Music Appreciation and Training for Cochlear Implant Recipients: A Review

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ABSTRACT

In recent years, there has been increasing interest in music perception of cochlear implant (CI) recipients and a growing body of research conducted in this area. The majority of these studies have examined perceptual accuracy for pitch, rhythm, and timbre. Another important, but less commonly studied aspect of music listening is appreciation, or appraisal. Despite the ongoing research into potential technological improvements that may improve music perception for recipients, both perceptual accuracy and appreciation generally remain poor for most recipients. Although perceptual accuracy for music is important, appreciation and enjoyment also warrant research as they contribute to clinical outcomes and perceived benefits. Music training offers excellent potential for improving music perception and appreciation for recipients. Therefore, the primary topics of this review are music appreciation and training. However, a brief overview of the psychoacoustic, technical, and physiological factors associated with a recipient's perception of music are provided, as these are important factors in understanding the listening experience for CI recipients. The purpose of this review is to summarize key articles that have investigated these issues, to demonstrate that (1) music enjoyment and appraisal is an important and valid consideration in evaluating music outcomes for recipients, and (2) that music training can improve music listening for many recipients, and is something that can be offered to persons using current technology.

KEYWORDS: Cochlear implants, music, quality of life, rehabilitation, training, sound quality

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Learning Outcomes: As a result of this activity, the participant will be able to (1) describe key articles related to music training and appreciation for cochlear implant recipients, (2) identify accuracy for music and appreciation, and (3) name the principles and issues related to developing music training programs.

Over the last decade or so, there has been increasing interest in the area of music perception of cochlear implant (CI) recipients, and as a result, a large increase in the number of research studies in this area. However, the vast majority of these studies have looked at the perceptual accuracy of recipients and/or the development of tests to assess this. Given the role, function, and applications of music in everyday life,* it could be argued that music appreciation should warrant at least as much, if not more, interest than perceptual accuracy. Appreciation and identification are different. For example, just because one can recognize an instrument or melody does not necessarily mean that one enjoys listening to that instrument/melody. Conversely, even though a listener is unable to name a particular tune, they may still find it quite pleasant to listen to. Hence improving identification accuracy would not necessarily translate to the recipient enjoying and/or listening to music more. Furthermore, only weak correlations have been found between perceptual accuracy and music appreciation.[1–3] Therefore, although improving perceptual accuracy for music is important, appreciation or enjoyment also warrants research, as it can result in significant clinical benefit.

Although the primary focus of this review is music appreciation and training, a brief overview of the psychoacoustic, technical, and physiological factors associated with a recipient's perception of music is provided, as these contribute to the ratings of music provided by CI recipients and their listening experience.

MUSIC

There are four basic psychological attributes to musical sounds—pitch, duration, loudness, and timbre.[4] Although pitch and loudness are predominantly, but not exclusively, derivatives of frequency and intensity respectively, timbre involves the perception of a larger number of factors. Music perception primarily involves pattern perception.[5] Whereas the sequencing or patterning of pitches forms the musical correlates of melody and harmony, the sequencing of durations or temporal patterns forms the foundation of rhythm.[4] Although these attributes are separate entities, it is the combinations of and interactions between the different attributes that largely contribute to music as we commonly know it. For example, melody recognition is dependent on both the ability to perceive and familiarity with its various structural features, such as the overall contour, relative pitch changes from one note to the next, and rhythm patterns. Further, variables pertaining to the individual listener, such as one's music experience, prior training, listening preferences, age, culture, or demographics, may also affect music listening.

Both speech and music are largely quasiperiodic signals comprising complex sound waves with the frequency, temporal, intensity, and timbral components presented in an organized manner. Both have spectral and temporal envelopes that vary in time.[4,6] However, although speech and music share numerous similarities, they also differ in many ways. The range of fundamental frequencies (F0s) and loudness levels for music is significantly greater than for speech, and accurate perception of the F0 itself is not imperative to speech recognition for nontonal languages such as English. On the other hand, accurate perception of the F0s of individual notes is important for music

Although essentially nondiscursive in its role, music can play multiple roles or have multiple functions in our lives, including social and emotional roles, reminiscence, relaxation, creation of a mood and/or identity, therapy, and communication. For example, in a group situation, it could facilitate communication that extends beyond words, enhance the group dynamics and interactions, and allow the creation of both an individual as well as group identity. At the level of the individual, music can be associated with a host of responses including physiological, motor, emotional, cognitive, and behavioral. As such, it would be one attribute contributing to quality of life.

