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Review articles

Contributions of musical approaches to the development of auditory, speech, and language skills of children and adolescents with cochlear implants: a scoping review

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ABSTRACT

Purpose: to map, through a scoping review, the contributions of musical approaches to developing auditory, speech, and language skills in children and adolescents using cochlear implants (CIs).

Methods: a review conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses-Extension for Scoping Reviews (PRISMA-ScR) and registered in PROSPERO, under the review registration number CRD42020205581. A bibliographic search was carried out in databases in 2020 and updated in August 2023. No date or language limits were applied.

Literature Review: altogether, 1,351 studies were found through the search strategy. After the eligibility assessment based on the PCC strategy, 11 studies were selected and analyzed in full text.

Conclusion: the studies have demonstrated that musical approaches contribute to developing auditory, speech, and language skills in children and adolescents using CIs.

Keywords: Music; Music Therapy; Cochlear Implantation; Perception; Deafness

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INTRODUCTION

The cochlear implant (CI) or bionic ear is one of the most significant technological advances in bioengineering. Through this electronic device, capable of directly stimulating the auditory nerve fibers, the sensory function of the hearing organ can be partially replaced, allowing individuals with severe or profound hearing loss (HL) the possibility of accessing the world of sounds[1,2].

More than four decades ago, when the CI began to emerge as a treatment for subjects presented with HL, people had generally modest expectations of the performance the device would provide. The indication was restricted to adults with profound HL in both ears, who obtained minimal or no benefit from the use of a hearing aid (HA). These first CI models were considered devices that only helped with orofacial reading. However, the growth in relevant fields such as psychophysics, signal processing, and neural excitation has gradually increased expectations of achieving good results[3].

Studies have shown that the CI can integrate users into the world of sound and the perception of speech sounds, satisfactorily favoring many children and adolescents – although the benefits are not identical for everyone[4-7].

An increasing effort of scientific research has been directed at the perception of sounds that do not involve speech, especially music. Studies have shown children's, adolescents', and adults' difficulties in perceiving and appreciating music. Besides the technical signal processing limitations of the device, anatomical changes due to sensory deprivation and pre-CI hearing experience lead to different individual listening conditions with the device[8-12].

Researchers in the field of audiology and related areas have been committed to proposing musical training for this population[13,14], as music plays an important role in people's lives. The literature also points out that musical approaches are effective strategies for promoting different types of skills, such as auditory, speech, and language skills, which can justify their applicability in the various contexts of human experience.

There is evidence that musical training can improve speech perception and other skills[15-17], mediated by CI. However, designing and implementing musical training with children and adolescents using CIs can be challenging for several reasons[18], and many studies involved paradigms due to musical training without rigorous experimental control[19-21].

Every individual has a musical aptitude – the sooner they benefit from a musical environment, the better they perform. Auditory experiences in the first years of life are essential for the individual to become a good listener and develop various skills necessary for their global development[22].

Various studies have aimed to discuss, through literature reviews, the benefits of musical approaches and their outcomes for CI users[18,19,21,23,24]. Music can knowingly have positive consequences for the lives of children and adolescents with HL. However, despite the promising results, it is necessary to search for the best scientific evidence, with frequent updates. Thus, the evidence must be systematically analyzed to verify whether different musical approaches effectively improve auditory, speech, and language skills in children and adolescents using CIs.

Hence, this study aimed to map, through a scoping review, the contributions of musical approaches to developing auditory, speech, and language skills in children and adolescents using CIs.

METHODS

Search strategy

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses – Extension for Scoping Reviews (PRISMA-ScR) and registered in PROSPERO under review registry number CRD42020205581.

This study was conducted in 2020 and updated in August 2023. Records were imported to Rayyan reference management software. It identified and removed possible duplicates to answer the clinical question, "Do musical approaches contribute to the development of auditory, speech, and language skills in children and adolescents using CI when compared to those without this type of intervention?"

A search strategy[25] was used in the bibliographic search, aiming to find studies describing the results of musical approaches for children and adolescents using CIs. The following databases were searched for indexed scientific articles: CENTRAL, MEDLINE/PubMed, EMBASE, CINHAL, Web of Science, ScienceDirect, LILACS, Scopus, ClinicalTrials.gov, and WHO-ICTRP. No date or language limits were applied. The process included a manual search, the use of

uniterms (common research terminology by the subject of interest) and synonyms, and reference lists in studies for additional citations.

