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Review

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.

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].

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:

- presents the rationale for music-based training;
- reviews published studies regarding music training of pediatric CI recipients;
- 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 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

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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 NH 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 [3,14–16]. 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 prelingually 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 (Fig. 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 1indicates 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 ongoing 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.).