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Music-Based Training for Pediatric CI Recipients: A Systematic Analysis of Published Studies

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Abstract

In recent years, there has been growing interest in the use of music-based training to enhance speech and language development in children with normal hearing and some forms of communication disorders, including pediatric CI users. The use of music training for CI users may initially seem incongruous given that signal processing for CIs presents a degraded version of pitch and timbre, both key elements in music. Furthermore, empirical data of systematic studies of music training, particularly in relation to transfer to speech skills are limited. This study describes the rationale for music training of CI users, describes key features of published studies of music training with CI users, and highlights some developmental and logistical issues that should be taken into account when interpreting or planning studies of music training and speech outcomes with pediatric CI recipients.

Keywords

cochlear implant; pediatrics; music; speech perception; training

1. Introduction

Present-day cochlear implants (CI), which typically remove the temporal fine-structure information in the stimulus waveform, provide coarse spectral cues and poor frequency resolution. This input, while sufficient for conveying speech in quiet and rhythmic in music, is poorly suited for transmitting those aspects of music and speech that require greater fine structure for accurate perception [1–7]. More specifically, pediatric CI recipients compare favorably with normal hearing (NH) peers on perception of rhythmic features in music, but have significantly poorer perceptual accuracy for tasks involving pitch (including melodies, harmony) and timbre [3–7], as well as spectrally complex features of speech (e.g., speech prosody, lexical tones, talker identification, speech in background noise) [4–7]. Several studies have shown significant correlations between perception of pitch, suprasegmental features of speech, and speech in noise [3–7].

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Given the degraded representation of pitch and timbre, recent recommendations for using music in auditory training for CI users [8, 9] may initially seem curious. This paper (a) presents the rationale for music-based training, (b) reviews published studies regarding music training of pediatric CI recipients, and (c) highlights considerations when interpreting research outcomes or developing music-based training protocols for pediatric CI users.

2. Rationale for music-based training for speech and language development

A number of studies have examined music training and experience-based plasticity in relation to speech and language of normal hearing (NH) persons [9–13]. Benefits of music training are predicated, in part, upon presumed overlap in brain networks that process acoustic features important to music and speech. While speech and music may share neural networks, some studies suggest that listening to or performing [9–13] music may have particular benefits in the development of more efficient and robust auditory processes. Music engagement activates a widespread bilateral network of brain regions associated with arousal and attention, semantic and syntactic processing, emotional response, and motor functions [9–13]. Within the context of auditory training, these aspects of music engagement can contribute to motivation and persistence [11], an important factor in longer training protocols.

The perceptual requirements associated with music listening also have implications for auditory training. Music listening and performance require fine-grained discrimination of ongoing changes in acoustic parameters of complex musical sounds [8, 10, 12, 13]. For example, the unique timbres that we associate with specific singers, instruments, or blends (multiple musicians) are the result of the onset transients, steady state, and decay of the fundamental frequency and upper harmonics. These complex tones, in turn, are combined into complex and rapidly changing patterns of pitch, rhythm, and amplitude.

Patel [11] suggests that training advantages associated with music occur in part because greater precision required for processing complex musical patterns fine-tunes the auditory system. In NH persons, music training has been credited with more rapid spectro-temporal processes at various levels of the auditory system [10, 11, 13]. In summary, studies regarding the overlap in neural networks, paired with the perceptual demands of music, have fueled speculation that music training may have clinical benefits for persons who have communication deficits, including users of CIs [8, 9, 11, 12].

As we consider the potential benefit of music-based training for pediatric CI recipients, it is important to reiterate that much of the research has examined participants with normal hearing who have access to the spectrally-rich, complex elements of music. In addition, many studies have focused on adult professional musicians, with many years of intensive training, which often commenced in early childhood [10, 11, 13]. Consequently, these sorts of outcomes may not generalize to the typically short-term training likely to occur in aural (re)habilitation for CI users.

From the standpoint of neural plasticity, one could make the case that pediatric CI users may benefit more from music training than adult users. However, one must still consider the possibility that advantages associated with younger age are less impactful than the degraded auditory input, which may undermine motivation as well as perceptual potential. For example, with regard to motivation and enjoyment, reports on pediatric users and music satisfaction are mixed [3, 14, 15, 16]. Some pediatric CI users engage in music regularly and report enjoyment; others describe music as sounding like noise or as marginally enjoyable. Thus, if optimal benefit for music training is related to exposure to complex fine structure and strong positive emotion and reward, how might electric hearing impact music training as part of habilitation practices with pediatric CI users? The following sections summarize published studies relevant to music training with CI users.