Articles to develop this review were searched with the following descriptors in the Medical Subject Headings (MeSH): "Music", "Music Therapy", "Pitch Perception", "Child", "Adolescent", "Infant", and "Cochlear Implantation". The following keywords were used: "Music Education", "Music Training", "Music Perception", "Hearing Aids", "Deaf", and so forth. The search strategy used the Boolean operators AND and OR (Table 1).

Table 1. Search strategy in the databases and registers

Databases	Descriptors e Keywords				
MEDLINE/PubMed, Scopus	"Music" OR "Music Therapy" OR "Pitch Perception" OR "Music Education" OR "Music Training" OR "Musical Simulation" OR "Music Perception" OR "Music activities" OR "Musical exposure" OR "Auditory training" OR "Auditory perception" OR "Sing"	AND	"Cochlear Implantation" OR "Hearing loss" "Hearing aids" OR "Deaf"	AND	"Child" OR "Adolescent" OR "Infant" "Pre-lingual" OR "Children" OR "Pediatric"
Web of Science, CINHAL	"Music" OR "Music Therapy" OR "Auditory Perception" OR "Music Education" OR "Music Training" OR "Music Perception" OR "Music Activities"	AND	"Cochlear Implants" OR "Hearing loss" OR "Hearing aids"	AND	"Infant" OR "Pre-lingual" OR "Children" OR "Pediatric"
EMBASE	"Music" OR "Music Therapy" OR "Auditory Perception" OR "Music Training" OR "Music Perception"	AND	"Cochlear Implants" OR "Hearing loss" OR "Hearing aids"	AND	"Children" OR "Pediatric"
Science Direct	"Music" OR "Music Therapy" OR "Music Education" OR "Music Training"	AND	"Cochlear Implants"	-	"Infant" OR "Children" OR "Pediatric"
WHO-ICTRP, ClinicalTrials.gov	Music" OR "Music Therapy" OR "Music Training"	AND	"Cochlear Implants" OR "Hearing loss"		
LILACS	"Music" OR "Música" OR "Musique" OR "Música"	AND	"Cochlear implants" OR "Implante coclear" OR "Implant cochléaire" OR "Implante coclear"		

Selection criteria

The selection process used the following criteria, based on the Population, Concept, and Context (PCC) strategy: (P): children and adolescents using CI; (C): non-computerized musical approaches in individual or group format, such as music education (activities that involve the process of acquiring musical knowledge), music therapy (activities that involve music without the objective of acquiring musical knowledge), and musical experiences and/or training (activities that work on the appreciation and discrimination of sounds or music), compared with a control group not exposed to musical approaches or exposed to other activities (such as sports, arts, and languages), with subjects on a waiting list, or with one another; (C): clinical studies in the scientific literature that aimed to verify the development of auditory, speech, and language skills in children and adolescents using CIs, exposed to musical approaches.

The analysis addressed results after intervention in the short run (up to 6 months), medium run (from 7 to 24 months), and long run (over 24 months).

Data analysis

Two authors independently and thoroughly screened all titles and abstracts identified through the search strategy.

After the search, all included abstracts were evaluated in full to determine their eligibility for inclusion in the study. The articles underwent critical analysis to identify their methodological characteristics, interventions, and results. In cases of divergence, the two reviewers reached a consensus.

The review included studies involving children and adolescents up to 18 years of age, with severe to profound sensorineural HL, users of unilateral or bilateral CI, and who had been submitted to intervention

with some type of musical approach. The exclusion criteria were studies that did not only use musical approaches as an intervention procedure.

LITERATURE REVIEW

Search results

Altogether, 1,543 studies were found in the databases, of which 192 were identified as duplicates and excluded after the first screening, using the automatic exclusion tool with terms of disinterest in Rayyan software, and eliminating studies that evidently did not meet the inclusion criteria (237). Then, 1,114 studies were rescreened by title and abstract reading, and 453 were excluded. Thus, 661 studies were selected for full-text reading, of which 11 met the PCC criteria. The flowchart detailing the process is shown in Figure 1.

