015). There is no agreement on the process to be followed for cases that do not pass the initial screening. There are protocols that propose immediate re-testing to reduce false positives, although most studies do not include this. This seemingly simple yet hugely important aspect can have a profound impact on the overall feasibility of this intervention.

A meta-analysis (Yong *et al.*, 2020) highlights the lack of information on the actual prevalence of hearing loss in school-age children. Articles include prevalence estimates ranging from 0.9% in Taiwan (Yang *et al.*, 2011) to 34% in Brazil (Nogueira and Mendonça, 2011). However, many articles show referral rates after screening, rather than prevalence, ranging from 0.16% in China to 15% in Malaysia (Khairi *et al.*, 2010). Without knowing the results of the diagnostic confirmation of the referred cases, it is impossible to estimate the sensitivity and specificity of the screening. As some existing protocols have a sensitivity as low as 12% (Sekhar *et al.*, 2011), they are considered inadequate for a viable screening strategy (Kam *et al.*, 2013).

A key issue in school hearing screening is the loss to follow-up of children who are referred for diagnostic confirmation with the ENT doctor. Out of 44 articles reviewed, only 8 provide data on the follow-up of pupils after referral, ranging from 10% to 65% (Flanary *et al.*, 1999). Possible reasons for such poor follow-up rates are the inability to contact families to report screening results, lack of parental awareness of the importance of hearing loss, the cost of follow-up medical care, families' inability to take time off work to attend appointments, and geographical barriers (Clark, 2008).

In some countries, school hearing screening programmes have been implemented in a very heterogeneous way. And there is an urgent need for more research in this area in order to establish standard school hearing screening protocols, not only to support and improve the quality of detection and early diagnosis of hearing loss through screening programmes but also to improve comparative studies between different programmes (Bussé *et al.*, 2021).

The screening programme must be coordinated with ENT medical services so that identified children can access the care and resources they need. Children who pass the screening should be informed of the hearing hygiene measures to be followed. Children who do not pass the screening should be referred to ENT for confirmatory diagnostic tests and treatment.

3. EMERGING TECHNIQUES AND METHODS

School hearing screening in its in-person format, as performed in health centres and schools, presents several problems and drawbacks that may affect its effectiveness and efficiency.

Some of the main challenges are as follows:

- Accessibility and coverage. Access to screening centres is not easy for the whole population.
- Costs and resources. Mass hearing screening requires a significant investment in terms of equipment, specialised staff and time.
- Time and school disruption. In-person screening can disrupt school hours, affecting academic activities.
- Training and education. The personnel

performing the tests must be properly trained to ensure the accuracy of the results.
- Stigmatisation and anxiety. Some children may feel anxious or uncomfortable undergoing medical evaluations, especially in a school setting.
- Technical limitations. Equipment used in hearing screening should be calibrated and maintained regularly to ensure accuracy.
- Follow-up and treatment. Identifying a hearing problem is only the first step. Without an effective monitoring system, detected cases may not receive the necessary attention in a timely manner.
- Language and cultural diversity. In multicultural settings, differences can complicate communication during screening and interpretation of results.
- Variability in protocols. Screening protocols can vary significantly between different regions and organisations, making it difficult to compare results and implement improvements.
- Reluctance of families. This can occur for a variety of reasons, including mistrust of the health care system, privacy concerns or lack of understanding about the importance of screening.

To mitigate the problems mentioned above, alternatives can be considered such as those encompassed by the concept of tele-audiology which, using digital technologies, enable audiological tests to be performed remotely or with less disruption. Compared to classical and/or traditional methods, the use of this type of technology offers a simpler, more accessible and more accurate way to evaluate hearing at this postnatal stage. Moreover, the remote applicability of the test allows for the possibility of testing at any time, even from home (Tsuiki *et al.*, 1974; Bento *et al*., 2003; Lancaster *et al*., 2008; Mcpherson *et al*., 2010; Gro- gan-Johnson *et al*., 2011; Botasso *et al*., 2015; Kiktová *et al*., 2020; Schafer *et al*., 2020).

