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Implementation of assistive technologies for rehabilitation of children with hearing impairments

Abstract

Relevance. Hearing impairments in children negatively affect speech development, cognitive functions, learning and social adaptation, whereas the use of assistive technologies helps compensate for sensory deficits, improve speech perception and promote the child's more effective integration into educational and social environments.

Aim: To analysed recent scientific publications on assistive technologies for the rehabilitation of children with hearing impairments, with a focus on the effectiveness of their use in children with cochlear implants.

Materials and methods. A systematic literature review was conducted in accordance with the PRISMA 2020 guidelines, with the research question formulated using the PICO framework. Clearly defined inclusion criteria and a standardised search strategy were applied across PubMed, Scopus, and Web of Science databases covering the period from 2010 to 2025.

Results. The analysis of 21 selected studies demonstrated that the use of assistive technologies is associated with improved speech perception, reduced negative effects of background noise, and increased academic engagement among children. The most pronounced effect was observed with the combined use of hearing aids or cochlear implant systems together with signal enhancement technologies (FM systems, induction loop systems), which improve the signal-to-noise ratio in challenging acoustic environments. The integration of multiple technological solutions contributes to individualised rehabilitation and enhances its functional effectiveness.

Conclusions. Technological rehabilitation is a relevant and effective method for supporting patients with sensorineural hearing loss, ensuring restoration or improvement of sound and speech perception through hearing aids, cochlear implants, and sound amplification systems. The integration of assistive communication

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technologies enables children with hearing impairments to participate more actively in the educational process, social interactions, and daily life, thereby improving their quality of life and psychosocial well-being. The practical significance of the results lies in substantiating the early individualised use of assistive technologies in the rehabilitation of children with hearing impairments.

Keywords: assistive technologies; FM systems; hearing aids; cochlear implant; hearing impairment; rehabilitation intervention; paediatric patients; speech recognition.

INTRODUCTION

Hearing impairment in childhood remains a major medical and social concern, with a substantial impact on child development, including speech and language acquisition, cognitive function, communication skills, and social adaptation. The timely identification of hearing disorders and the implementation of contemporary rehabilitation approaches are essential for ensuring the optimal development of paediatric patients and improving their quality of life. Advances in early diagnostic methods, together with the use of assistive technologies, hearing aids, cochlear implants, and comprehensive rehabilitation interventions, have expanded the opportunities to support children with hearing impairment. At the same time, these developments highlight the need for further investigation into the effectiveness of modern rehabilitation strategies.

Between 1990 and 2021, the global prevalence of hearing impairment among children across different age groups increased steadily. According to the Global Burden of Disease Study 2021, approximately 97.83 million children and adolescents under the age of 20 were living with hearing impairment of varying severity in 2021, with significant long-term consequences for their physical, cognitive, and psychosocial development. Between 1990 and 2021, the number of children affected by hearing impairment increased from approximately 79.9 million to 97.8 million, while the prevalence rate per 100,000 population rose from 3,537 to 3,711. These findings indicate a substantial increase in the scale of the problem and emphasise the need for greater attention to the prevention, early diagnosis, and rehabilitation of hearing impairment among children and adolescents worldwide [1].

According to estimates by the World Health Organisation (WHO), more than 1.5 billion people worldwide experience some degree of hearing impairment. Approximately 430 million of these individuals have disabling hearing loss, a condition that significantly limits everyday communication and requires specialised treatment and rehabilitation. This number is expected to continue increasing by 2050 [2]. According to the project report of The BEARR Trust, approximately 30,600 people in Ukraine were living with hearing impairment as of 2025 [3]. The same report indicates that the global prevalence of clinically significant hearing impairment among newborns is approximately 1-3 cases per 1,000 live births, making it one of the most common congenital conditions detected through universal newborn hearing screening in the first days of life. In Ukraine, analyses of regional audiological screening programmes indicate a prevalence of approximately one case per 2,000 newborns. However, around 40% of cases remain undiagnosed until after the child reaches six months of age, substantially delaying timely intervention and rehabilitation. These findings were obtained during the 2023 assessment of newborn hearing screening programmes conducted across 16 regions of Ukraine [4]. Consequently, in 2025, the Ministry of Health of Ukraine approved a new regulation, "On Approval of the Procedure for the Provision of Medical Care for the Organisation of Hearing Screening and Diagnosis of Hearing Impairment in Children", which establishes the organisational and methodological framework for hearing screening, including screening stages, risk assessment criteria for hearing loss, and standards for audiological assessment in children up to six years of age [5].

Furthermore, according to O. Kuzenko *et al.* [6] and J. Wang *et al.* [7], approximately 15-17% of school-aged children exhibit some degree of hearing impairment, ranging from mild to moderate forms that may adversely affect academic achievement and social adaptation. Hearing impairment during the school years is often gradual or subclinical, making timely detection through routine medical examinations more challenging. At the same time, this period is critical for the development of cognitive, linguistic, and socio-communicative skills; therefore, even mild hearing loss may have cumulative adverse effects on learning, behaviour, and the child's emotional and psychological development. These findings highlight the need for continuous audiological monitoring not only during the neonatal period but throughout childhood and adolescence, with particular attention to school-aged children. In particular, the systematic review by J. Wang *et al.* [7] demonstrated the increasing prevalence of hearing impairment among children and emphasised the importance of early detection and comprehensive rehabilitation. Similarly, the systematic review by R.S. Melo *et al.* [8] reported positive effects of rehabilitation programmes on balance and functional performance in children with sensorineural hearing loss.