3. Training CI users on music perception: What have we learned from adult CI recipients?

To date, the majority of empirical studies of music training for CI users have focused primarily on enhancement of musical skills [2]. Enhanced music perception has inherent clinical value because music is prevalent and culturally significant in every known culture [2]. A relatively small number has directly examined transfer to speech. Most music training studies have been conducted with adults. Because the signal conveyed via the CI is similar for adult and pediatric users, adult studies provide a point of departure for considering possible benefits of music training. Despite the degraded representation of pitch and timbre, music training has been associated with perceptual enhancements of melodic contour and familiar melody recognition, timbre recognition and appraisal, and music listening enjoyment; however, considerable variability exists across subjects for differing perceptual tasks and for rate and extent of improvement. Though correlational studies imply possible overlap in perceptual processing, studies with CI users have yet to document clear causality between music training and enhanced speech perception [2].

While findings with adult CI users indicate potential benefits of music training, these findings should be generalized to pediatric CI users with considerable caution, given differences in neural plasticity and hearing history. The auditory pathways of pre-lingually deaf CI users have developed in response to electric hearing, and they lack the ‘typical’ mental representation of pitch and timbre. Pediatric users may be less critical of the tone quality of music through the CI, because they have no ‘normal’ hearing comparisons; this could enhance motivation. In short, despite similar peripheral input, adults and children may differ significantly in response to musical sounds. Evaluation of music-based training for these children should be informed by systematic studies conducted with pediatric CI users. The review of music training with pediatric CI users, which follows, is the primary focus of this paper.

4. Can training enhance music perception of pediatric CI recipients?

4.1. Materials and methods

To date, few published studies have examined music training of pediatric CI users [16–23]. Therefore, the following broad criteria were used in this review: peer-reviewed publications, written in English, music training as an intervention, and participants age 18 or younger at the start of the study. Even with these broad criteria, only nine relevant studies were identified. Review methods such as meta analyses, which examine effect size across a group of studies were not feasible, given the diverse methodological differences in implementation and reporting (including narratives) of results.

The limited number of studies is not particularly surprising. Designing and implementing music training with children is logistically daunting for a number of reasons, including: recruiting and retaining an appropriate, sufficient sample size; adequate funding to support methodology; feasibility of scheduling the training and testing; maintaining consistency of training parameters over time. All of these pose significant challenges to mounting a well-designed study. Some of the parameters of the studies reviewed below most likely were influenced by real challenges associated with enrolling and sustaining participation of pediatric patients in what can be complex protocols.

4.2. Interpretation of pediatric studies

4.2.1 Developmental considerations—It is difficult to identify overarching trends and to make direct comparisons across these studies, given the heterogeneity in study parameters within and across studies. From a developmental perspective, participants in these studies varied considerably on onset of deafness, age when implanted, duration of CI use, and age when trained/tested (See Table 1). Across studies, participants ranged in age from 4 to 18 years of age. Within some individual studies [16, 21, 22], the age range for participants encompassed three different stages of Piagetian development. As is the case with speech and language, music perception and performance are influenced by cognitive, behavioral, and social maturation. Consequently, chronological and hearing age at the time of the study can influence successful engagement in music training and outcomes [3, 21].

Table 2 indicates which studies reported age at testing [17, 18] and implantation [17, 18, 23] or duration of CI use [21]; which variables were integrated into analyses; and whether these factors had significant impact. Some studies [19, 21] enrolled children within a relatively narrow age range, which is likely to result in less maturational variability across participants.

The extensive age range (ages 4–14) reported by Rocca [20] relates to music training in a manner different from the other studies reviewed. Rather than implementing a study-specific training protocol with test outcomes, Rocca described on-going music instruction within an educational curriculum. Emphasizing that musicality changes as a function of maturation as well as hearing history, she described (through narratives) expected stages of vocalization or musicality as a function of length of CI use (e.g., 1–4 yrs., 5–11 yrs. post implant.).