These new techniques may be particularly beneficial for schoolchildren with undiagnosed hearing loss, enabling early and appropriate intervention to ensure optimal academic and social development (Skarżyński *et al*., 2016; Bağlama *et al*., 2018; Shinn *et al*., 2019; Chin *et al*., 2020; Yong *et al*., 2020).

Tele-audiology has emerged as an innovative solution to overcome geographical barriers and improve access to hearing services. There is a wide variety of methods included in tele-audiology, although they can be grouped by distinguishing between techniques that require specialised personnel and those that can be performed autonomously or with minimal supervision.

Those that are professional guided, taking advantage of information and communication technologies (ICT), allows for comprehensive remote hearing evaluations, as well as consultation with professionals using online communication tools and/or special equipment. Testing without direct contact with a professional can include self-administration of audiometric tests with mobile phone apps, questionnaires, portable devices and wearables, among others (Lescouflair, 1975; Bento *et al*., 2003; Richardson *et al*., 2004; Lancaster *et al*., 2008; Mcpherson *et al*., 2010; Botasso *et al*., 2015; Prieve *et al*., 2015; Kiktová *et al*., 2020).

a) **Techniques that require the intervention of a professional**:
   - *Pure Tone Audiometry*
     Description: A test that measures hearing ability at different frequencies.
     Professional Intervention: A hearing care professional or audiologist must operate the equipment and analyse the results.
     Equipment needed: Audiometer, calibrated headphones.
   - *Otoacoustic Emission (OAE)*
     Description: This evaluates cochlear function (outer hair cells) by detecting otoacoustic emissions generated by the ear.
     Professional Intervention: Performed by a specialised technician or audiologist who operates the equipment and analyses the

data.
Equipment needed: Portable OAE device.

- *Auditory Brainstem Response (ABR) Test*
Description: This measures the electrical responses of the auditory nerve to sound stimuli.
Professional Intervention: An audiologist must perform and analyse this test, as it is more complex.
Equipment needed: Portable ABR device.
- *Impedance Audiometry*
Description: This evaluates the function of the middle ear, such as the mobility of the eardrum and the function of the ossicles.
Professional Intervention: This must be performed by an audiologist or specialised technician.
Equipment needed: Impedance meter or tympanometer.
- *Video Otoscopy*
Description: Visual inspection of the ear canal and eardrum with a camera connected to a monitor.
Professional Intervention: A technician or audiologist must perform the test and check the health of the outer ear.
Equipment needed: Video otoscope.
- *Videoconferencing*
Description: Hearing tests and hearing behaviour visualised live via videoconferencing.
Professional Intervention: A technician or audiologist must perform the test online.
Equipment needed: Videoconferencing via computer, tablet or smartphone.

The use of these devices allows for any audiological technique to be performed remotely with results similar to the reference techniques (D'Onofrio and Zeng, 2022). They record auditory responses and send the data to a professional for live or delayed analysis.

In children who are able to cooperate, audiometry is the standard test. These devices must be easy to use, robust and affordable. They can be equipped with noise cancellation technology to facilitate testing (Bento *et al*., 2003; Liao *et al*., 2010; Skarżyński *et al*., 2016; Monica *et al*., 2017; Samelli *et al*., 2017; Santoso *et al*., 2020).

In young or uncooperative children, objective techniques such as acoustic otoemissions (AOE), auditory evoked potentials (AEP) or others can be used.

Typically, families and teachers must be instructed in how to perform the test (Madzivhandila *et al*., 2024), although portable devices can also be used directly by schoolchildren themselves with minimal supervision, allowing for basic hearing tests to be performed at home or at school. These devices are designed to be easy to use without specialised training.