recognition. The spectral shape, formants, and the onset or offset transients between formants affect the resulting timbre, but they are not essential for the identification of the melody. In speech, these same elements provide vital cues to the listener as to what is actually being said.[6]

Speech and music also differ in their broader functional roles, as well as in the processing skills required for their interpretation by the listener. Speech is a discursive form of communication with individual words largely having a predefined meaning. Music, on the other hand, is often more abstract and nondiscursive in its role, not necessarily having a clearly defined semantic function. Music perception frequently entails the simultaneous processing of multiple input sources such as concurrent instruments, multiple rhythms, or countermelodies.

These contrasts in the nature and parameters of music and speech signals, along with the different perceptual skills that listening to these sounds entail, may partially contribute to the disparity between current CI users' performance on speech versus music tests. This may be further confounded by the fact that sound processing strategies in CIs are designed for speech stimuli, and are limited in their ability to process more complex sounds such as music.

NORMALLY HEARING LISTENERS

To better appreciate the difficulties CI recipients experience with pitch and timbre perception, an understanding of how normally hearing (NH) listeners perceive the fundamental elements of pitch and timbre is required.

Pitch

In psychoacoustic terms, pitch usually refers to the low to high ordering of sounds on a melodic scale, with systematic variations in pitch providing a sense of melody.[7] The coding of the F0 is the primary, but not sole, determinant of pitch perception; features such as the intensity can also have a small effect.[8] The strength or salience of the pitch percept is determined by the harmonic content, with the low harmonics, which are resolvable by the auditory system, being most important.[9] For the NH listener, pitch perception for pure tones is associated with both the peak of the travelling wave on the basilar membrane and the temporal pattern of neural firing. For complex sounds, though, the process is more involved. Several models may explain how the normal auditory system determines the pitch of complex tones. Although no one particular model can account for all of the phenomena or anomalies associated with pitch perception, the majority of the currently preferred theories can be divided into three classes—pattern-recognition models, temporal-based models, or a combination of these (spectro-temporal models).[7,10,11]

Common to these classes of models, though, is the initial spectral analysis; the mechanics of a normal functioning basilar membrane enable it to act as a bank of band-pass filters, analyzing the input signal and dividing it into its frequency components. Pitch information can be determined from the resolved lower harmonics of a complex tone[12–14] or from temporal cues from unresolved harmonics. For these unresolved components, several harmonics would interact along the membrane, with specific sites being excited by several harmonics simultaneously. Although this results in a complex vibration pattern, the pattern repeats at a rate equal to the F0. Therefore the pitch of a complex sound also can be determined from the repetition rate of interacting harmonics.[15]

Timbre

Unlike pitch and loudness, timbre is a multidimensional attribute related to differences in sound spectra. In a musical context, it is the attribute that would allow us to differentiate between two different instruments playing the same note at the same loudness level. Grey[16] identified three different spectral dimensions to timbre: (1) rise time (onset or attack time); (2) spectral centroid (the "center of gravity" of the spectrum, contributing to the perception of brightness or dullness); and (3) spectral flux (the number of components in the spectrum, and the spread of these).

In music, each instrument has a unique timbre partially emanating from its harmonic structure, particularly the number and spacing of the higher harmonics. For example, von Bismarck[17] reported that sounds with more harmonics tend to be judged as "fuller" sounding, on a scale from empty to full. These features may contribute more to satisfaction levels when listening to music than instrument identification skills, particularly for nonmusicians, where aesthetic enjoyment is a primary function of music.[18]

THE PERCEPTUAL CONSEQUENCES OF A COCHLEAR HEARING LOSS

The previous section largely pertains to NH adults. However, several researchers have reported that a cochlear hearing loss can alter these perceptions.[19,20] Decreased pitch discrimination ability for both pure tones and complex tones is commonly reported, along with perceptual anomalies such as inconsistencies in pitch-scaling tasks.[19,21–23] The degree of this effect is unpredictable though, and not strongly correlated with absolute hearing thresholds. Reduced frequency selectivity resulting from increased auditory filter bandwidths is commonly cited.[21,23–25] These broader bandwidths decrease the resolvability of low-order harmonics, impeding the perception of the F0.[26] This would not only have a deleterious effect on pitch perception, but timbre perception also would be affected as the spectral shape perceived would be altered.[21] A study by Leek et al[27] of 68 hearing aid (HA) wearers found that over two thirds reported that music was an important part of their lives, with 28% of them feeling that having a hearing loss had interfered with their enjoyment of music. Feldmann and Kumpf[28] found that 79% of their 221 HA users reported that having a hearing loss affected their enjoyment of music.