According to the Ministry of Health of Ukraine and the WHO, approximately 40,000 people in Ukraine live with a disability related to hearing impairment. Among pupils attending different types of general secondary schools, around one-fifth are children with hearing loss or deafness, highlighting the need to provide specialised conditions for education, communication, and rehabilitation [2, 6]. Hearing impairment is one of the most common developmental disorders identified in newborns. In approximately 85% of cases, hearing loss is congenital or develops during the first one to two years of life, that is, during the pre-linguistic period and the earliest stages of speech and language development, which are critical for subsequent cognitive, linguistic, and social development. According to published evidence, up to 80% of hearing impairment cases are sensorineural in origin, for which modern hearing rehabilitation approaches, including cochlear implantation systems, may be used [4]. Given the high prevalence of hearing impairment among children, the increasing global number of individuals with hearing loss, and the fundamental importance of hearing for speech and language acquisition, cognitive development, and social integration, cochlear implantation has become widely established as one of the most effective interventions for preventing and reducing the consequences of profound hearing loss. However, the effectiveness of cochlear implantation is not limited to the surgical procedure itself; it depends to a large extent on subsequent rehabilitation incorporating modern assistive technologies aimed at improving auditory perception, developing communication skills, increasing the child's independence, and enabling full participation in education and social life.

Thus, there remains a need to synthesise current scientific evidence regarding the role of assistive technologies in the comprehensive rehabilitation of children with hearing impairment and to identify promising directions for their application in improving auditory perception, communication, and social integration. The aim of this study was to systematise and analyse current scientific evidence concerning the use of assistive technologies in the rehabilitation of children with hearing impairment, with particular emphasis on children with cochlear implants.

MATERIALS AND METHODS

A systematic review of contemporary scientific literature was conducted to evaluate assistive technologies used in the rehabilitation of children with hearing impairment, including children with cochlear implants. The literature analysis encompassed studies investigating the effectiveness of vibration and visual alert systems, FM systems, induction loop systems, as well as text- and video-based communication devices, with particular emphasis on their impact on independence, social integration, and participation in education. The systematic review was conducted in accordance with the PRISMA 2020 Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), following the updated recommendations for transparent and comprehensive reporting [9].

The research question was formulated using the PICO framework, where Population (P) comprised children aged 0-18 years with hearing impairment, including those following cochlear implantation; Intervention (I) included assistive technologies (hearing aids, cochlear implant systems, FM systems, induction loop systems, vibration and visual alert devices, and text- and video-based communication technologies); Comparison (C) consisted of standard rehabilitation approaches or the absence of specialised assistive technologies; and Outcomes (O) included measures of speech recognition, participation in education, social integration, and quality of life [9].

The literature search was conducted in the PubMed, Scopus and Web of Science databases for the period from 1 January 2010 to 31 December 2025. Combinations of keywords and MeSH terms were used: "hearing impairment", "children", "assistive technology", "cochlear implant", "FM system", "assistive listening devices", "speech perception", using the logical operators AND/OR. In addition, references in relevant articles were analysed to identify further sources. The inclusion criteria comprised: (1) studies involving children under the age of 18 with various forms of hearing impairment; (2) a description of the use of at least one type of assistive technology in the context of rehabilitation; (3) the presentation of quantitative or qualitative results relating to clinical, functional or psychosocial outcomes; (4) publication in peer-reviewed journals in English or Ukrainian. The analysis excluded review articles without a clear search methodology, expert opinions, individual case reports without a systematic assessment of effectiveness, and studies relating exclusively to adult patients.

Results of the systematic search. During the identification phase, 312 records were identified in the databases. After removing duplicates (n = 44), 268 publications were retained for further analysis. During the initial screening of titles and abstracts, 194 studies that did not meet the predefined inclusion criteria were excluded. A full-text assessment was carried out for 74 articles, of which 21 studies met all selection criteria and were included in the qualitative synthesis. A schematic representation of the study selection process in accordance with the PRISMA 2020 guidelines is presented in Figure 1, which shows the number of records and the reasons for their exclusion at each stage.

The risk of bias in the included studies was assessed using appropriate tools: the Newcastle-Ottawa Scale for cohort and observational studies, and the AMSTAR-2 tool for published systematic reviews. The analysis was carried out by two independent researchers; any discrepancies in the assessments were resolved through discussion until a consensus was reached.