Professionals can guide families or carers through a hearing evaluation in real time using video conferencing platforms. This method is useful for observing the child's behaviour and making subjective evaluations. It also enables professionals to interact directly with patients, observe procedures and provide instructions in real time. Various techniques and tools, such as digital hearing aids and supra-aural headphones, are used during video conferencing to assess hearing ability. They can also report test results in real time and arrange a new appointment for further examinations (Nees and Berry, 2013).

b) **Techniques that can be self-administered**:

- *Automated Audiometry (Apps and Webs)*
Description: Audiometry tests that can be performed via apps on smartphones or tablets.
Professional Intervention: This requires no direct intervention, although the results can be sent to a professional for analysis. It can be done at home or in school settings without specialist supervision.
Available apps: hearScreen, Shoebox Audiometry, hearZA, among others.
Equipment needed: Smartphone or tablet with calibrated headphones.
- *Speech-in-Noise Testing (Apps and Webs)*
Description: Assessment of hearing in noisy environments, where the child must identify words from among background noise.
Professional Intervention: Not required, but

the results can be reviewed by a specialist if desired. This is self-administered in school settings or at home.

Apps available: uSound Test, HearWHO (WHO), among others.

Equipment needed: Smartphone or tablet with headphones.

- *Online/Offline Hearing Screening Test*

  Description: Simplified hearing tests that can be performed on web-based platforms, ideal for detecting basic hearing problems.

  Professional Intervention: Not required, but a consultation with a specialist is recommended if the result is abnormal. It can be done individually or under school supervision.

  Platforms available: Audicus Online Hearing Test, Phonak Hearing Test, among others.

  Equipment needed: Internet access, computer or mobile device with headphones.

- *Questionnaires for Families and Teachers*

  Description: Questionnaires to help identify behaviour related to hearing problems (difficulty following instructions, delayed response, etc.).

  Professional Intervention: This can be completed by families or teachers without direct intervention by a specialist, although consultation with a specialist is recommended if worrying patterns are detected.

  Format: Paper or digital forms (online and offline).

Some websites, such as “HearingScreening.org” and “Sound Scouts”, also provide additional educational resources for hearing health professionals and educators, offering an easy and efficient way to screen large numbers of school children.

These platforms often include interactive and engaging games specifically designed for hearing screening in children, thus facilitating assessment. These games may include tasks such as identifying sounds, following auditory and other instructions.

In addition, they often include options for customisation and adaptation to different age groups, which facilitates the implementation of screening in school settings. Another advantage of this type of technology is the possibility of active noise control, which makes it possible to reduce the influence of ambient noise during the test. There are also virtual reality-based hearing screening programmes that simulate real-life listening scenarios and assess a schoolchild’s ability to understand speech in noisy environments (Lancaster *et al*., 2008; Grogan-Johnson *et al*., 2011; Benaouda, 2012; Swanepoel *et al*, 2014; Wu *et al*., 2014; Botasso *et al*., 2015; Mahomed-Asmail *et al*., 2016; Yousuf Hussein *et al*., 2018; Eksteen *et al*., 2019; Eugenio and De la Cruz, 2019; Sternin *et al*., 2019; Kiktová *et al*., 2020; Zitelli and Mormer, 2020; de Sousa *et al*., 2022; Carvalho *et al*., 2023).

There are many applications available, with or without internet connection, for all kinds of electronic devices. Some examples are given in Table 2.

Most applications demonstrated significant sensitivity and specificity values, and can be considered accurate methods for the detection of hearing loss (Smits *et al*., 2013; Melo *et al*., 2022; Cunha *et al*., 2023; Schimmel *et al*., 2024; Taitelbaum-Swead *et al*., 2024).

Wearables for hearing screening in children are an emerging technology, and while there is not a large number of devices specifically geared towards hearing screening, there are some interesting options and projects under development that take advantage of the portability and technology of wearables to facilitate audiological studies. These may be hearing aids, headphones or other sensors. These sensors measure the response of the auditory system and detect any deficiencies. In addition, they can monitor continuous data on noise exposure and other environmental factors that can affect hearing and can be used to identify and prevent hearing problems (Trapl *et al*., 2013; Molini-Avejonas *et al*., 2015; Qian *et al*., 2020; Lammers *et al*., 2021; Qu *et al*., 2021).

Several devices in development use smartphones as a platform to process the data collected by the wearable, facilitating the analysis and interpretation of results by families or remote healthcare professionals. The development of hearing wearables is booming and has great potential to improve the accessibility and effectiveness of hearing screening for children, especially in remote communities or those with limited access to specialised services. As technology advances, we are likely to see more devices aimed at continuous monitoring and hearing screening in a simple and non-invasive way.