THE PERCEPTION OF MUSICAL STIMULI WITH A CI

The electrical stimulation that occurs with a CI results in sound percepts different from that experienced through acoustic hearing. Existing research indicates that those with a cochlear hearing loss, including CI users, have temporal resolution skills equivalent to those of the NH population.[29–32] However, there is a discrepancy in their frequency-resolution skills, which in turn impacts on music perception. Accurate perception of Western music requires the listener to discriminate frequency modulations as small as 6%, which corresponds to approximately one semitone. For an implant user, the place and temporal mechanisms used to perceive pitch are affected by a multiplicity of factors.

Whereas the cochlea's auditory filters are nonlinear and level-dependent with continuous center frequencies, a CI sound processor has a limited number of wide filter bands with fixed center frequencies. A wide filter may preclude the lower harmonics of complex sounds from being fully resolved, making it difficult for the listener to precisely derive the harmonic frequencies and make reliable pitch judgments. Even if the individual harmonic components were resolved, falling into separate filters, the CI recipient would only be able to determine which filter the component passed to, as the corresponding electrode would be activated. They would be unable to determine the precise position of the signal within that filter's bandwidth and, accordingly, the exact frequency of the resolved component. Further, if the resolved components were in adjacent filters that subsequently activated two or more adjacent electrodes, some CI users may be unable to resolve the places of stimulation to accurately determine pitch information. The ability to distinguish the pitch of one electrode from another is also dependent upon the degree of spatial specificity when activating individual electrodes and the amount of current spread in the cochlea.[12,33,34]

The inaccuracy in pitch perception resulting from poor frequency resolution might be further confounded by a mismatch between the frequency of the CI's filter and the corresponding characteristic frequency in the cochlea. With typical electrode insertion depths extending to the first 1.5 turns of the cochlea only, filter bands assigned to active electrodes tend to be lower in frequency than the characteristic frequency normally associated with that stimulation site.

Another factor to consider is that in processing a complex acoustic signal, there is activity on several electrodes concurrently. This gives rise to the potential of channel interactions, decreased electrode independence, and reduced spatial specificity. For example, the longitudinal spread of current in the cochlea may result in a large population of auditory neurons being excited, thereby decreasing the specificity of place-pitch cues.[34,35]

Pitch cues are also available through the temporal domain where either modulating the amplitude or changing the rate of the stimulating pulse train can provide pitch cues to the listener. Most current speech-processing strategies use pulse trains delivered at a constant, relatively high rate; they do not vary the stimulation rate as a consequence of features in the input signal.[36,37] Therefore pitch information would predominantly be obtained from the variations in the pulses' amplitude. Amplitude-modulated pulse trains delivered at relatively high rates to the implant provide rapid temporal fluctuations in the electric stimuli; these fluctuations can provide a pitch percept that can be used to convey musical information.[38–41] CI users appear able to derive reliable pitch cues from amplitude modulations in the low modulation frequency region only, up to around 300 Hz.[38,39] This would suggest that many recipients would have difficulty obtaining reliable pitch cues from temporal variations in stimuli with a F0 above approximately middle C.[35,42–44] The salience of amplitude-based pitch cues is also dependent upon a sufficient modulation depth, consistency in the alignment of the phases of the modulations across the electrodes, and a high carrier rate.[38–40,42,45]

Most commercially available CIs use a filter bank in conjunction with pulsatile stimulation where biphasic current pulses are presented sequentially to the electrodes. Spectral information is represented as the variations in current across electrodes, with the temporal information being represented via the temporal fluctuations of the stimulating waveform presented at each electrode. However, as the output of the filter bank is smoothed, only the temporal envelope cues are preserved with the fine-structure information being eliminated. Research by Smith et al[46] suggested that the fine-structure information may be more important for pitch perception than the envelope cues. However, the extent that CI users can perceive this fine-structure information is unclear.[42,47]