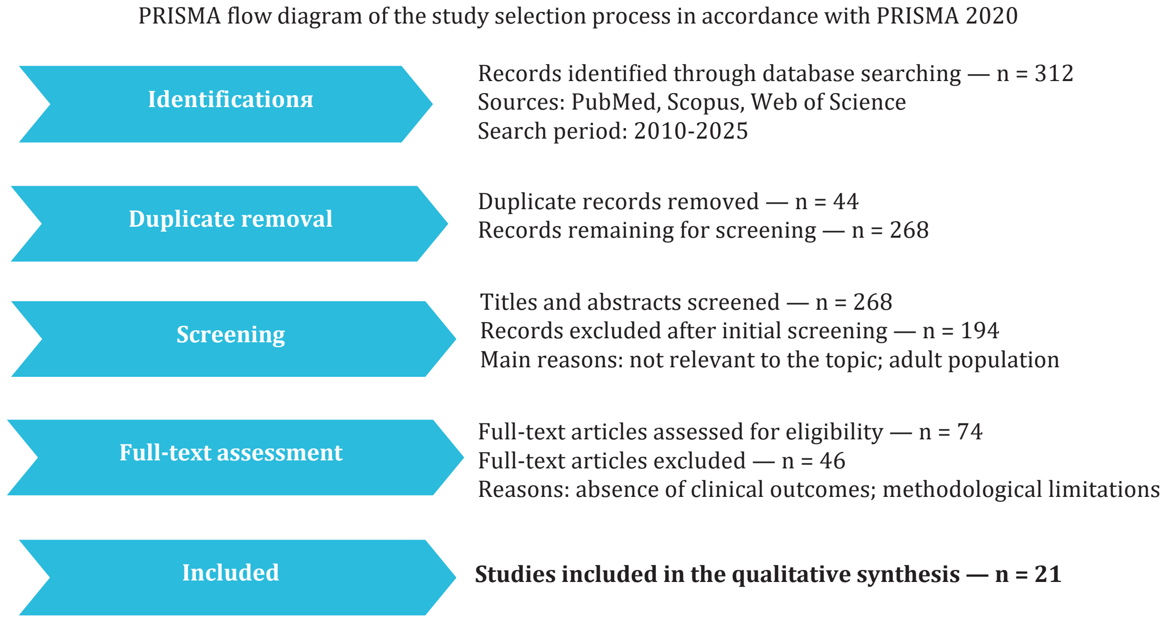

Figure 1. PRISMA flow diagram of the study selection process in accordance with PRISMA 2020

Source: developed by the authors in accordance with the PRISMA 2020 recommendations, based on the results of the systematic search and study selection

Characteristics of the included studies. The qualitative synthesis included 21 studies published between 2010 and 2025. These were predominantly prospective cohort studies, clinical observations and comparative studies of the effectiveness of hearing aids and assistive technologies in children with hearing impairments. In particular, the studies by Z. Guo *et al*. [1], J. Wang *et al*. [7] and R.S. Melo *et al.* [8] were analysed. Studies were selected in accordance with the PRISMA 2020 guidelines. The main outcomes assessed were speech recognition scores, signal-to-noise ratio (SNR), level of learning engagement, social integration and quality of life indicators [10].

RESULTS AND DISCUSSION

The analysed studies examined a broad range of assistive technologies used to support children with hearing impairment. These included hearing aids, cochlear implant systems, FM systems, induction loop systems, visual and vibration alert devices, and digital communication technologies, including text- and video-based communication platforms. Most studies focused on evaluating the effectiveness of hearing aids, cochlear implants, and FM systems, whereas visual and vibration alert devices were generally considered supplementary tools for supporting daily activities and enhancing the safety of children with hearing impairment.

A national policy priority is the development and optimisation of support systems for children with special educational needs, including those with hearing impairment. In Ukraine, international standards of care for children with hearing impairment are being implemented, including universal neonatal hearing screening, expanded access to advanced hearing rehabilitation technologies such as cochlear implants, strengthened early intervention programmes targeting hearing and speech disorders in newborns and young children, and the further development of inclusive education and social integration initiatives. These developments highlight the need to improve existing approaches to auditory-verbal development in children with hearing impairment, as well as to modernise the organisational and technological aspects of corrective and developmental support. According to S.T. Mohamed *et al.* [10], the period from 2020 to 2025 witnessed substantial advances in understanding the special educational needs of children with hearing impairment, reflected in the adoption of more inclusive approaches, wider implementation of assistive technologies, and greater emphasis on the individualisation of educational and rehabilitation support.

The findings are consistent with contemporary international evidence [1-2], confirming the effectiveness of the comprehensive use of assistive technologies in children with hearing impairment. The combined use of hearing rehabilitation devices and signal enhancement systems creates favourable conditions for the development of auditory-verbal skills, improved academic achievement, and enhanced social adaptation. Given the clinical heterogeneity of hearing impairment, Table 1 presents a classification according to aetiology, severity (hearing threshold), time of onset, symmetry of impairment, and audiogram configuration to facilitate a systematic approach to assessment.

Table 1. Classification of hearing impairment according to the main clinical criteria

By aetiology	By severity (hearing threshold)	By time of onset	By symmetry	By audiogram configuration
Conductive hearing loss Sensorineural hearing loss Mixed hearing loss Central hearing loss	Mild: 20-40 dB Moderate: 41-55 dB Moderately severe: 56-70 dB Severe: 71-90 dB Profound: over 90 dB	Congenital Acquired	One-way Two-way	Flat High-frequency Low-frequency Dome-shaped / U-shaped

Source: compiled by the authors based on [1-2, 7]

According to Y.C. Hung *et al.* [11], hearing impairment may be classified into several principal forms according to its aetiology, each characterised by distinct pathogenic mechanisms, clinical manifestations, and approaches to treatment and rehabilitation. Sensorineural hearing loss results from damage to the sensory structures of the inner ear (the cochlear hair cells), the auditory nerve, or the central auditory pathways. This is the most common form of hearing impairment and is generally permanent or progressive in nature. Its causes include genetic factors, intrauterine infections, perinatal injury, ototoxic medications, noise-induced trauma, viral infections, and vascular disorders. A distinct clinical entity is sudden hearing loss, characterised by a rapid decline in hearing function occurring within a period of up to 72 hours. According to O. Kuzenko *et al*. [6] and J. Wang *et al*. [7], when the pathological process involves the inner ear or the auditory nerve, the condition is referred to as sudden sensorineural hearing loss (SSNHL). When no underlying cause can be identified despite comprehensive clinical investigation, the condition is diagnosed as idiopathic sudden sensorineural hearing loss, which represents the most common form of SSNHL encountered in clinical practice.