With regard to questionnaires, it should be noted that they allow for the assessment of hearing and of risk factors, as well as the assessment of parental suspicions. This hearing screening option, which is available both online and on portable devices, is based on specific questionnaires. They play an important role in school screening by providing an efficient tool to identify possible hearing problems. They are a quick and inexpensive way of assessing hearing health, allowing for early identification of potential difficulties that could affect learning, academic performance and social development.

The questionnaires may include specific questions about the schoolchildren's hearing ability and experience of sound in different environments, their history of hearing problems, and observations of hearing-related behaviours. In addition, they can be adapted to different age groups and skill levels, allowing for a more personalised and accurate assessment.

Some of these may also include assessment of habits and risk factors related to hearing health. Test results can be sent automatically to practitioners for real-time (online) or delayed assessment (Trapl *et al*., 2013; Nees and Berry, *2013*; Zanin and Rance, 2016; Eugenio and De la Cruz, 2019; Schafer *et al*., 2020).

These questionnaires act as an initial filter to determine which children might need more detailed hearing assessments. They enable the inclusion of multiple factors, such as medical history, observed behaviours and academic performance. They may also address issues such as difficulty understanding speech, sensitivity to noise or the presence of tinnitus.

Questionnaires should be easy to understand and answer, with options available in printed and/or digital format. They should be designed to be concise, avoiding complex and lengthy questions. Their digitisation means that the results are processed automatically, enabling efficient data storage and analysis.

Digital systems can provide immediate feedback to users on the need for professional hearing assessment, based on the answers to the questionnaire.

Furthermore, there is the possibility of online questionnaires for suspected hearing loss in young children under 2 years of age by their caregivers to act as a basis for further assessment by a specialist, if necessary.

3.1. Advantages of tele-audiology

These new methods have the following advantages (Lo and McPherson, 2013; Botasso *et al*., 2015; Sternin *et al*., 2019; Carvalho *et al*., 2021), among others:

- Availability and convenience. They enable hearing screening in rural or under-resourced areas where access to specialised services may be limited, and allow for testing to be carried out at any time and from anywhere, reducing the need to travel to specific centres.
- Reduction of school disruption. Hearing tests can be conducted at home or in the school environment with minimal disruption to academic activities. Schoolchildren can be assessed in a familiar environment, reducing anxiety and improving the quality of the results.
- Reduced costs. By eliminating the need for travel and optimising health staff time, tele-audiology significantly reduces the costs associated with in-person screening. Portable equipment and specialised software for audiometry can be more cost-effective in the long run.
- Increased efficiency. It allows for the process to be automated, reducing the time and effort required by professionals.
- Improved accuracy. The use of intelligent

algorithms can improve the accuracy of hearing screening.
- Personalised assessment. They can provide personalised assessment and feedback based on test results, allowing for targeted interventions and support according to specific needs.
- Scalability. They can be applied to a large number of subjects at once, speeding up the screening process and allowing access to a larger number of people in a shorter amount of time.