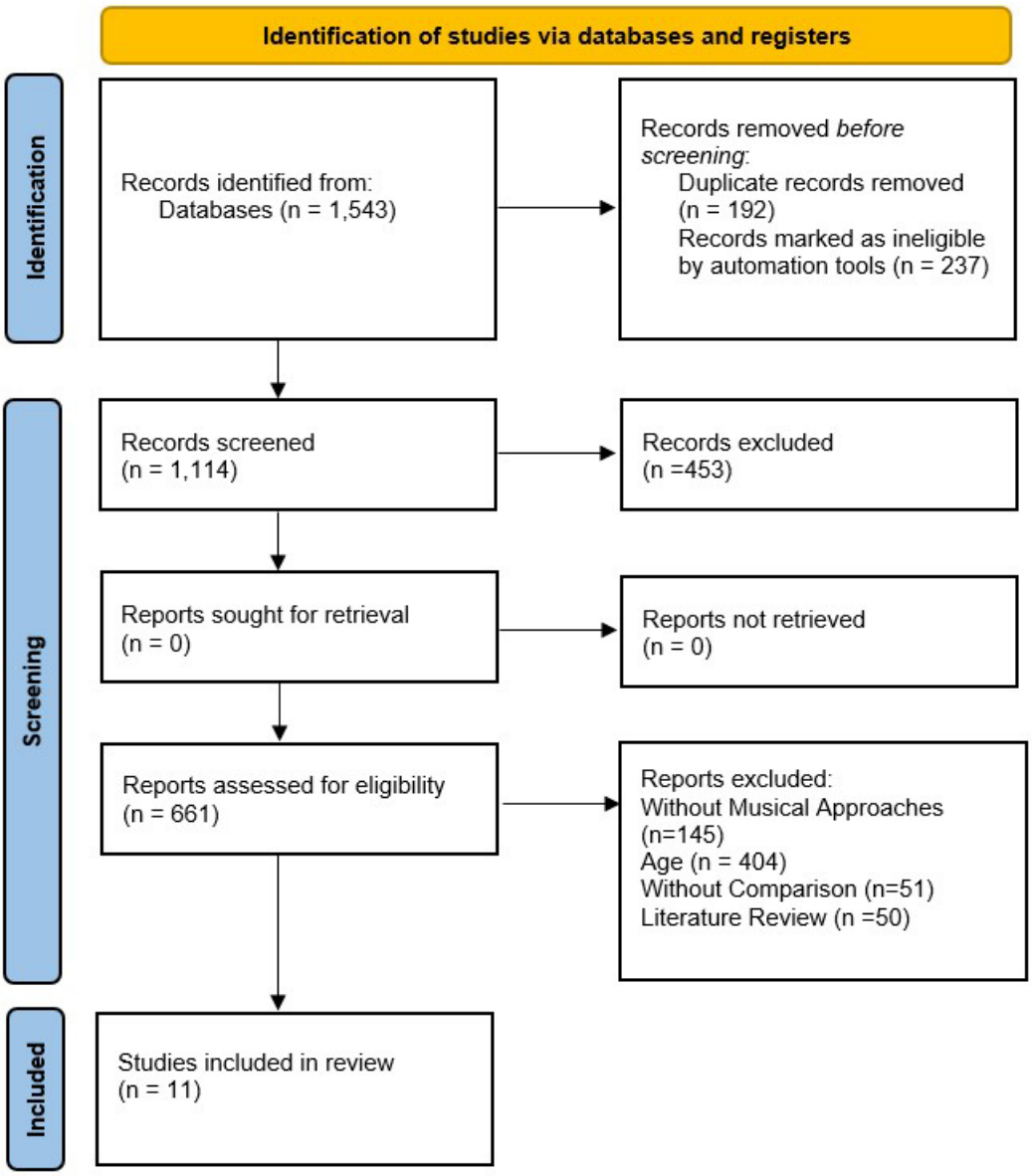

Figure 1. PRISMA flowchart – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Overall, 650 studies were removed – 145 (24.96%) for not using musical approaches, 404 (61.12%) for not assessing only children or adolescents, 51 (7.72%) for not having any comparison group, and 50 (7.56%) for being literature reviews. Therefore, 11 (1.66%) studies were selected for full-text reading and qualitative analysis (Table 2).