According to C. Pflug *et al*. [12] and R.S. Melo *et al.* [8], conductive hearing loss is caused by impaired transmission of sound through the structures of the outer or middle ear. The most common causes include inflammatory disorders of the middle ear (acute and chronic otitis media), otitis media with effusion, tympanic membrane perforation, congenital abnormalities of the auditory ossicles, and other mechanical obstructions that interfere with sound conduction. In this form of hearing loss, the inner ear remains functionally intact, and hearing function can often be fully or partially restored following treatment of the underlying cause.

Mixed hearing loss combines features of both conductive and sensorineural hearing loss, indicating the simultaneous involvement of the middle and inner ear structures. According to E. Nightengale *et al.* [13], central hearing loss results from impaired processing of auditory information within the central nervous system, involving the subcortical auditory pathways or the cerebral cortex. In such cases, the peripheral components of the auditory system may remain anatomically and functionally intact. According to N. Tye-Murray *et al.* [14], this type of hearing impairment is frequently associated with prolonged chronic inflammatory diseases of the middle ear complicated by secondary damage to the sensory apparatus and therefore requires a comprehensive multidisciplinary approach to treatment and rehabilitation.

A detailed classification of hearing impairment according to its type, severity, time of onset, symmetry, and audiogram configuration not only enables the systematic organisation of clinical information but also provides the basis for accurate diagnosis and assessment of a child's medical and rehabilitation needs. Hearing assessment is critically important throughout all stages of child development, as the timely identification of hearing disorders allows appropriate intervention strategies to be selected and helps prevent secondary impairments in speech and language, cognitive development, and social functioning. However, according to PravoChuty [4], even after a diagnosis has been established, comprehensive rehabilitation remains essential. This includes the use of modern assistive technologies, hearing aids or cochlear implantation, auditory-verbal training, and support for the child's adaptation to educational and social environments.

Rehabilitation is essential for patients with incomplete recovery of hearing and aims to restore functional abilities and improve quality of life. Counselling regarding the potential benefits of hearing rehabilitation technologies and other supportive interventions is recommended, as systematic reviews have demonstrated their positive effects on functional performance and social participation. According to E.M. Fitzpatrick *et al*. [15], the successful implementation of these technologies requires appropriate counselling and adequate resource provision. The regular use of hearing devices and complementary rehabilitation measures should therefore be regarded as an integral component of comprehensive rehabilitation, promoting optimal functional integration and social participation for the child.

Rehabilitation of patients with residual sensorineural hearing loss following an acute episode is necessary to restore functional abilities and improve quality of life. According to the Clinical Guideline "Management of Patients with Sudden and Acute Sensorineural Hearing Loss" [16], approved by the Ministry of Health of Ukraine in 2022, patients should receive counselling regarding the potential benefits of hearing rehabilitation technologies and other assistive interventions. The use of hearing devices contributes to improved auditory function, enhanced quality of life, and better emotional well-being, while also increasing opportunities for participation in everyday activities.

Device-based rehabilitation for children with hearing impairment is based on the use of technological solutions designed to compensate for hearing deficits and improve communication abilities. These include hearing aids, cochlear implant systems, sound amplification devices, and vibration and visual alert systems. Additional support is provided by modern digital communication technologies, including text-based services and specialised mobile applications. Hearing aids remain one of the principal interventions for auditory rehabilitation in children with hearing impairment. Unlike hearing rehabilitation in adults, paediatric hearing aid fitting is intended not only to compensate for hearing loss but also to facilitate the development of auditory perception, speech and language, and communication skills. Consequently, specialised paediatric hearing aids and age-appropriate fitting algorithms are used, taking into account the developmental characteristics of the auditory system, the degree of hearing loss, and the child's speech and language needs [17]. Specific requirements apply to paediatric hearing aids, as summarised in Table 2.

Table 2. Functional and safety criteria for paediatric hearing aids

Criterion	Description of characteristics
Flexibility of features	Configured according to the paediatric DSL fitting algorithm with minimal distortion
Mechanical safety	Use of hypoallergenic materials, robust construction, and the absence of small detachable parts
Acoustic safety	Control of the maximum output sound pressure level, compression (preferably speech compression), and the option to disable the volume control
Predictability of use	Availability of visual indicators showing device operation, systems for monitoring the correct placement of the earmould, and remote control functionality
Operational reliability	Reliable operation under a range of operating conditions
Ability to activate/deactivate "adult" features	Availability of options to activate or deactivate specific features, including the directional microphone and programme switching, according to the user's needs

Note: DSL – desired sensation level
Source: compiled by the authors based on [2, 7, 17]

According to J.N. Li *et al.* [17], contemporary hearing aids are available in a range of designs, the most common being behind-the-ear and in-the-ear models. Behind-the-ear devices are worn behind the pinna and offer extensive opportunities for individual adjustment according to the degree of hearing loss. In-the-ear models are custom manufactured to fit the anatomical characteristics of the user's external auditory canal and are positioned directly within the ear.

