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Music Perception of Cochlear Implant Recipients with Implications for Music Instruction: A Review of Literature

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Abstract

This review of literature presents a systematic analysis of the capabilities and limitations of cochlear implant recipients regarding music perception. Specifically, it a) analyzes individual components of music (e.g., rhythm, timbre, and pitch) as they interface with the technical characteristics of cochlear implants and the perceptual abilities of cochlear implant recipients; and b) describes accommodations for music instruction that support successful participation of children with cochlear implants. This article consolidates research studies from various disciplines (audiology, hearing science, speech-language pathology, cochlear implants, and music therapy) to provide practical recommendations for educators in fostering the musical growth of children with cochlear implants.

The cochlear implant (CI) is an assistive hearing device designed for persons with severe and profound deafness who receive little benefit from hearing aids. While conventional hearing aids essentially amplify sound waves and transmit the signals via the ear canal, cochlear implants support audition through electrical stimulation of the auditory nerve. The external components of the CI (microphone and speech processor) pick up sound signals and filter and extract sound waves considered important for speech perception. These processed signals are then delivered directly to the internal electrode array surgically inserted into the cochlea to stimulate auditory nerves, and then are transmitted to the auditory central pathway for interpretation. Because the technical characteristics of the CI are different from conventional hearing aids, music perception by CI recipients will differ in important ways from that of hearing aid users.

Although the input of sounds heard through the CI device does not provide an exact replica of normal hearing, research literature indicates that many children derive impressive benefits from the implants in speech and language development (e.g., Robbins, 2009; Spencer, Barker, & Tomblin, 2003; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). This has allowed many pediatric CI recipients to attend mainstream schools. As outcomes for speech reception have improved, there has been increasing interest in the perception of music, an acoustic signal for which current CI technology is not optimally suited (Gfeller et al., 2008; Looi, 2008). Families are increasingly hopeful that implant benefits can expand beyond spoken communication to include music participation and enjoyment (Gfeller, 2009).

This article reviews studies from the fields of audiology, hearing science, speech-language pathology, cochlear implants, and music therapy, with an emphasis on those studies that include stimuli and task responses required in music instruction. It also interprets the applicability of what are often highly controlled and abstract perceptual tasks in a laboratory setting to typical music listening or production requirements for successful music participation. Consequently, this review provides a practical resource for music educators as they make decisions regarding appropriate educational and enrichment experiences for pediatric CI recipients.

The feasibility of music participation for children with CIs is complex, in part because music encompasses a diverse continuum of very simple patterns (e.g., electronically-generated pure tones) to highly complex combinations. It is important to systematically analyze particular structural components of music as they interface with the CI in order to determine more clearly the feasibility of specific aspects of music instruction. In addition, response to music is likely to differ from one CI recipient to the next given the variability in hearing history, life experiences, and developmental level in functional areas that support musical skills (e.g., cognition, motor skills, etc.). A comparison of studies with children and adult CI recipients indicates that children have similar outcomes with regard to the perceptual acuity of the isolated stimuli of rhythm, timbre, and pitch. Thus, studies concerning adult CI recipients provide general trends with regard to the perception of the key structural components of music. However, prelingually-deaf children may differ from postlingually-deaf adults in their use of contextual cues (such as memory of melodic rhythms) in recognition tests using familiar songs (Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005). Furthermore, children whose entire experience with music has been through a CI may have less stringent expectations than postlingually-deaf adults regarding what constitutes aesthetically pleasing sound quality (Gfeller, Witt, Spencer, Stordahl, & Tomblin, 2000b). The following section summarizes findings with regard to the music perception of pediatric CI recipients. Results of studies with adults have been included if the findings could be generalized to music instruction for children. Accommodations in instructional methods that can support successful participation by children with cochlear implants are discussed.