Studies included in the review

Table 2. Qualitative analysis of the studies

Authors	Sample	Intervention	Objectives	Results
Torppa et al. (2014a)[26]	42 children (4 to 13 years old), divided into 2 groups: experimental group - composed of 21 children using unilateral CI, exposed to musical activities; and control group - 21 children with normal hearing, not exposed to musical activities.	Experimental group: subdivided into 2, comprising 8 children exposed to home musical activities once or twice a week e.g., singing, playing a musical instrument, or other musical activity, such as music appreciation (listening); and 9 children exposed to music classes weekly. Musical activities were evaluated through questionnaires addressed to parents and daycare center/school staff. The 42 children were assessed twice with standardized protocols over 16 months: digit test, prosody, duration pattern discrimination, intensity, and fundamental frequency.	To investigate prosodic perception in early implanted children concerning auditory discrimination, auditory working memory, and exposure to music.	There was an improvement in the prosodic perception of participants who had music classes and musical activities at home. Children with CI who were exposed to music performed statistically equivalent to the control group, except in the digit test.
Lo et al. (2020)[27]	30 children (6 to 9 years old) were divided into two groups: 16 children with typical hearing (without exposure to musical training) and 14 children with CI or bilateral hearing loss (with exposure to musical training).	Weekly music therapy group sessions and intervention through an application used at home.	To assess whether musical training promotes musical and speech development. Pseudo-randomized clinical study.	The authors concluded that musical training promotes musical and speech development.
Innes-Brown et al.(2013)[28]	20 children aged 9 to 13 years divided into two groups: experimental group – 11 children with hearing impairment (6 used unilateral CI and 5 bilateral hearing aids) and control group - 9 children with typical hearing development.	All children participated in a weekly lunchtime music club at school, consisting of 45 minutes of class for 1 year, with vocal games, integration of auditory, visual, and kinesthetic learning modes, and other musical learning approaches, such as the Kodály method. Standardized tests were used to assess pitch discrimination, rhythm, and timbre recognition administered 4 times over 1 year.	To determine a baseline for the performance of hearing-impaired children on standardized musical perception tests (rhythm, pitch, and timbre) and determine whether exposure to structured music would have an effect on musical perception.	The results highlight the importance of temporal cues for musical perception. There was no correlation between test performance and music club participation. However, teachers reported that participation improved children's confidence, social development, and engagement in music lessons generally.
Good et al. (2017)[29]	18 children and adolescents using CI, aged 6 to 15 years, divided into two groups: experimental group – 9 children exposed to music classes. Control group - 9 children exposed to art classes.	9 children were exposed to musical training (piano lessons, singing, and other musical approaches): 5 with unilateral CI and 4 with bilateral CI. 9 children were exposed to art classes (painting): 4 with unilateral CI and 5 with bilateral CI. The training period was 6 months for both groups. Measures were taken before during and after training to evaluate musical perception (Montreal Battery for Evaluation of Amusia - MBEA) and emotional prosody of speech: identification of the emotional intention of a semantically neutral sentence under audio-only and audiovisual conditions.	To evaluate whether children using CI obtain similar benefits when exposed to musical training.	The results showed that musical training improved the perception of music elements and the emotional prosody of speech. The group exposed to visual artistic activities did not improve these skills.