In paediatric practice, behind-the-ear hearing aids are generally preferred because the anatomical characteristics of the external auditory canal in young children limit the suitability of in-the-ear devices. Furthermore, the child's continuous growth necessitates the regular replacement of custom earmoulds and periodic adjustment of hearing aid settings to ensure optimal sound quality. The effectiveness of hearing rehabilitation depends not only on the appropriate selection of the hearing device but also on subsequent auditory rehabilitation. Following hearing aid fitting, it is essential to develop the child's ability to perceive and interpret auditory information. The rehabilitation process includes gradual exposure to different acoustic stimuli, training in sound source localisation, discrimination between speech and non-speech sounds, and the enhancement of auditory attention and communication skills. Such a comprehensive approach facilitates successful adaptation to hearing aid use and improves auditory-verbal outcomes [15, 17].

Cochlear implantation is a modern, high-technology method of auditory rehabilitation indicated for patients with severe or profound sensorineural hearing loss when conventional hearing aids do not provide sufficient speech perception or auditory development [17]. Unlike hearing aids, which amplify acoustic signals and rely on the remaining function of the auditory system, cochlear implant systems provide direct electrical stimulation of the auditory nerve fibres, thereby compensating for the impaired function of damaged sensory cells within the inner ear [18].

According to F. Nassrallah *et al*. [18], a cochlear implant system consists of two components: an internal and an external unit. The internal component comprises the receiver-stimulator and an electrode array implanted into the cochlea. The external component includes the speech processor, transmitting coil, and connecting elements responsible for transmitting information between the external and internal parts of the system. Signal transmission is achieved through magnetic coupling between the transmitting coil and the implanted receiver. Studies by J.N. Li *et al*. [17] and F. Nassrallah *et al.* [18] have shown that cochlear implants improve the perception of environmental sounds, enhance speech intelligibility, and increase communication effectiveness across a variety of acoustic environments. Cochlear implantation is particularly important in childhood because it provides the foundation for the development of auditory-verbal skills, educational attainment, and social adaptation. However, the effectiveness of cochlear implantation depends not only on the surgical procedure but also on comprehensive post-implantation rehabilitation. Following device activation, key components of rehabilitation include individual programming of the speech processor, ongoing technical support, auditory training, speech and language development, and the enhancement of communication skills. It is this combination of technological hearing restoration and long-term auditory-verbal rehabilitation that enables the full potential of cochlear implantation to be realised.

According to J.S. Kim & C.H. Kim [19], Assistive Listening Systems (ALSs), also referred to as Assistive Listening Devices (ALDs), comprise a group of technologies designed to improve speech understanding and sound quality in challenging acoustic environments, particularly in public settings where background noise, distance from the sound source, or reverberation reduce speech intelligibility for individuals with hearing impairment. ALSs operate by improving the signal-to-noise ratio, which is essential for effective speech recognition by people with hearing loss in everyday listening situations, particularly when conventional hearing aids or cochlear implants alone do not provide sufficient benefit. An FM system is a wireless type of ALS that uses frequency modulation to transmit sound directly from a source, such as a lecturer's microphone or a public address system, to the user's receiver. The receiver may either be integrated into the hearing aid or cochlear implant or provided as a separate device connected to a hearing aid or headphones. Figure 2 illustrates the principal capabilities of FM systems in improving speech perception.

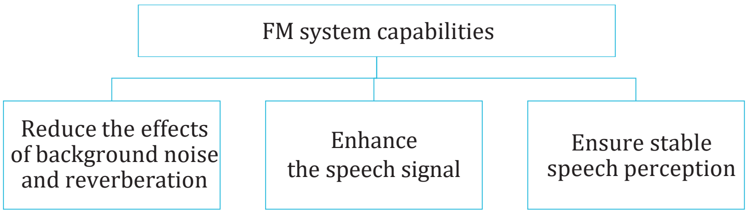

Figure 2. Key capabilities of FM systems

Source: compiled by the authors based on [2, 7, 19]

The system presented in Figure 2 amplifies the speech signal without being affected by background noise or the distance between the sound source and the listener. It reduces the effects of reverberation by transmitting the signal on a dedicated radio frequency independent of the room's overall sound field, thereby ensuring stable speech perception even in large halls or open spaces. Scientific studies have demonstrated that the use of FM systems significantly improves speech recognition in noisy environments, which is particularly important in educational settings. An induction loop is a type of ALS that generates an electromagnetic field within a defined area, which can be received wirelessly by hearing aids or cochlear implant processors equipped with a telecoil (T-coil). This technology overcomes problems associated with background noise and distance by transmitting the signal directly to the hearing device without intermediate acoustic transmission [20]. Both FM systems and induction loop systems are widely used; their comparative characteristics are presented in Table 3.

Table 3. Main characteristics of FM systems and induction loop systems

Characteristic	FM systems	Induction loop systems
Principle of transmission	Radio-based signal modulation (radio frequency) to the receiver	Magnetic field generated within a room and received by the hearing aid/telecoil
Connection to the hearing aid	Requires a separate receiver or integration	Directly via the T-coil (telecoil) in the hearing aid or cochlear implant
Signal transmission	Via a dedicated receiver	Direct transmission
Sound quality / SNR	Excellent SNR over distance	Very high SNR over distance
Power consumption	Receivers may increase the hearing aid's battery consumption	No impact on the user's hearing aid battery; power is supplied by the loop system
Applications	Open spaces, large halls, and classrooms	Public venues, theatres, conference halls, cinemas, and lecture theatres
Advantages	Flexible transmission range; supports a large number of users	Easy to use; no separate receivers required

Note: SNR – signal-to-noise ratio
Source: compiled by the authors based on [2, 20]

The findings reported by A. Flores Ramones & M.S. Del-Rio-Guerra [21] demonstrate that vibration and visual alert systems are important components of assistive technologies, providing alternative notification channels for individuals who are deaf or have severe hearing loss. Conventional auditory alerts are often inaccessible to people with hearing impairment, creating safety risks and limiting participation in everyday activities. By using vibration (tactile) and visual (light-based) alerts, information about important events can be conveyed through alternative sensory systems, consistent with the principles of sensory substitution and multisensory support in assistive technologies.