3.2. Limitations and challenges of tele-audiology

- Maintenance, updating, and compliance with legislation. When implementing the use of internet-based telemedicine, the operating system, browser and servers used must be easy to maintain and update. The equipment must provide sufficient image and sound quality.
- Telehealth services must comply with national and international regulations regarding patient privacy and security, especially with regard to data transfer and storage.
- Accuracy and reliability. There are challenges associated with the accuracy of the results because the accuracy of self-administered and remote tests may be lower than that of tests conducted in a controlled clinical setting. It must be ensured that schoolchildren have access to the necessary resources to perform the tests properly, such as quality headphones and a quiet environment, as the presence of ambient noise during testing can reduce the accuracy of the results. Live monitoring of ambient noise, attenuating outside sound with supra-aural headphones or trying to use a quiet room may help reduce the need for a soundproof or acoustically treated booth, although this may not be feasible in all circumstances. Therefore, to improve diagnostic accuracy in the absence of an acoustically treated environment, the use of headphones with real-time ambient noise cancellation is also recommended, as well as detailed instructions for the proper use of the headphones by the patient.
- Additional important considerations include the security of patient locations, of documents and electronic devices and of telecommunications, the identification of all persons present at the different locations, and the documentation of informed consent by the patient.
- Accessibility. Tele-audiology and applications must also be accessible for use by everyone, particularly when it comes to remote hearing assessments and/or access to self-administered questionnaires.
- Digital divide. Not all families have access to the devices and connectivity needed to use these technologies. It should be considered that, given the technification required for these examinations, the current digital divide may negatively affect minorities and/or vulnerable or digitally illiterate families, those living in rural areas and very young children, as access to and use of these methods may pose difficulties.
- Telemedicine may be more limited in developing areas, as electricity availability and internet access may be scarce or less efficient. Therefore, in these circumstances, the use of battery-operated devices may be useful (D'Onofrio and Zeng, 2022).
- Licensing to practise medicine in different countries and payment for services are two of the concerns that also affect telemedicine services.
- Finally, session time is also increased in some audiometric tests. However, the latter is not a real problem, as the time saved is much greater, at least for the patient, who does not have to travel (Cardier et al., 2016).
- Education and support. Families must receive adequate training and support to use these methods correctly.

3.3. Future considerations and the role of Artificial Intelligence

Artificial intelligence (AI) can bring several benefits to hearing screening, improving the efficiency and accuracy of detecting potential hearing problems in children. These include:

- Automation of hearing tests. Assessments can be made more efficiently, reducing the workload for health professionals and educators. Automated diagnostics may include:
  - Audiometric analysis. AI can analyse the results of audiometry and other tests to identify early patterns that indicate hearing loss or other problems. Machine learning algorithms can be trained to recognise different types of hearing loss extremely accurately.
  - Speech assessment. AI tools can assess the patient's speech quality and hearing ability in real time.

- Fast and accurate data analysis. AI can analyse large hearing test datasets in an agile way, making it easier to identify patterns and detect potential hearing problems at the earliest possible stage. Machine learning algorithms can be trained to interpret questionnaires and audiometric test results to provide preliminary diagnoses that can then be reviewed by professionals. This speeds up the screening process and reduces the workload.
- Personalised screening. AI can personalise the hearing screening process based on individual factors such as age, medical history and family history. This allows for more effective approaches to the identification of hearing problems. In addition, AI can tailor hearing tests according to each child's responses, allowing for a more accurate and targeted assessment.
- Continuous monitoring. AI systems can facilitate continuous monitoring of hearing health over time, allowing for the early detection of changes in hearing and the implementation and evaluation of necessary interventions.
- Telemedicine platforms. AI can be integrated into telemedicine platforms to improve the quality of remote hearing assessments. This is especially useful in environments where the physical presence of a professional may be limited, such as in rural areas.
- Game development. It can be used to develop interactive educational games that test children's hearing in a playful manner, making hearing tests more engaging and less stressful, even with virtual reality.
- Identification of risk factors. AI algorithms can analyse large demographic and medical databases to identify risk factors that may be associated with hearing problems in children, enabling targeted care.

It is important to note that while AI can be a valuable tool, it should not replace professional assessment and diagnosis. The combination of human expertise and AI capabilities can lead to more effective hearing screening and early intervention, thus improving the quality of life of children with hearing difficulties (Wu *et al.*, 2014; D'Onofrio and Zeng, 2022).

4. CONCLUSIONS

Postnatal hearing screening programmes have the potential to mitigate some of the negative effects of childhood hearing loss, although they have not yet been widely developed due to a lack of both political and financial commitment and the incorrect assumption that the vast majority of childhood hearing loss is detected through universal neonatal hearing screening.

Where school hearing screening programmes exist, protocols and methods are inconsistent, partly due to a lack of regional and/or state guidelines. There is therefore an urgent need to promote research in this area in order to establish globally standardised protocols, not only to promote and improve the quality of early detection, diagnosis and treatment of hearing loss, but also to improve comparability between studies.