4.2.2. Music experiences beyond the training program—In addition to influencing cognitive aspects of engagement and measurement, older age can act as a proxy for longer implant use and more extensive exposure to music and music training outside of the study protocol [17]. That being said, unlike linguistic skills (e.g., reading, writing, spoken communication) typically included in core educational curricula, music exposure or instruction is more likely to be elective, and thus varies across children, depending upon local educational policies and familial attitudes [3, 14]. Therefore, some children may have accumulated more life exposure to music (e.g., at home or school) than others. Four studies (17–19, 21) documented whether children were previously or concurrently enrolled in music lessons or classes beyond the training specific to the study. In clinical trials, it is certainly difficult to control for all life experiences, including informal or formal music listening and training. It would typically be more realistic to account for other music training as part of the study design or data analyses.

4.2.3. Training parameters—These studies also varied considerably with regard to types and format of training, content (stimuli and response), frequency and duration of training, and outcome measures (See Tables 2 and 3).

4.2.3.1. Training type, content, and format: Regarding type and format, some studies [16, 17, 19, 20, 21] used interventions based upon particular pedagogical approaches (e.g., YAMAHA, Orff) typical of music education for preschool or school-aged children. These methods tend to use naturalistic and multimodal musical activities, which have the advantage of being well matched to the developmental capabilities and motivational needs of children; some research has suggested that particular training advantages occur with multimodal experiences [10].

While most of the publications reported on the implementation of a study-specific music training protocol, Rocca [20] described training that is an integral part (music classes 1x weekly) of a full educational curriculum for hearing impaired children ages 4–14. In that academic setting, the type of intervention and habilitative goals were individualized to reflect each's child's unique needs, strengths, and were modified in response to ongoing maturation and observed learning.

Pedagogical approaches (especially those occurring over many hours or weeks) varied with regard to musical elements and how they were implemented over time in training (e.g., singing, playing instruments, listening, movement to music), and thus do not lend themselves to the brief descriptions feasible within most research publications. It is difficult to ascertain from these studies, with much degree of certainty, specific auditory stimuli and response tasks that were utilized. Pedagogical methods are often implemented by expert instructors, who may focus on the child's needs over methodological control, and may understandably modify training as a function of the child's age, motivation, and progress over time. Consequently, strict control over pedagogically oriented training parameters is unlikely.

The Torppa study [22] is unique in that the authors of the study did not implement the music training. Rather, they examined the impact of already-occurring music training on cognitive and linguistic capabilities by comparing CI users who were, or were not involved in naturalistic music experiences (e.g., singing, musical play, lullabies, etc.) at home, at school, and in the community (e.g., as part of preschool classes) over the time span of the study (14–17 mos.). Questionnaires completed by parents were used to quantify the extent to which their child was involved in music experiences.

Though developmentally appropriate, naturalistic interventions are difficult to replicate, and interpretation of those factors most relevant to improvement can be problematic. One might compare forms of training based upon music education to classroom instruction in reading and writing; one typically sees linguistic improvement over time, but it is challenging to determine whether particular pedagogical approaches or environmental factors yield the greater outcomes, and how much training is enough to yield significant benefits.

In contrast, several training studies provided highly-structured computer-generated training sessions with specific auditory stimuli and highly controlled responses [18, 21], or used a manual outlining specific keyboard exercises [23]. For example, the Fu et al. study [18] implemented a computer-generated program presenting melodic contours with differing interval sizes (see Table 3). Auditory training protocols of this sort are intended to train more efficient perception of specific musical sounds (e.g., pitch contours, music instrument recognition, etc.) [18, 21, 23]. These approaches have the advantage of greater experimental control and replicability. However, highly controlled tasks may suffer from less ecological validity; one cannot presume that discrete perceptual skills transfer to all complex and multifaceted aspects of music perception or performance.

4.2.3.2. Training frequency and duration: As Table 3 indicates, the frequency and duration of training also varied within and across studies. Studies varied from as few as 3 lessons taken during one week [16] to on-going weekly music instruction from ages 4 to 14 [20]. Even though duration of training varied considerably within and across studies, most did not examine outcomes as a function of extent of training. The Fu [18] study controlled for hours of training from pre to post-testing for the duration (10 wks.) of the study. Interestingly, participants varied considerably in rate of learning, which seemed more impactful than total hours spent in training; training reached asymptote after 4 weeks. Chen et al., [17] found that duration of training was influential, but only for younger participants (< 6 yrs. age).