A host of other variables can impact on a subject's ability to use place cues to perceive pitch. These include those related to the electrode (e.g., insertion depth, placement, and miscellaneous anomalies), the sound processor (e.g., the processing strategy specifications, stimulation mode, or current path), interaction with other features of the stimuli (such as loudness levels or pulse duration), and patient factors (e.g., pathological processes, auditory neuron survival, neural density, tissue impedance surrounding the array, and the distribution of target neurons relative to the activated electrode location).[33,37,42]

Many of the previously mentioned factors are also pertinent issues in the perception of timbre with a CI, with both pitch and timbral percepts being related to the spectral envelope of the input signal. Accurate timbre perception requires the perception of both the temporal envelope and the signal's spectral shape. For a NH individual, such spectral selectivity derives from the different frequency components of the acoustic stimulus being separated into different auditory filters, with each frequency component resulting in activity at discrete sites along the basilar membrane. The aim of multichannel CIs is to restore some of this frequency resolution by electrically stimulating different sites along the cochlea. However, the degree of discretion between these individual stimulation sites is not nearly as precise as for NH individuals, and varies from one CI user to the next. Existing CI processors conduct a crude spectral analysis of the input signal. Although fine spectral details are not essential for speech recognition in quiet situations, spectral selectivity appears to be considerably more important for listening to music stimuli.[35] As discussed previously, the coding of spectral shape in CIs is limited.[26] Further, accurate timbre perception also may be further affected by the presence of perceptual spectral smearing for many CI users, possibly arising from factors such as current spread around the electrode, neural survival characteristics, or the presence of channel interactions.[37,42] Such spectral smearing, in combination with the strategy's coarse spectral analysis of the input signal, may in part account for the low quality ratings often given to musical stimuli by recipients.

In summary, the perception of music stimuli through a CI is affected by a host of variables ranging from the actual process of electrically stimulating the cochlea, through to the sound processing undertaken by the sound processor, as well as the specifics of the individual recipient. These serve to impact upon the listener's perception of the resulting sound, although the degree and nature of this effect varies immensely across individuals.

MUSIC PERCEPTION BY CI USERS

Although this review focuses on music appreciation and training, a brief overview of studies assessing perceptual accuracy is provided to enable the reader to better understand the current status of research findings and the needs of recipients with regard to music training.

Adults with CIs perform similarly to NH adults as well as those using HAs on measures of rhythmic or temporal discrimination.[5,48–51] It is worth clarifying at this point the differentiation between "gross temporal cues" that impart a sense of rhythm in music, as opposed to temporal cues that provide a sense of pitch. Temporal patterns in the frequency range of 0.2 Hz to 20 Hz provide a distinctive rhythm to musical stimuli, whereas higher-frequency components of the acoustic signal provide the pitch information.[37]

However, the collective findings across a range of studies indicate that CI users perform significantly worse than NH controls on pitch-based tasks.[37,52] For example, Sucher and McDermott[53] compared the abilities of eight adult CI recipients to 10 NH adults in a pitch-ranking task. As expected, the CI users were significantly worse than the NH subjects at ranking both six-semitone and one-semitone intervals. As a group, the CI users only performed at chance level in ranking the one-semitone intervals. Looi et al[54] found a significant disparity ($p < 0.001$) between the pitch perception skills of CI and HA users with similar levels of hearing loss in pitch-ranking sung vowels an octave, a half octave, and a quarter octave apart. Further, the CI group's average for the quarter-octave interval (51.75% correct) was also not significantly different from chance-level performance ($p = 0.238$). That is, as a group, the CI subjects were unable to discriminate the pitch of two notes a quarter octave apart. For the HA group, performance for all three interval sizes was significantly above the chance-level score. Using the same pitch-ranking task as the previous[54] study, Looi et al[55] tested nine patients scheduled to receive a CI prior to implantation with HAs, and subsequently 3 months after activation of their implant. Results were similar to the previous study, with CI recipients unable to reliably rank pitches a quarter of an octave apart postsurgery when using only their CI.

Despite a wide variety of methodologies in the aforementioned studies, the existing literature concurs that the pitch perception skills of most CI users are significantly poorer than those of NH subjects as well as HA users with equal levels of hearing loss.[37,52] This is likely to impact on music perception.