Based on current knowledge of the subject, an initial recommendation could be the implementation of school hearing screening by means of tonal audiometry with supra-aural headphones at frequencies 1, 2 and 4 kHz, with a referral threshold level for audiological studies of 20 dBHL at one of the frequencies in one or both ears. However, the definition of the referral threshold should be established considering the availability and capacity of diagnostic and rehabilitation services, as very demanding thresholds will lead to a higher number of false positives. Re-screening should be a mandatory step to control the number of these false positives. In the case of children for whom audiometry is not possible, other objective techniques should be used.

It is important for diagnostic and rehabilitation services to be available and accessible to refer children who do not pass the hearing screening, along with an effective follow-up system to avoid cases missed in the process and to check that detected cases are being adequately cared for.

The establishing of guidelines for hearing screening is a critical step in expanding standardised programmes, as it will facilitate the quality studies needed to reliably understand the regional prevalence of postnatal childhood hearing loss. In addition, standardisation will serve to optimise the sensitivity and specificity of the tests used for screening, which will contribute towards the better efficiency of such programmes (Yong *et al*., 2020). The analysis and management of this data is a critical component in monitoring quality control and evaluating long-term success (Helfer *et al*., 2003).

Most science societies recommend several check-ups during the school years (sometimes coinciding with changes of cycle within the different educational stages). At the very least, screening at age 2-3 years, 5-6 years, 7-8 years, 11-12 years, and 15-16 years is considered important (WHO, 2021; Bower *et al.*, 2023).

Within the context of inclusive education, it is important to have innovative methods for early detection of hearing loss at school. Within this new methodology, tele-audiology allows for hearing assessments to be performed remotely with any type of technique and in a wide variety of locations, using online communication tools and/or special equipment. The self-administration of questionnaires and audiometric tests via apps for mobile phones, portable devices or wearables can also be included under this heading.

All these new techniques offer advantages such as greater availability, simplicity and accuracy in hearing evaluation. They also allow for greater participation in the process of detecting hearing loss, as tests can be performed remotely and autonomously, thus reducing the need for specialised personnel. These techniques also allow for the collection of continuous data on exposure to noise and other environmental factors that may affect hearing, providing additional information to identify and prevent hearing problems.

The new techniques are not without their limitations, but it is hoped that artificial intelligence will help overcome them by improving their efficiency and accuracy. These advances in the detection of hearing loss are essential to ensure equal opportunities and quality education.

5. CODEPEH RECOMMENDATIONS 2024

Postnatal hearing loss is a major problem throughout childhood and beyond (Figure 1).

- There is a need for effective protocols for the early detection and early treatment of postnatal childhood hearing loss, as passing neonatal hearing screening does not guarantee normal hearing throughout childhood.
- Hearing screening is recommended during infant health check-ups, at the time of schooling, and at the beginning or end of each cycle of the different educational stages (screening at the ages of 2-3 years, 5-6 years, 7-8 years, 11-12 years, and 15-16 years is considered important), and in the event of any red flags and/or suspicions observed by the family or caregivers.
- Tele-audiology is a new tool for effective and efficient postnatal hearing screening. It involves internet-connected portable audiological devices and online platforms and applications.
- This postnatal hearing screening using new technologies has many advantages and also some drawbacks or limitations that must be taken into account.
- Artificial intelligence (AI) will enable and optimise screening processes and data analysis and processing to improve prevention and early diagnosis of postnatal hearing loss.
- As with other population-based screening programmes for children, postnatal hearing screening should be included in the public health service portfolio.