Vibration alert systems use tactile stimulation to notify users of important auditory events, such as telephone calls, alarm clocks, or emergency warnings. These systems may take the form of wearable devices, wristbands, vibrating mats, or bed shakers that activate when the surrounding system detects a relevant sound event. Practical studies have shown that wearable vibration devices can effectively detect important sounds and communicate them to the user through tactile feedback, thereby improving awareness of environmental events and enhancing safety in everyday life [22]. According to "Healthy Hearing" [23], tactile alerts are particularly effective when auditory signals are unavailable or insufficient, such as during sleep or in noisy environments.

Visual alert systems employ flashing strobe lights, LED indicators, or visual notification devices that flash or vary their light intensity when an auditory event is detected, for example a doorbell, telephone call, or smoke alarm. These visual notifications enable users to recognise important events immediately without relying on auditory cues, which is particularly valuable in domestic and public environments where conventional sound-based alerts are inaccessible to individuals with severe hearing loss. Combining visual and vibration alerts further improves the reliability of notification systems and enhances environmental accessibility by engaging multiple sensory modalities simultaneously [24].

These technologies are increasingly integrated into modern smart home systems incorporating intelligent sensors, mobile notifications, IoT devices, and wearable technologies, enabling users to receive real-time alerts with adjustable vibration intensity and visual indicators according to individual preferences. The development of such solutions reflects the broader trend towards implementing assistive technologies that enhance accessibility, independence, and everyday functioning for people with hearing impairment. According to E. Bahçekapılı & A. Ayaz [25], the use of visual and vibration alerts in assistive systems is consistent with the concept of sensory substitution, whereby information about auditory events is transmitted through alternative sensory modalities, such as tactile or visual input, thereby compensating for the loss of auditory information. This approach is based on the principle of neuroplasticity, which enables the brain to adapt to signals received through alternative sensory pathways.

Text telephones and devices supporting text- or video-based communication are important components of contemporary assistive technologies, providing accessible and barrier-free communication for people with hearing impairment. These technologies enable users to exchange information through alternative communication methods, including text messaging, chat interfaces, and video calls incorporating sign language or real-time captions. According to P.A. Rodríguez-Correa *et al*. [26], modern smartphones equipped with text-based communication functions support SMS, instant messaging (IM), chat applications, and adaptive keyboards, substantially improving access to telephone communication compared with conventional voice calls. Studies have shown that text-based communication enhances independence and social participation among individuals with hearing loss by eliminating reliance on auditory speech perception, which may be difficult or impossible for these users.

In addition, contemporary smartphones and computer-based platforms support video communication using sign language, enabling people who use sign language to participate in video calls and video conferencing in which information is exchanged visually. This mode of communication is particularly valuable for users whose primary language is sign language rather than written text, providing a highly accurate and natural means of interaction. According to the review by M. Rivas Velarde *et al*. [27], video platforms supporting ASL significantly improve communication accessibility in professional, educational, and social settings.

The effectiveness of these technologies is supported by research on digital accessibility and inclusive communication, demonstrating that the integration of text and video-based communication tools reduces communication barriers, improves psychosocial well-being, and enhances social participation among individuals with sensory impairments. For example, studies by M.J. Myers *et al.* [28] and S. Sabbagh *et al*. [29] have shown that the use of video communication incorporating sign language or automatic captioning in customer service settings improves the quality of interactions across healthcare, education, and employment.

Overall, the findings indicate that the integration of assistive technologies into the rehabilitation of children with hearing impairment is consistent with contemporary evidence-based practice, as reflected in the clinical and experimental studies included in this review. These technologies enhance the effectiveness of auditory-verbal rehabilitation, expand opportunities for children's communication development, and support their successful adaptation to educational and social environments. Consequently, assistive technologies should be regarded as an integral component of comprehensive auditory-verbal and psychosocial support for children with hearing impairment.

CONCLUSIONS

1. The results of an analysis of 21 scientific publications released between 2010 and 2025 highlight the

important role of assistive technologies in the comprehensive rehabilitation of children with hearing impairments. The most common forms of assistive technology remain hearing aids, cochlear implants and remote sound transmission systems (FM systems), the effectiveness of which has been confirmed by numerous clinical and review studies.

2. The analysis of the literature showed that the use of modern hearing rehabilitation technologies improves auditory perception, speech intelligibility, speech perception in the presence of background noise, and overall communication effectiveness. The integration of assistive communication technologies enables children with hearing impairment to participate more actively in educational activities, social interactions, and everyday life, thereby improving their quality of life and psychosocial well-being.

3. It was established that, alongside conventional hearing aids and cochlear implants, additional assistive technologies play an important role, including FM systems, induction loop systems, vibration and visual alert devices, text communication tools, video communication platforms, and automatic captioning technologies. Their use expands access to information, enhances safety, and promotes greater independence for children in their daily lives.