Research on the Music Perception of CI Recipients

Rhythm

Musical tasks associated with rhythm that have been systematically examined include discrimination of changes in tempo, identification of different meters, discrimination of simple rhythmic patterns, recognition of rhythmic patterns held at a steady tempo, and adaptive tests (increases or decreases in the rate of stimulus presentation) that establish a threshold of accuracy for rhythm pattern identification. Excluding the results of adaptive tasks that push perceptual limits (e.g., Gfeller, Woodworth, Witt, Robin, & Knutson, 1997), CI recipients have shown similar accuracy in rhythm-based tasks when compared to normal hearing (NH) persons (Gfeller & Lansing, 1991, 1992; Gfeller et al., 2000a; Kong, Cruz, Jones, & Zeng, 2004; Leal et al., 2003; Looi, 2008; Schultz & Kerber, 1994; Vongpaisal, Trehub, & Schellenberg, 2006).

Although research studies typically use more controlled rhythmic patterns than those contained in “real-world” music, the perceptual requirements are similar to several tasks found in music instruction (e.g., differentiating a march from a waltz or imitating rhythmic patterns). Perception of the melodic rhythm can also help CI recipients recognize simple melodies such as “Happy Birthday” that have distinct rhythmic patterns (Gfeller et al., 2000a, b, 2002a, 2007; Hsiao, 2008; Olszewski, Gfeller, & Driscoll, 2006; Olszewski et al., 2005).

In summary, because CI recipients perform similarly to NH persons on rhythm perception tasks, most children with implants should be capable of successful participation in and enjoyment of music tasks that primarily require the perception of rhythmic patterns. This is especially true if the rhythmic stimuli are not obscured by competing sounds, if patterns are played at a moderate tempo, and if the child's cognitive skills can support the attention and memory components of the task.

Timbre recognition

In studies with CI recipients, timbre recognition has typically involved the identification of musical instruments played individually or in blends (e.g., in an ensemble) (Gfeller, Knutson, Woodworth, Witt, & DeBus, 1998; Looi, 2008). Research indicates that CI recipients are significantly less accurate than NH listeners on instrument identification tasks (Fujita & Ito, 1999; Gfeller et al., 1997, 1998, 2000b; Looi, 2008; Schulz & Kerber, 1994). The CI provides sufficient information to enable discrimination between instruments with contrasting sounds (e.g., flute and piano), though not at an optimal level (Looi, 2008; Stainsby, 2001). Single musical instruments tend to be easier to identify than more complex combinations or blends (Looi, 2008). However, pediatric CI recipients whose educational plans have not included music instruction in school may demonstrate less accuracy in instrument identification because of less exposure to instrumental sounds (Gfeller, 2000; Gfeller et al., 2000b).

Timbre recognition can improve significantly as a result of systematic training (Driscoll, Oleson, & Gfeller, 2009; Gfeller et al., 2002b). Children can improve discrimination and recognition of many timbral sounds as long as the characteristics of each instrument presented are sufficiently distinct (Gfeller, Driscoll, Kenworthy, & Van Voorst, in press). To ensure success in music instruction, music educators should begin with instruments that have sufficiently different tone quality for discrimination tasks.

Appraisal of Timbre

Appraisal is a term that involves the evaluation of the tone quality on dimensions of pleasantness or characterization of the tone quality (e.g., brilliant vs. dull, thin vs. full) (Gfeller et al., 1998). CI recipients rate musical instruments as less pleasant than do NH listeners (Gfeller et al., 1997, 1998; Looi, 2008). Though individuals' preferences for specific instruments vary, group data indicate that some instruments sound less pleasant through a CI than others (Gfeller et al., 1997, 1998, 2002b; Looi, 2008). For example, studies have shown that CI recipients ranked the following instruments from most to least pleasant: piano, flute, trumpet, and violin (Gfeller et al., 1998, 2002b).

Appraisal is influenced by factors such as onset of hearing loss or individual expectations. For example, children with early-onset deafness may find the tone quality of instruments more satisfactory than some adults whose memory for instrumental timbre prior to hearing loss is still strong (Gfeller, 2000). Music educators who teach children with CIs should experiment with various instruments outside of the regular class time to identify the most and least pleasing instruments.