6. TABLES AND FIGURES

Table 1 *Red flags for detecting hearing loss in childhood*

(SOURCE: CODEPEH, compiled by author)

RED FLAGS
Between the ages of 6 months and 15 years, you must observe whether....
BEFORE TWO YEARS OF AGE
✔ They are not scared or upset by sudden loud noises
✔ They do not respond with vowel sounds when spoken to
✔ They do not localise or turn their head to familiar voices or sounds
✔ They neither do vocal play nor imitate sounds
✔ They do not rattle toys or objects within reach
✔ They do not react to their name
✔ They do not pay attention to stories
✔ They do not listen to nursery rhymes, or imitate the gestures that go with them
✔ They do not say daddy/mummy
✔ They do not point to familiar objects or people when they're named
✔ They do not understand simple instructions, such as "give me...", "take...", "come...", "say goodbye..."
BETWEEN TWO AND FOUR YEARS OF AGE
✔ They do not listen to what is being said if they are not looking at the speaker
✔ They do not name familiar objects
✔ They do not make two-word sentences
✔ They do not progress in speech and communication skills
✔ They do not identify where sounds come from
✔ They are easily frustrated
✔ They frequently say "What?", "Huh?"....
FROM FOUR YEARS OF AGE
✔ They are hypersensitive to certain sounds
✔ They have a preference for one of their ears when listening and/or approaching a source of sound
✔ They do not chat with other children
✔ Only their family understands what they say
✔ They have behavioural problems or social difficulties
✔ They show a learning delay and changes in their school performance
✔ They show signs of spoken or written language disorders, which indicate poor speech discrimination
✔ They say that voices and other sounds seem muffled
✔ They have difficulty hearing high-pitched sounds
✔ They misunderstand conversations in noisy places
✔ They have trouble understanding conversations on the phone
✔ They frequently ask for what is said to them to be repeated
✔ They ask others to speak slowly, clearly and/or loudly
✔ They turn up the volume of the TV and any other electronic devices
✔ They complain of ringing in their ears

Table 2 *Platforms, games, applications, questionnaires (among others)*

(SOURCE: CODEPEH, compiled by author)