Authors	Sample	Intervention	Objectives	Results
Hidaldo et al. (2017)[30]	31 children divided into two experiments: 16 children with typical hearing development aged 5 to 6 years (Experiment 1). 15 children aged 5 to 9 years using CIs and/or hearing aids (Experiment 2).	Experiment 1: naming task to evaluate temporal adaptation in speech interaction applied 30 minutes after a 30-minute rhythmic musical training session. Experiment 2: The test was administered twice, 30 minutes after a rhythmic musical training session and 30 minutes a week after a conventional speech therapy session. 1-week break between sessions. Rhythmic exercises such as body percussion, clapping, and playing maracas, among other musical approaches. Test made by a virtual game to name drawings. Virtual opponent.	To investigate temporal adaptation in speech interaction in children with normal hearing and children with CI and/or hearing aids and whether musical training can improve these skills in children with hearing loss.	The results showed the importance of musical rhythmic training for improving the temporal capacity of children with hearing impairment.
Polonenko et al. (2017)[31]	50 children aged 6 to 18 years: 16 with typical hearing development, 26 bilateral CI users, and 8 with bimodal adaptation (CI + hearing aid). Divided into two groups: an experimental group - exposed to musical activities; and a control group - not exposed to musical activities.	The experimental group was exposed to music theory classes, instrumental practice of at least one non-percussive instrument, and singing lessons.	To verify whether musical perception correlates the benefits of music classes with the development of auditory and musical perception. Tests were used to analyze the perception of discrimination of similar melodies, changes in pitch, rhythm, and memorization.	They concluded that children who participated in musical training were faster and more accurate in perceiving music, regardless of their hearing condition.
Bedoin et al. (2018)[32]	10 children using unilateral and bilateral CI aged 5 to 10 years, divided into two groups for evaluation.	The children were exposed to 16 weeks of morphosyntactic training (similar to speech therapy training), including 8 sessions with computerized musical interventions (rhythmic training) and 8 with morphosyntactic training. Pre- and post-training measures: performance tests in receptive syntactic processing with morphosyntactic tests (grammatical judgment and syntactic comprehension), nonword repetition, visuospatial attention, and memory.	To propose a long-term training program to improve the syntactic processing of children using CIs.	Musical activities improved performance in syntax comprehension, grammatical judgment, and repetition of nonwords in musical training. Effects were observed for attention tasks, especially fast and accurate sequential analysis, but not for memory tasks.
Torppa et al. (2018)[33]	43 children divided into two groups: experimental group - 21 children using unilateral CI, aged 4 to 13 years. Control group - 22 children with typical hearing development.	12 children in a group exposed to musical interventions, such as singing lessons, and 9 not undergoing musical interventions. Measurements: a) computerized tests to evaluate perception and recognition of words, timbre, and intensity, throughout 14 to 17 months. b) brain responses in the mismatch negativity (MMN) and P3a-evoked potential (ERP). ERP 75 minutes, including placement and removal of the EEG cap. The behavioral experimental session took 30 to 45 minutes.	To evaluate how children with CI who sing informally develop in the perception of speech in noise compared to those who do not sing.	Speech perception in children using CIs improved mainly due to tests with longer intervals of grade changes. The results suggest that singing and playing musical instruments may have the potential to improve speech perception in noise in children with CI.

Authors	Sample	Intervention	Objectives	Results
Yang et al. (2019)[34]	18 children divided into two groups: 10 children using unilateral CI, aged 7 to 13 years. 8 children with typical hearing, matched for age.	Children using CI had 21 months of formal musical training before starting choir rehearsals, for 2 weeks rehearsing just one song for 3 hours a week plus 1 hour of training at home. The children in the other group were not exposed to musical training, only choir rehearsal. Measurements: after 2 weeks of rehearsal, all children recorded a file with the music rehearsed with voice only, without accompaniment. Acoustic and metrics were analyzed to quantify tuning accuracy and musical performance.	To assess the singing proficiency of children using CIs.	Choir members with CI demonstrated high accuracy in pitch and time measurements and performance similar to children with typical hearing. They concluded that well-directed musical activities can be an effective strategy for developing oral skills, including the use of the singing voice, for post-implantation CI users.
Abdi et al. (2001)[35]	14 children with unilateral and bilateral CI, aged 2 to 12 years, divided into two groups: 9 children 2 to 6 years old. 5 children 6 to 12 years old. No control groups.	The children participated in weekly music classes based on the Orff method. In the period from 3 to 13 months, once a week. Measures: questionnaire for parents and rehabilitation professionals.	To evaluate the feasibility of methods that use music as a means of enabling children using CI.	All children improved their musical skills and musical perception ability. There was involvement and reports of family satisfaction at the end.
Torppa et al.(2014b)[36]	43 children, aged 4 to 13 years, divided into 2 groups: experimental group - 21 children with unilateral CI. Control group: 22 normal hearing, not exposed to musical interventions.	The experimental group was exposed to musical interventions, such as singing lessons, held at home, weekly, for 1 hour, for 1 year before the study collection began. Measures: ERP recording twice (at 2 moments 14-17 months apart) to compare MMN (pre-attentive discrimination) and P3a (attention to salient sounds) with changes in piano tone, timbre, duration, and gaps.	To evaluate whether singing can facilitate auditory perception and attention in children with CI.	Results show an interaction between MMN, P3a, brain development, implantation, and singing, expanding neural networks for attention and more accurate neural discrimination associated with singing.

Considering the 11 studies[26-36], 350 subjects were assessed, of which 185 were males, and 153 were females; one study[27] did not specify the characteristics of the subjects. Their ages ranged from 0 to 18 years. A total of 112 participants were unilateral CI users, while 93 participants had bilateral CI. The participants' ages at surgery ranged from 1 to 9 years.