Pitch and melody

Numerous studies indicate that CI users are significantly less accurate than NH persons on a variety of pitch-based tasks such as discrimination (determining if two sounds patterns are the same or different, e.g., frequency difference limens), pitch ranking (determining if one pitch is higher or lower than a reference pitch), recognition (being able to identify a particular interval, pitch pattern, or melody), and production (being able to correctly sing an interval, pitch pattern, or melody; matching an external pitch by singing or tuning an

instrument) (Galvin, Fu, & Nogaki, 2007; Gfeller et al., 2002a, 2007, 2008; Hsiao, 2008; Kong et al., 2004; Kong, Stickney, & Zeng, 2005; Looi, 2008; Nakata, Trehub, Mitani, & Kanda, 2006; Stordahl, 2002; Sucher & McDermott, 2007; Vongpaisal et al., 2006). Considerable variability has also been found among CI recipients. For example, a small proportion of implanted children may be able to distinguish intervals as small as a semitone across portions of their listening range, while many may be unable to detect changes smaller than 3 to 8 semitones (Gfeller et al., 2007).

Children with congenital or very early-onset deafness differ from persons with postlingual deafness in that they lack a mental representation for what constitutes pitch and “normal” pitch relations among notes within musical scales. The concept of “high” versus “low” musical sounds, while somewhat abstract even for NH preschoolers, can be particularly problematic for young pediatric CI recipients. For example, a sequence of notes in an ascending musical scale may sound to some CI recipients like only one pitch. Other CI users may perceive a change in pitch, but the magnitude of pitch change may be compressed or distorted; they may also perceive pitch reversals (McDermott, 2004). These perceptual difficulties impact everyday musical tasks such as recognition of simple melodies (e.g., “Happy Birthday” and “Twinkle, Twinkle”) (Gfeller, Jiang, Oleson, Driscoll, & Knutson, 2010; Hsiao, 2008; Olszewski, Gfeller, & Zhang, 2005; Stordahl, 2002).

Perhaps the most challenging pitch-based task for many CI recipients is accurate production of pitch, as is required when singing a melody, when singing in tune with an external pitch (e.g., an accompaniment or other voices), or tuning a musical instrument. Objective testing of singing by pediatric CI recipients (Nakata et al., 2006; Xu et al., 2009) indicated that children with CIs were significantly less accurate than NH children with regard to pitch matching, overall frequency range, and production of intervals.

Because singing in tune is especially difficult for many CI recipients, major accommodations are necessary. There are some outliers who may be able to participate successfully within portions of the vocal range or produce partial approximations of the sounds. In addition, at a younger age, many children with normal hearing are not completely accurate in singing melodic patterns, thus a CI recipient for whom this skill is difficult may still be able to join in on some singing activities without undesirable embarrassment or disruption to the entire class. This accommodation hinges upon a flexible attitude of the educator in modifying instructional methods or objectives.

On the other hand, learning instruments such as piano or keyboard that provide a constant pitch and a visual representation of pitches, intervals, and chords is helpful. This allows CI recipients to check their auditory perceptions against a visual model of the sound being produced. As a result, some CI recipients have improved their perceptual acuity for the isolated pitches in a music scale through dedicated practice in playing and listening to the keyboard (Gfeller, 2000; Yucel, Sennaroglu, & Belgin, 2009).

In summary, any musical task that requires perception or production of pitch and melody is likely to be quite challenging for many CI recipients. Music instructors should understand that aural limitations for pitch perception are related to the characteristics of the CI and do not reflect lack of effort, intelligence, or compliance with teaching. Keep in mind, however, that individual CI recipients may show greater perceptual accuracy for sounds in different pitch ranges, depending upon the specific frequencies presented. It is difficult to predict precisely the extent of success that each CI user will experience in pitch-based music tasks. Some children may show improved pitch perception with considerable practice; for others who show little change as a result of instruction, focusing instruction on other goals is

advisable. Accommodations in instructional objectives (e.g., larger intervals or more modest outcomes) can help a CI user to participate successfully in music instruction.

Song lyrics

Although not considered a structural component of music per se, song lyrics are often paired with musical sound patterns. In fact, the lyrics of songs may assist CI recipients in song recognition more than pitches or melodic patterns (Hsiao, 2008; Olszewski et al., 2005). Research involving recorded music of television theme songs indicates that young CI recipients are able to recognize these songs most effectively when the music is presented in the original version, which may include lyrics (Nakata et al., 2005; Vongpaisal et al., 2006).