Timbre Tests

Unlike pitch and loudness, timbre is a multidimensional attribute related to differences in sound spectra, and its perception is usually assessed in music studies via instrument identification tests. Similar to the pitch perception research, a host of studies have shown that CI recipients are significantly poorer than NH listeners at recognizing musical instruments.[37,52,56–58] For example, Gfeller et al[58] compared CI and NH subjects in their recognition of eight different instruments playing the same seven-note melodic sequence. NH subjects scored 91% correct whereas the CI recipients only scored 47%. Looi et al[54] compared the ability of 15 CI and 15 HA participants in their ability to identify single musical instruments, solo instruments with background accompaniment, and musical ensembles. The mean percent correct scores for the three respective subtests were: CI group—61%, 45%, and 43%; HA group—69%, 52%, and 47%. There were no significant differences between the groups, despite the contrasting modes of auditory stimulation involved. For both groups, performance was significantly better for single-instrument stimuli than multiple-performer instrumentations. Similar results were found by Looi et al[3] when testing nine adults on the waiting list for a CI pre- to postsurgery. The authors propounded that the additional instruments present in the second and third subtests added to the complexity of the sound, which may have reduced the subjects' ability to recognize the stimuli.

Melody Tests

Although pitch perception is an integral part of melody recognition, it is by no means the only element to consider; for example, the perception of rhythm, lyrics, timbre, genre, or musical style must also be considered. CI recipients are more reliant on rhythm cues or the structural features such as lyrics for melody recognition than NH adults; this would be expected given the pitch perception difficulties discussed previously.[57,59–64]

Gfeller and colleagues[62] investigated the recognition of up to 36 familiar melodies, subdivided into three musical styles or genres—pop, country and western, and classical. The excerpts for the two former styles included lyrics whereas the excerpts for the classical genre were entirely instrumental. The mean recognition score of 15.6% for the 59 adults with CIs was significantly lower than the score of 54.7% for the 30 NH control subjects. As hypothesized, the CI group was significantly less able to identify the purely instrumental classical extracts compared with the other two styles where lyrics were present. Looi et al[54] reported that their CI subjects were significantly poorer than the HA subjects in the study at identifying 10 familiar melodies presented with rhythm cues intact (CI group: mean = 52%; HA group: mean = 91%; $p < 0.001$).

In summary, it is largely accepted that those with significant levels of hearing impairments, regardless of their age or the type of listening device they use (CI and/or HA), are not disadvantaged on rhythm-based tasks. Their performance on tasks requiring spectral analysis, however, is significantly poorer than that of their NH counterparts, particularly evident in studies involving CI users. Examples of these tasks include pitch discrimination, instrument identification, and melody recognition. There is a large variability between individual recipients' abilities to accurately perceive music though, with no single variable or explanation being able to account for this. However, as mentioned, perceptual accuracy for music and music appreciation are two separate issues, and given the functional role music plays in one's life, it may be argued that appreciation and enjoyment are more important outcome measures than identification and discrimination skills for music.

Appraisal and Quality Ratings

Assessing identification and perceptual accuracy is different from appraising sound quality. Although both are often incorporated into CI music studies, they are separate areas and provide different information. Quality ratings can be assessed, using both objective and/or subjective measures. In most studies that incorporate music appraisal ratings, recipients are either asked to retrospectively report on perceived sound quality in a questionnaire format or they are asked to rate the quality of the excerpts used in the timbre identification task.

Gfeller et al[56] investigated the appraisal of the trumpet, clarinet, violin, and piano in 28 Clarion CI (Advanced Bionics Corporation) users compared to 41 NH listeners. Appraisal ratings from the CI subjects were lower than those of the NH population, and significantly correlated with both the amount of reported postimplant music listening ($r = 0.49$; $p = 0.008$) and musical background scores ($r = 0.41$; $p = 0.028$). Speech perception results were not predictive of recognition or appraisal scores, and only a weak correlation was found between recognition scores and overall musical experience scores or the length of hearing loss. No significant correlation was found between accuracy and appraisal scores.

In a larger study, Gfeller et al[58] compared CI and NH subjects in their appraisal of eight different musical instruments playing the same seven-note melodic sequence. Higher-frequency instruments such as the flute, violin, and piano played in its upper registers, were perceived by

CI subjects to have a noisier and duller quality than the corresponding appraisals provided by the NH subjects. No significant correlations were found between speech perception scores and the general appraisal or recognition scores.[58]

Looi et al[3] compared CI recipients and HA users in their appraisal ratings for single and multi-instrument stimuli. For the nine subjects on the CI waiting list, ratings provided post-implantation were significantly higher than preimplant ratings (with HAs; $p = 0.026$). This was consistent with a trend observed from the experienced CI and HA groups, whereby the CI group provided higher ratings than the HA group for all three subtests, although the difference was not statistically significant. For all groups, single-instrument stimuli received significantly higher ratings than those involving multiple instruments (CI and HA groups: $p < 0.001$; waiting list group: $p = 0.034$). The findings of this study suggest that although neither device enabled highly satisfactory music appreciation, the CI users judged music to sound more pleasant than the HA users. Also, music involving multiple instruments was appraised by all subject groups to sound less pleasant, on average, than music played by single instruments.