Eight studies[26,27,29-32,34,36] used the term music training, of which seven used procedures for sound or musical learning and discrimination[26,28-31,34,36]. Another five studies[26-28,33,35] considered various terminologies, such as music class[27,28], musical experience[26,33], and music therapy[27,35]. Three studies[27,29,30] used individual musical approaches, either in the clinic or at the participants' home, applied by nonmusician professionals or the parents. The remainder[26,28,31-36] used musical approaches in groups in social contexts, such as schools and daycare centers.

The musical approaches used various types of musical activities, which were developed to arouse the participants' interest. Thus, the activities in some studies[28-34,36] sang familiar songs, such as "Twinkle, twinkle, little star"[36], while in other ones they used musical instruments[26,28-31,35], structured rhythmic training[30], sound discrimination[26], or formal music methods, such as Orff[35] and Kodály[28].

Concerning the skills tested, the 11 studies included in this review indicate that musical approaches are an effective strategy for developing various skills. The findings showed that children and adolescents using CI, exposed to musical intervention at an early age, performed equal to or better than their hearing peers in prosodic[28] and musical perception[31]. Compared to those who used CIs or other electronic HAs but were not exposed to musical interventions, they performed better in syntactic speech comprehension[32], intensity and duration discrimination[26], speech-in-noise perception[33], phonological awareness[26,27], prosodic perception[26,29], auditory perception[26,36], musical perception[27-29,35], orality[27,34], singing[34], and social skills[28].

As for the duration of the musical approaches, some studies[28,29,32,35] carried them out for 6 or fewer months[27], while others[26,30,31,33,34,36] did so for 6 to 24 months.

All 11 analyzed studies[26-36] were characterized as clinical studies.

The studies had limitations regarding the variability of musical methodologies and their heterogeneity and sample sizes. Although studies on this topic are common, a significant number of them[8,30-32,34] reported that participants used not only CI but also other electronic devices, such as HA. Also, they included participants with different degrees of HL in the same group, did not control the time since implant, included participants with unilateral and bilateral CI in the same group, or compared them with one another, or with normal hearing subjects, and lacked blinding regarding the types of intervention. The heterogeneity commonly found in the sample of these studies hinders the generalized judgment of contributions of musical approaches to the population of children and adolescents with CI.

Applicability of evidence in general

Although musical approaches do not aim specifically to improve the skills highlighted in this review, the studies showed the relationship between music and the development of auditory, speech, and language skills in children and adolescents using CIs. Studies are scarce with methodologically structured musical approaches to generalize any statement about these approaches.

Possible Biases in the Review Process

The search strategy developed for this review included sources of unpublished studies in to minimize publication bias. The entire search was carried out without date or language limits. It is important to highlight that the study selection process was thoroughly carried out, initially by the two authors and then reviewed by two reviewers, avoiding possible biases in the review process.

Practical Implications

Studies indicate a relationship between musical approaches, especially in the context of early intervention, and the development of auditory, speech, and language skills in children and adolescents using CIs when exposed to at least 6 months of musical intervention based on music-learning processes. In general, the results suggest that the effects of musical interventions based on learning to sing and play musical instruments are more effective when combined with a speech-language-hearing rehabilitation therapy intervention.

Research Implications

Further experimental, controlled, and blind studies, such as blind randomized clinical studies, are necessary to generalize a judgment about the real contributions of musical approaches to the population of children and adolescents using CI.

Studies should be conducted by interdisciplinary teams that include an experienced musician to avoid biases in musical approaches, as found in most of these studies. Before beginning a study, it must choose a musical approach consistent with the ages and needs of its research subjects. Many studies confuse musical approach terminology and do not detail them methodologically, which makes it impossible for them to be replicated.

This review supports the results of previous studies, which generally indicate that musical approaches improve auditory, speech, and language skills in children and adolescents using CIs.

CONCLUSION

The studies have shown that musical approaches contribute to developing auditory, speech, and language skills in children and adolescents using CIs.

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PMS: study conceptualization and design, data collection, analysis, and interpretation, manuscript writing, resources, and approval of the final version for publication;

NBFL: data analysis and interpretation and critical review of the article for relevant intellectual content;

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