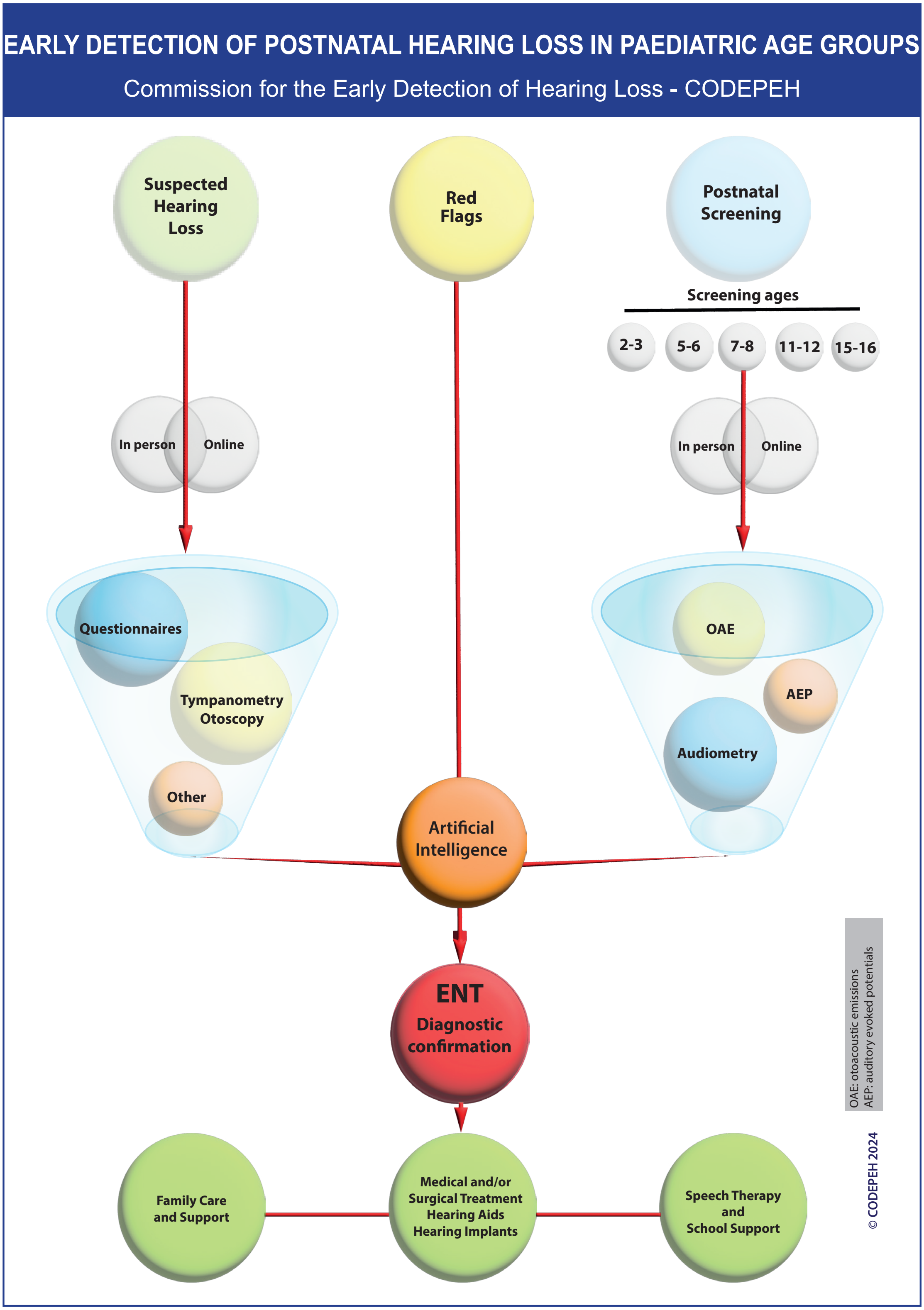
Platforms and portable audiometry	✓ https://learntoscreen.org ✓ https://www.soundscouts.com ✓ https://eaudiology.audiology.org/ ✓ https://www.theaudiologyproject.com/hearscreenusa ✓ https://www.shoebox.md/ ✓ https://www.ata.org/ ✓ https://screenout.id/home ✓ https://www.resound.com/en-us/online-hearing-test ✓ https://geoaxon.com/kuduwave-pro ✓ https://telehearportal.com/login
Games	✓ https://www.audiogames.net/ ✓ https://soniclearning.com.au/our-programs/fast-forword/ ✓ https://www.hearingcoach.com/ ✓ https://www.jabraenhance.com/survey
Applications	✓ hearWHO https://www.who.int/teams/noncommunicable-diseases/sensory-functions-disability-and-rehabilitation/hearwho ✓ MIMI Hearing test https://mimi.io/mimi-hearing-test-app ✓ SoundPrint https://www.soundprint.co ✓ HearScreen: https://www.hearxgroup.com/hearscreen/ ✓ UHEAR https://medicinapps.com/product/uhea%E2%80%AAr%E2%80%AC/ ✓ Digit-in-Noise Test (DIN)
Questionaires	✓ Screening Tool for Auditory Processing Disorders (SCAN): https://www.pearsonassessments.com/store/usassessments/en/Store/Professional-Assessments/Speech-%26-Language/SCAN-3%3AC-Tests-for-Auditory-Processing-Disorders-for-Children/p/100000236.html ✓ Children's Auditory Performance Scale (CHAPS): https://www.phonakpro.com/content/dam/phonakpro/gc_hq/en/resources/counseling_tools/documents/child_hearing_assessment_childrens_auditory_performance_scale_chaps_2017.pdf ✓ Early Hearing Detection and Intervention (EHDI) Program https://www.asha.org/advocacy/early-hearing-detection-and-intervention/ ✓ Parental Evaluation of Developmental Status (PEDS) https://psycnet.apa.org/doiLanding?doi=10.1037%2Ft04824-000 ✓ "LittlEARS" https://www.medel.com/es-es/about-hearing/hearing-test/little-ears-auditory-questionnaire

Videoconferencing

General platforms: Zoom, Skype, Microsoft Teams, WEBEX, etc.: These platforms are commonly used for remote consultations. They enable real-time communication, facilitating the assessment of auditory behaviours and the administration of simple tests. They also have the option of live subtitling as an accessibility measure.

Figure 1 ***Early detection of postnatal hearing loss in paediatric age groups***

(SOURCE: CODEPEH, compiled by author)



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