Gfeller et al[65] investigated the appraisal of melodies across the same three musical styles of pop, country and western, and classical. The CI subjects provided similar ratings across the three genres with a strong preference for stimuli perceived to be "simple." This was in contrast to the NH group who demonstrated definite stylistic preferences, along with a preference for stimuli perceived to be more complex. The authors propounded that it was possible that the CI subjects could not differentiate between the three styles, hence the uniformity across their ratings. The CI recipients gave significantly lower appraisal ratings than the NH group for stimuli in the classical genre. Whereas both the country and western, and pop styles tended to have strong, easy-to-follow beats in addition to the vocal cues, the classical-style excerpts were void of any lyrics or vocal cues.[65]

In a retrospective questionnaire-based study, Looi and She[66] asked 100 CI recipients to compare the sound of musical instruments and instrumental families to "how they would expect these to sound to a NH person." Overall, the recipients rated instruments to sound significantly different from their expectations, with all instruments except the drum kit reported to be significantly "emptier," and most instruments being significantly rougher, tinnier and noisier. As sounds with more harmonics tended to be judged as sounding "fuller,"[17] the ratings of "empty" and "tinny" may be in part related to the reduced representation of harmonic information through the CI. Similar to the findings of Gfeller et al,[65] country and western was rated to be significantly more pleasant, easier to follow and identify, and "more normal" than all but one of the other styles assessed. This was attributed to country and western music being less complex and having lyrics. Recipients significantly preferred instrumentations with smaller numbers of performers to larger groups and less complex or "busy" music.

Looi et al[67] developed a music quality rating test battery specifically for assessing appraisal of musical stimuli. Real-world stimuli were used, with factors such as song familiarity, "favorite" songs, musical genre, and acclimatization (i.e., experience with a processing strategy) being accounted for. LeBlanc[68] in his interactive theory of music preference emphasized that both the input stimuli and the listener's characteristics (including their background, experience with and attitude to the stimuli, preconceptions, etc.) impact upon music preference decisions. In the Looi et al[67] study, neither music genre nor song familiarity had a significant effect on the ratings provided, although there were only seven participants in the trial. However, the authors outlined some of the considerations that may need to be accounted for in designing a test specifically for music appraisal that could be used in a clinical or research situation.

General Music Listening Habits

Gfeller et al[48] designed and implemented a questionnaire to assess the musical background, listening, and enjoyment of 65 adults using a variety of multichannel CIs. The amount of time spent listening to music post-implantation was significantly lower than preimplantation, with one third commenting that they avoided music due to its aversive sound. Many CI recipients reported music to sound strange and noisy, and in some cases so poor that they deliberately avoided it. Similar findings have been reported elsewhere. In a study by Leal et al,[57] 86% of 29 CI subjects stated that they spent less time listening to music postimplant than preimplant, with 38% reporting that they did not like listening to music. Mirza et al[69] surveyed 35 CI patients in regard to their appreciation of music. In rating their enjoyment of music out of 10 (where $0 =$ not at all and $10 =$ very much), mean ratings were 8.7 prior to hearing loss, compared with 2.6 with the implant. For the 16 respondents who reported listening to music routinely postimplantation, the mean enjoyment rating was 5.6, compared with 9.3 prehearing loss. Sixty-nine percent of the 35 respondents said that they were disappointed with the sound of music through the CI. Lassaletta et al[70] used a modified version of Gfeller et al's[48] questionnaire to evaluate the music enjoyment of Spanish CI users. Of the 67 returned questionnaires, respondents reported spending significantly less time listening to music ($p = 0.01$) and lower enjoyment levels for music ($p = 0.007$) postimplantation compared with predeafness.

Looi and She[66] found that although there was a significant decrease in music listening levels and enjoyment postimplantation when compared with prehearing loss, the time spent listening to music along with enjoyment levels was significantly greater postimplant than in the time just prior to getting a CI, when assumedly the recipient would have had a significant bilateral sensorineural hearing loss.