This heterogeneity in type, frequency, and duration of training, from a logistical standpoint is hardly surprising. Sustained participation by children and families in a longer-term study is extremely challenging, especially with very young children. Also, longer-term training co-occurs with increasing cognitive maturation, thus it can be difficult to differentiate training and maturational effects unless appropriate design and analyses methods are implemented.

4.2.3.3. Outcome measures: As Table 2 illustrates, published studies varied considerably with regard to outcome measures, in part because these studies focus on different aspects of music, and because tests may be more or less suitable for use with children of different ages. For those studies examining perceptual accuracy, the stimuli and response tasks across studies involved very different demands with regard to cognitive and auditory processes.

Some of the studies did not measure perception, but relied solely or primarily [16, 20, 23] on ratings of parents or clinicians (e.g., ratings of enthusiasm for music). While clinically useful, parent rating are subject to bias and problems with rater reliability.

Only four studies examined audiograms or speech measures directly as part of the study design [19, 20, 22, 23]. Interestingly, only one study [22] ascertained specific benefits on measures relative to speech perception and linguistic development, thus the studies reviewed offered little direct evidence regarding transfer of music training to speech outcomes.

5. Discussion

This modest body of literature regarding music training and possible transfer to speech and language reflects a very early stage of inquiry. Every research agenda has a beginning, and the authors of these studies have taken those first steps. These initial studies provide useful insights into the challenges associated with systematic evaluation of music training, and suggest factors that optimally should be addressed in future studies. Both music and speech are complex communicative forms comprising many subskills influenced by maturation as well as auditory input and experience. Consequently, a better understanding of music training and potential transfer to speech and language will require many years of efforts from a number of research and clinical centers. Likely, this complex task might benefit from collaborative efforts by multiple CI centers who can muster shared effort in recruitment and implementation of longer-term protocols.

In the meantime, let us compare this situation with studies of training methods for speech and hearing. Though a much larger body of research does exist for training speech perception than for music, if clinicians waited for incontrovertible evidence of many forms of speech and language therapy, therapists would have at hand a very modest menu of options for habilitation with pediatric CI users. A number of commonly used methods have been embraced as a result of the keen clinical observations, or because a given approach has face value in relation to highly regarded theoretical understandings of speech and language development. Furthermore, as we consider neural plasticity in general, one can argue that many forms of listening that engage a child over time and that challenge increasingly difficult listening are likely to be beneficial. Thus, while it is too soon to advocate for music training as superior to more conventional speech training methods, evidence of perceptual enhancements by CI users from music training seems promising.

What are some factors that should be considered if implementing future clinical or research trials? As we reflect on these initial studies, a number of factors are emerging as relevant and inform the development of future music training studies for pediatric CI users. Those are described below.

5.1. Training parameters in relation to patient characteristics

No single study will be able to address all aspects of the diverse universe of sounds that are encompassed within the term, ‘music,’ which includes multifaceted combinations of pitch, timbre, rhythm, and amplitude organized into diverse forms and styles. The selection of training parameters (e.g., stimuli and response, training format, frequency and duration) should take into account not only the most salient features of music as they related to speech, but also the child's chronological, hearing, and mental age, and motivational factors (e.g., familial and patient priorities, interests). Information regarding typical patterns of musical development in NH children can provide a point of departure for selecting stimuli, tasks, and valid, reliable, and feasible outcome measures. The hearing history of the child can also help to determine meaningful, relevant contextual cues important in synthetic (emphasizing top-down processing) training protocols. The interpretation of outcomes will be enhanced by integrating into analyses non-music factors (e.g., residual hearing, history of device use). Optimally, relevant participant characteristics (e.g., hearing profile, age, prior music training) should be documented and integrated into the design or analysis of research protocols.

5.2. Logistical challenges associated with implantation of training studies

The most elegant research designs will fail if logistical challenges are not sufficiently addressed, particularly when the intervention involves longer-term multi-session training. Among the challenges to consider are: securing financial support for implementation; sustained cooperation of staff and participants over the length of the study; securing proximal facilities (clinic or computer) that encourage sustained participation; and recruiting an adequate sample size with appropriate characteristics (e.g., age, months of CI use). These challenges are anything but trivial, and thus require considerable creativity and persistence by the research team who undertakes these clinical trials.