4. The findings of the analysed studies indicate that the integration of assistive technologies into educational environments has a positive impact on academic achievement, social adaptation, and the quality of life of children with hearing impairment. The use of modern communication support technologies encourages more active participation in the learning process, improves interaction with peers, and facilitates inclusion in society.

5. The practical significance of these findings lies in confirming the value of the early implementation of assistive technologies as an integral component of the multidisciplinary rehabilitation of children with hearing impairment. The selection of specific technological solutions should be individualised according to the child's age, degree of hearing loss, educational needs, and everyday functional requirements. Future research should focus on evaluating the long-term effectiveness of emerging digital assistive technologies, automatic speech recognition and captioning systems, and their impact on educational outcomes, social integration, and the quality of life of children with cochlear implants.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

[1] Guo Z, Ji W, Song P, Zhao J, Yan M, Zou X. Global, regional, and national burden of hearing loss in children and adolescents, 1990-2021: A systematic analysis from the Global Burden of Disease Study 2021. BMC Public Health. 2024;24:2521. DOI: 10.1186/s12889-024-20010-0

[2] World Health Organization. World report on hearing [Internet]. 2021 March 3 [cited 2025 November 11]. Available from: https://www.who.int/publications/i/item/world-report-on-hearing

[3] The BEARR Trust. Project report: The voice of Ukrainians with hearing impairments [Internet]. 2025 February 6 [cited 2025 November 11]. Available from: https://bearr.org/2025/02/06/project-report-the-voice-of-ukrainians-with-hearing-impairments/

[4] PravoChuty: Analysis of hearing screening status among newborns in Ukraine [Internet]. [cited 2025 November 11]. Available from: https://vidchui.org/proekty/pravochuty-analiz-stanu-skryningu-sluhu-sered-novonarodzhenyh-v-ukrayini/

[5] Order of the Ministry of Health of Ukraine No. z0746-25. On the Approval of the Procedure for the Provision of Medical Care in Relation to the Organisation of Screening and Diagnosis of Hearing Impairments in Children [Internet]. 2025 April 29 [cited 2025 November 11]. Available from: https://zakon.rada.gov.ua/go/z0746-25

[6] Kuzenko O, Liannoi M, Kravets N, Vaskiv T. Ways of implementing auditory-verbal rehabilitation tasks in children with cochlear implants. Educ Horiz 2024;59(2):55–61. DOI: 10.15330/obrii.59.2.55-58

[7] Wang J, Sung V, Carew P, Burt RA, Liu M, Wang Y, et al. Prevalence of childhood hearing loss and secular trends: A systematic review and meta-analysis. Acad Pediatr. 2019;19(5):504–14. DOI: 10.1016/j.acap.2019.01.010

[8] Melo RS, Lemos A, Paiva GS, Ithamar L, Lima MC, Eickmann SH, et al. Vestibular rehabilitation exercise programs to improve postural control, balance, and gait in children with sensorineural hearing loss: A systematic review. Int J Pediatr Otorhinolaryngol. 2019;127:109650. DOI: 10.1016/j.ijporl.2019.109650

[9] PRISMA Statement. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [Internet]. [cited 2025 November 11]. Available from: https://www.prisma-statement.org/

[10] Mohamed ST, Hazzaa N, Abdel Rahman T, Ezz Eldin DM, Elhusseiny AM. Efficacy of vestibular rehabilitation program in children with balance disorders and sensorineural hearing loss. Int J Pediatr Otorhinolaryngol. 2024;179:111931. DOI: 10.1016/j.ijporl.2024.111931