Collectively, these studies suggest that the sound of music through the implant is suboptimal and does not allow the user to fully appreciate musical stimuli. Many recipients describe the sound as noisy, disappointing, and not enjoyable, and consequently, they spend less time listening to music when compared with preimplant and/or prehearing loss levels. There is no indication that one type of CI or speech processing strategy is preferable for music appreciation, although a wide range of music listening habits and preferences is prevalent across the implant population.

In many of these subjective, comparative studies, it is ambiguous as to exactly when the recipient was being asked to make their comparative judgments. Some studies used the term "preimplant,"[57] others stated "prior to hearing loss" or "prior to a profound loss,"[48,69] whereas some authors use the terms interchangeably.[48] Consequently, it may not be clear as to whether the comparative responses were based on sound percepts with unaided or aided hearing, and the severity of the hearing loss at that time. Further, if the respondents were making judgments based on when they had normal or near-normal hearing, it must be asked how long ago this period of time was and how clear was their recollection or memory for these musical sounds.

Correlations with Subject Variables

The only relatively consistent correlations between aspects of music perception and a variety of subject variables, found across various studies, have been for the factors of age[5,49,60,62,64] and postimplant (or "current") music listening habits.[48,49,56,62,65] Speech processing strategy, device manufacturer, or electrode insertion depth is not associated with better (or worse) music perception and/or appreciation.[1,2,63,70]

In a recent, large-scale study, Gfeller and colleagues[1] retrospectively analyzed for factors that may predict CI users' music perception and appraisal. They found different sets of predictor variables for perception-based tasks than appraisal-based tasks. Device type or speech processing strategy was not a significant predictor variable for any task, and speech perception scores primarily contributed only to tests that included lyrics. Unlike most previous studies, the authors found that formal music training preimplant at a high school level or beyond was a significant predictor for tests with no lyrics; in these tests the listener would be more reliant on spectral information. Performance on a cognitive, visual-monitoring task also was predictive of performance in some of the music perception and appraisal tests. Overall success with music listening will be affected by a host of variables including those related to the CI listener themselves (e.g., their age, language skills, hearing history, musical training, listening experience, cognitive skills); those related to the task (e.g., difficulty of the task, open-set versus closed-set response mode, appraisal versus perception assessments, test listening environment); those related to the stimuli (e.g., complexity of the music, instruments used, presence of lyrics or other visual cues); and device-related issues.[1]

The lack of a consistent positive correlation between time with the CI and any music perception task indicates that increased experience with a CI does not improve music perception. That is, to improve music perception with a CI, a recipient will usually need more than just incidental music exposure. To further support this, Gfeller et al[2] found that music perception and appraisal scores remained relatively consistent over a 2-year period. Accordingly, the value and need for music training should be considered, which is discussed later.

Factors Affecting Music Listening Enjoyment

Research by Looi and She,[66] Gfeller et al,[48] and Lassaletta et al[70] has shown that recipients can enhance their listening enjoyment to some extent by controlling their listening environment (e.g., quiet, nonreverberant room, good quality sound equipment, appropriate volume, etc.) and using visual cues (e.g., watching the performer or following a score or lyrics). These recommendations are similar to communication tactics that would be suggested to recipients for speech perception. Further, being selective in their choice of music, such as listening to music that they are familiar with, choosing less complex music with a strong beat, and/or choosing music with lyrics, also has been reported by recipients to enhance their music experience.

MUSIC PERCEPTION WITH ELECTRO-ACOUSTIC STIMULATION

Due to the poor pitch perception performance for many implant subjects, researchers have proposed a host of approaches to endeavor to improve or compensate for this limitation. One such approach shown to have benefit is to combine the use of residual acoustic hearing with the CI for suitable patients. This may be achieved through the use of a HA in the contralateral ear[3,71] or unilaterally through the use of either a modified surgical technique[72] and/or a shorter electrode array[73,74] to preserve as much low-frequency hearing as possible. HAs potentially provide more reliable F0 information than CIs to enhance pitch perception, whereas the CI theoretically provides additional high-frequency information. Hence the combination of the two devices may be beneficial for recipients with sufficient residual hearing at the low frequencies.[71–77]