6. Conclusions

Based upon studies with NH children and adult CI users, music-based training holds promise for fine-tuning the auditory system, but more systematic evaluation is needed to better understand how successfully skills will transfer to pediatric CI users. The development and implementation of longer-term training for pediatric CI users present logistical and conceptual challenges not for the faint of heart. The publications reviewed in this article help to identify several methodological approaches and concerns, as well as important perceptual elements.

Factors related to the training content, validity, reliability and feasibility of a study include: selecting specific elements of music and speech that are developmentally suitable and appropriate for the characteristics of the participants; selection of valid, reliable, and age-appropriate speech and music measures; maintaining consistent participation in training protocols across subjects and over time; and documenting or controlling for non-music factors (e.g., hearing history, family SES, etc.) relevant to interpretation of outcomes. It is likely that meaningful progress will require the collaboration of professionals from varied backgrounds and multiple centers in order to adequately address the complex factors related to the question of music training for pediatric CI users.

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Table 1

Age range of children enrolled in published studies of music training for pediatric CI users

Author	Age of children enrolled			
Abdi, 2001 [16] 2.5-12.5 yrs.				
Chen, 2010 [17] 5 to 14 yrs.				
Fu, 2015 [18] 5.5-9.7 yrs.				
Innes-Brown*, 2013[19] 9 to 12 yrs.				
Petersen, 2015 [20] 15.6-18.8 yrs.				
Rocca, 2012 [21] 4-14 yrs.				
Torppa, 2014 [22] 4-13 yrs.				
Yucel, 2009 [23]	NA			
Age in Years	**1 2 3**	**4 5 6 7**	**8 9 10 11**	**12 13 14 15 16 17 18**
Developmental Stages (Piaget)	**Sensori motor**	**Pre operational**	**Concrete operations**	**Formal operations**

*This study compared outcomes of children with CIs, HAs, and NH. Data for only the CI users are included in the tables.

NA=Not available

Table 2

Type and duration of training and outcome measures

Study	Type of Training	Duration	Outcome measure
	Based on Music Education Pedagogy or Curricular Guidelines		
Abdi, 2001 [16]	1) Orff music instruction for children (3–6 yrs.); 2) Se-tar (string instrument) lessons for children 6.5–12.5 yrs. [participants chosen on own and parent inclinations; no selection criteria; all prelingually deaf]	1 lesson per wk., 3 to 13 mos.	Case studies; teacher rating of 1–10 on 9 musical skill areas and responsiveness; no quantitative analyses
Chen, 2010 [17]	YAMAHA music instruction (listening, singing, score reading, playing instruments)	2 to 36 mos, mean 13.2 mos.	Pitch ranking of 49 pitch pairs (256–495 Hz)[AFC, same, higher, lower]; intervals=prime to 11 semitones, ascending or descending
Innes-Brown, 2013 [19]	School music instruction using Kodaly and Orff pedagogy: vocal play, aural, visual, kinesthetic play, listening exercises with solo musical instruments	45 min. wkly. class, 24 wks.	Discrimination (same-different) of pitch patterns, 261–698 Hz; rhythm patterns, 523 Hz); Timbre recognition (closed set, recordings of 12 solo instruments), teacher observation of enjoyment; tests administered 4 times over study
Petersen, 2015 [20]	active music making; rhythm, singing, ear training for pitch, melody, timbre; in Royal College curriculum components;	20 hrs. scheduled 6 days x 2 wks.	Pre vs. post training: MMN for pitch, rhythm, intensity, timbre tokens, SRT for speech comprehension, Auditory discrimination test
Rocca, 2012 [21]	UK Music Education curricula; Nordoff Robbins music therapy methods: Singing, playing instruments	Class/lessons 1x wkly. at school, age 4–14; individualized for each child	Narrative description describe expected progress in relation to educational objectives for school music education/therapy curriculum (beginner, 1–4/5 y post CI, intermediate, 5/6–11 y post CI, advanced, 12–18y post CI) no perceptual testing
	Structured or semi-structured listening exercises delivered via computer or keyboard: home based		
Fu, 2015 [18]	Home computer training on melodic contours (9 five-note contours x 6 semitone spacing) 2 timbres, melody, rhythm; root note randomly varied between 200–800 Hz (excluding testing Hz); audio, visual feedback; criterion level of 80% correct, adjust difficulty	12–54 hrs over 10 wks.	% correct on nine 3-note, 5-note melody contours X 6 semitone, root note 440 Hz; tested wks. 4, 8, 10; asymptote at 4 wks.
Petersen Prt. 2 [20]	Computer listening exercises (along with music instruction)	10–20 min. daily for 2 wks.	MMN, SRT for speech, Auditory discrimination test
Yucel, 2009 [23]	Playing, listening to pitch pairs (same or different discrimination), melodic, rhythmic patterns on keyboard at home using color coded pitch intervals and instructions; levels of task difficulty	Time spent in music training over 2 years: Individual: Minimum of 35 minutes; Maximum of 240; M=122.91–175.41 min.	Evaluation every 3 months: Parental ratings (1–5) of music: sound awareness, voluntary participation, discrimination of same, different pitches, melodies, rhythm patterns, emotional response. 5 standardized speech measures: sound detection, word identification (closed, open set) of word recognition, sentence comprehension
	Quantification of familial or community-based naturalistic music activities		
Torppa, 2014 [22]	Engagement with music lessons in family, community Determined through questionnaire	14–17 mos.	Discrimination of word/sentence stress perception, F0 discrimination; intensity, duration, prosody, digit span measured 2x over 16 mos. Music activity level assessed by questionnaire