[11] Hung YC, Chen PH, Lin TH, Lim TZ. Children with unilateral hearing loss after newborn hearing screening in Taiwan. Am J Audiol. 2022;31(3):646–55. DOI: 10.1044/2022_AJA-22-00019
[12] Pflug C, Kiehn S, Koseki JC, Pinnschmidt H, Müller F, Nienstedt JC, et al. Prognostic factors in non-organic hearing loss in children. Int J Audiol. 2022;61(5):400–7. DOI: 10.1080/14992027.2021.1922942
[13] Nightengale E, Yoon P, Wolter-Warmerdam K, Daniels D, Hickey F. Understanding hearing and hearing loss in children with Down syndrome. Am J Audiol. 2017;26(3):301–8. DOI: 10.1044/2017_AJA-17-0010
[14] Tye-Murray N, Spehar B, Sommers M, Mauzé E, Barcroft J, Grantham H. Teaching children with hearing loss to recognize speech: Gains made with computer-based auditory and/or speechreading training. Ear Hear. 2022;43(1):181–91. DOI: 10.1097/aud.0000000000001091
[15] Fitzpatrick EM, Al-Essa RS, Whittingham J, Fitzpatrick J. Characteristics of children with unilateral hearing loss. Int J Audiol. 2017;56(11):819–28. DOI: 10.1080/14992027.2017.1337938
[16] Ministry of Health of Ukraine. Clinical guideline: Management strategy for patients with sudden and acute sensorineural hearing loss. Kyiv: Ministry of Health of Ukraine; 2022. 74 P.
[17] Li JN, Chen S, Zhai L, Han DY, Eshraghi AA, Feng Y, et al. The advances in hearing rehabilitation and cochlear implants in China. Ear and Hearing. 2017;38(6):647–52. DOI: 10.1097/AUD.0000000000000441
[18] Nassrallah F, Tang K, Whittingham J, Sun H, Fitzpatrick EM. Auditory, social, and behavioral skills of children with unilateral/mild hearing loss. J Deaf Stud Deaf Educ. 2020;25(2):167–77. DOI: 10.1093/deafed/enz041
[19] Kim JS, Kim CH. A review of assistive listening devices and digital wireless technology for hearing instruments. Korean J Audiol. 2014;18(3):105–11. DOI: 10.7874/kja.2014.18.3.105.
[20] Kaufmann T, Sterkens J, Woodgate JM. Hearing loops. The preferred assistive listening technology. J Audio Eng Soc. 2015;63(4):298–302.
[21] Flores Ramones A, Del-Rio-Guerra MS. Recent developments in haptic devices designed for hearing-impaired people: A literature review. Sensors. 2023;23(6):2968. DOI: 10.3390/s23062968
[22] Yağanoğlu M, Köse C. Real-time detection of important sounds with a wearable vibration-based device for hearing-impaired people. Electronics. 2018;7(4):50. DOI: 10.3390/electronics7040050
[23] Turner J. Alerting devices for hearing-impaired individuals [Internet]. 2025 February 10 [cited 2025 November 11]. Available from: https://myhearingcenters.com/blog/alerting-devices-for-hearing-impaired-users/
[24] Minnesota Department of Human Services, Deaf and Hard of Hearing Services. Assistive technology: Alerting devices for people who are deaf or hard of hearing [Internet]. [cited 2025 November 11]. Available from: https://mn.gov/deaf-hard-of-hearing/assistive-technology/alerting-devices
[25] Bahçekapılı E, Ayaz A. Assessing the impact of assistive technologies on the lives of the hearing impaired: A bibliometric analysis. In: Transforming media accessibility in Europe. Cham: Springer; 2024. P. 337–56. DOI: 10.1007/978-3-031-60049-4_19
[26] Rodríguez-Correa PA, Fernández-Batanero JM, Montenegro-Rueda M. Benefits and development of assistive technologies for communication between deaf and hearing people: A systematic review. Front Educ. 2023;8:1121597. DOI: 10.3389/feduc.2023.1121597
[27] Rivas Velarde M, Jagoe C, Cuculick J. Video relay interpretation and overcoming barriers in health care for deaf users: Scoping review. J Med Internet Res. 2022;24(6):e32439. DOI: 10.2196/32439
[28] Myers MJ, Annis IE, Withers J, Williamson L, Thomas KC. Access to effective communication aids and services among American Sign Language users across North Carolina: disparities and strategies to address them. Health Commun. 2022;37(8):962–71. DOI: 10.1080/10410236.2021.1878594
[29] Sabbagh S, Amiri M, Khorramizadeh M, Iranpourmobarake Z, Nickbakht M. Neonatal hearing screening: Prevalence of unilateral and bilateral hearing loss and associated risk factors. Cureus. 2021;13(6):e15947. DOI: 10.7759/cureus.15947

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Впровадження асистивних технологій для реабілітації дітей з порушенням слуху

Анотація

Актуальність. Порушення слуху у дітей негативно впливають на розвиток мовлення, когнітивні функції, навчання та соціальну адаптацію, тоді як використання асистивних технологій допомагає компенсувати сенсорні дефіцити, покращити сприйняття мовлення й сприяти ефективнішій інтеграції дитини в освітнє та соціальне середовище.

Мета. Аналіз сучасних наукових публікацій, присвячених асистивним технологіям у реабілітації дітей із порушеннями слуху, з акцентом на ефективність їх використання у дітей із кохлеарними імплантами.

Матеріали та методи. Проведено систематичний огляд літератури відповідно до вимог PRISMA 2020 із визначенням дослідницького питання за моделлю PICO, чіткими критеріями включення та стандартизованою стратегією пошуку в базах PubMed, Scopus та Web of Science за 2010-2025 роки.

Результати. Аналіз 21 відібраного дослідження засвідчив, що застосування асистивних технологій асоціюється з покращенням розпізнавання мовлення, зменшенням негативного впливу фонового шуму та підвищенням академічної активності дітей. Найбільш виражений ефект спостерігався при комбінованому використанні слухових апаратів або систем кохлеарної імплантації з технологіями підсилення сигналу (FM-системи, індукційні петлі), що забезпечують покращення співвідношення сигнал/шум у складних акустичних умовах. Інтеграція декількох технологічних рішень сприяє індивідуалізації реабілітації та підвищенню її функціональної результативності.

Висновки. Апаратна реабілітація є актуальним і ефективним засобом підтримки пацієнтів із сенсоневральними порушеннями слуху, забезпечуючи відновлення або покращення сприйняття звуків і мовлення за допомогою слухових апаратів, кохлеарних імплантів та систем підсилення звуку. Інтеграція допоміжних технологій для комунікації дозволяє дітям із порушеннями слуху активніше брати участь у навчальному процесі, соціальних взаємодіях та повсякденному житті, покращуючи їхню якість життя та психосоціальне благополуччя. Практичне значення результатів полягає в обґрунтуванні раннього індивідуалізованого застосування допоміжних технологій у реабілітації дітей із порушеннями слуху.

Ключові слова: допоміжні технології; FM-система; слухові апарати; кохлеарний імплант; слухові порушення; реабілітаційне втручання; пацієнти дитячого віку; розпізнавання мовлення.