The extent to which lyrics assist song recognition is influenced by the familiarity of vocabulary in the lyrics, the tempo at which the lyrics are sung, modifications in phoneme production associated with singing (singer's formant, changes in production associated with particular vocal styles such as opera, rock music, etc.) (Gregg & Scherer, 2006), or masking properties of instrumental accompaniments (Buzzell, Gfeller, Driscoll, & Kinnaird, 2008; Fetterman & Domico, 2002; Gfeller et al., 2007, 2008). Thus, song lyrics can be helpful in perceiving, enjoying, and singing along to music. However, the benefit is likely to be greater if songs have suitable vocabulary, are sung without accompaniment (or quiet accompaniment), and are sung in a clear and natural style (Gfeller, Olszewski, Turner, Gantz, & Oleson, 2006; Nakata et al., 2005; Stordahl, 2002; Vongpaisal et al., 2006).

In summary, CI recipients as a group perform similarly to NH persons in rhythm-based tasks, but less accurately on the perception of timbre. Pitch perception is the most problematic listening task for CI recipients, which impacts determination of pitch changes, melodic pattern recognition, and singing or playing instruments in tune. These research studies highlight the importance of judicious selection of musical stimuli, response tasks, and environmental conditions in order for children to achieve satisfying musical instruction.

Discussion

Though CI recipients tend to be less accurate than NH individuals on perceptual tasks involving pitch and timbre, considerable intra-subject and inter-subject variability has been found. For example, one CI recipient may do very well on instrument identification but perform quite poorly on melody recognition. Across subjects, one implant recipient may require very large pitch changes (e.g., two octaves) for pitch ranking tasks, while another CI recipient accurately perceives a semitone (Gfeller et al., 2008). Thus, though group data provide some general predictors of which musical tasks more amenable to implanted children, individualized assessment is important when choosing musical instruction and setting educational objectives for each child. For example, the teacher may conduct informal perceptual testing of music skills, such as the ability to determine the direction of pitch changes or the size of an interval that can be perceived.

Despite the challenges CI recipients face in developing aural skills, children with implants can succeed in many types of musical activities as long as instructional methods and goals are suitably matched to the individual child's strengths and limitations. Some accommodations to outcome objectives may be required, including less demanding or complex listening examples, extra repetition and time, and alternative tasks or modified expectations that are acceptable for use in the group lessons. A child may be integrated more successfully into music classes if the educator evaluates the relative difficulty of various lesson components and supplements with additional tutoring.

It is also essential to understand that aural difficulties affecting music perception should not be considered the “fault” or weakness of the child. Music perception is not highly correlated with intelligence or speech perception skills. Thus, a very intelligent child who has excellent speech perception may still find pitch perception problematic. This limitation is primarily a reflection of the technical constraints of signal processing specific to individual components of musical structures such as pitch.

On the other hand, a quiet acoustic environment with little reverberation, quality sound equipment, and music played at moderate volume can enhance music perception and enjoyment for CI recipients. More time spent listening to music and receiving formal training (e.g., music classes or lessons, focused training) may improve accuracy on pitch discrimination, pitch pattern recognition, complex song recognition, solo instrument recognition, and appraisal of solo instruments and complex songs (Chen et al., 2010; Galvin et al., 2007; Gfeller et al., 2008; Rocca & Tucker, 2008; Yuba, 2007; Yucel et al., 2009). Providing opportunities to observe the singer or instrumentalist for visual cues, written lyrics or musical scores (as appropriate) for tracking, and contextual cues that support recognition (e.g., information about what is being heard), as well as ample exposure to particular songs, can also be helpful in enhancing participation and learning (Gfeller et al., 2000a, b).

In sum, this review of literature presents a systematic analysis of the capabilities and limitations of cochlear implant recipients regarding music perception. Individual components of music such as rhythm, timbre, and pitch and their interface with the technical characteristics of cochlear implants are analyzed. Because CIs provide poor pitch resolution and atypical timbral quality, successful participation in music instruction will require music educators understand of the technical restrictions of the CI and its influence on the child's perception of musical sounds. In addition, pedagogical flexibility, such as a willingness to use trial and error, modify the curriculum or instructional methods, and establish more realistic expectations regarding the individual child's needs, will also be necessary.

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