MMN=Mismatched Negativity

M=mean

Table 3

Study parameters and results

Study	Sample Size	Comparison Groups?	Demographic variables reported	Variables used in Analyses	Results
Abdi [16]	23	No	AI DT MOU	No quantitive analyses	No perceptual data analyzed; case studies relaying teacher ratings for music skills and attitude
Chen[17]	13	14 control (no training)	AI AMT AT DT Gender HD MOU OC	AI AT * DT * Gender * HD MOU Gender *	Pitch ranking of 49 tone pairs, individual accuracy range of 9.5–92.5%; NSD by pitch interval size, accuracy significantly correlated with DT (r=.389) for younger age (<6 yrs.), and older AT (>6yrs); boys more accurate, but more boys in older AT group
Fu [18]	6	No	AI AMT (none) AT DT Etiology Gender HD MOU OD Oral communication	AI AT DT	Highly variable with chance to nearly perfect; group data significantly improved melodic contour recognition at 4 wks. (mean improvement 53.1%). No significant impact of age at testing, or age when implanted; asymptote at 4 wks.
Innes-Brown [19]	6 CI users	9 NH, 5 HA users	AI AMT (all) AT DT Gender HD Residual hearing	Residual hearing * for pitch, timbre	Baseline and posttests: CI users significantly less accurate than NH, HA users on pitch patterns, timbre recognition, NSD for rhythm patterns; residual hearing predictive of scores; percussive instruments easier to recognize; Training effect: CIs showed improved pitch, timbre, but NS change after training; observational narratives from teachers indicate enhanced engagement, interest in music
Petersen [20]	N=11	10 normal hearing age mates; testing, but no training	AMT (all but 1) DT HD MOU		NSD
Rocca [21]	> 100 children over 22 yrs.	NA		No statistical analyses	No formal testing; Narratives reported improved listening, singing reflecting the stages of musical development in music curriculum
Torppa [22]	21 CI: 7 who fit music training criteria 12 (None)	21 NH children, matched for age, gender, music activities; music training not quantified			Training correlated with improved F0 discrimination, stress perception, prosody, auditory memory

Study	Sample Size	Comparison Groups?	Demographic variables reported	Variables used in Analyses	Results
Yucel [23]	N=9	N=9 no music training			NSD for speech tests between training and control group; parent rated (1–5) SD for music group in awareness of sound, melody, dynamic, rhythmic change, emotional response of increased music skills at end of 2^{nd} yr; Highly variable results on all measures; interest, age of implantation not significant factor

AI= age implanted

AMT=Additional music training beyond study

AT=age at time of testing

DT=Duration of training

HD=hearing device (HA, CI type, strategy) information

MOU= months of CI use

OD=onset of deafness

* p<.05 or better; += statistically significant only for participants < 6 yrs. Age

NSD=no significant difference