Gfeller et al[76] investigated whether this combination of electric and acoustic hearing in the same ear, with a short electrode array (as detailed in Gantz et al[74]), could assist a CI recipient in their ability to perceive pitch. It is worth emphasizing at this point, though, that this approach is only viable for a select group of patients who have significant levels of low-frequency acoustic hearing. These "hybrid" subjects used a CI with a short electrode array in conjunction with a HA. The performance of 101 conventional CI users was compared with 13 hybrid subjects and 21 NH subjects on a pure tone pitch-ranking task involving one, two, three, and four semitone intervals. As expected, the NH subjects were better than both of the CI groups across all interval sizes (conventional CI group: $p < 0.001$; hybrid group: $p = 0.0083$). However, the hybrid group performed better than the conventional CI group, and more similarly to the NH group, at ranking the pure tone stimuli. The results for both CI subject groups varied depending on the F0 of the first note of each item, with more accurate percepts in the lower-frequency range.

Gfeller et al[77] compared the open-set recognition of real-world songs, as well as the closed-set recognition of eight musical instruments between hybrid CI users, conventional CI users, and NH listeners. In the song identification task, four hybrid subjects, 29 conventional CI users, and 17 NH listeners were involved. Excerpts of pop and country music were presented in the free field both with and without lyrics. NH listeners were significantly better than the conventional CI users at identifying songs with and without lyrics ($p < 0.001$). The hybrid users were also significantly better than the conventional CI users for recognizing songs without lyrics ($p < 0.001$). For the instrument recognition task, 14 hybrid subjects, 174 conventional CI users, and 21 NH listeners were involved. Each instrument played the same seven-note phrase at a low, medium, and high-frequency range. Recognition results showed that the conventional CI group was not only significantly less accurate than the NH group for all three frequency ranges, but also significantly less accurate than the hybrid group for the low- and high-frequency range. Overall the study reported that subjects with the conventional CI were significantly worse than those with a hybrid CI or NH. The hybrid CI group performed comparably to the NH group for instrument recognition in the low-frequency range, suggesting that preserved low-frequency residual hearing can help with some music recognition tasks.

In both of the aforementioned studies,[76,77] there was greater disparity between the performance of the implant users with the short array compared with those with the conventional array, than between the NH subjects and short-array implant subjects. The authors extrapolated that the preservation of low-frequency acoustic hearing may assist with music perception for hybrid CI users. It should be reiterated that the short electrode array is only suitable for a limited group of patients. These potential recipients tend to have steeply sloping hearing losses, and could therefore have significantly greater levels of postsurgery residual hearing than conventional CI recipients. It is feasible that a recipient with a conventional array may perform equivalently to a recipient with a short array, should they have similar levels of postsurgery residual hearing. That is, it is the level of residual hearing, rather than the type of electrode array, that is the important variable in studies of this kind.

Kong et al[75] compared the melody recognition skills for five adult recipients utilizing a HA in the nonimplanted ear, across three listening modalities—CI alone, HA alone, and both devices simultaneously (bimodal stimulation [BMS]). Three sets of 12 familiar melodies devoid of rhythm cues were presented. The HA alone condition resulted in scores on average 17 percentage points better than for the CI alone condition, with very similar performance for the HA alone and BMS conditions. The author commented that the use of the HA may have enabled some of the lower-frequency fine-structure cues to be preserved, increasing the potential for the subject to extract F0 information from the signal.[75] In another bimodal study, El Fata et al[78] found that recipients whose median low-frequency hearing thresholds in the aided ear was < 85 decibels hearing level (dB HL) were significantly better at melody recognition than those whose thresholds were >/= 85 dB HL.

Of the recipients in Looi and She's[66] study who had tried both a CI alone and BMS for listening to music, significantly more reported that the latter provided a better sound quality. With the HA, recipients felt that instruments sounded more pleasant and natural, musical styles sounded "more normal," and they were better able to follow the melody or identify the style.

The findings of Looi and Radford[79] suggest that results for children may be slightly different. They compared four groups of children—NH, CI alone, HA alone, and children using BMS—on a pitch-ranking task. There was no significant difference between the BMS and CI alone groups. Those using only acoustic hearing (i.e., NH and HA) scored significantly higher than the electrical stimulation (i.e., the CI and BMS) groups ($p < 0.05$). This suggests that there was no significant bimodal advantage for these prelingually deafened children, and the children using electrical stimulation scored significantly poorer than those using only acoustic stimulation.

As mentioned, in most current CI processing strategies, only the amplitude envelope information is retained, with the fine-structure information being discarded.[75] This fine-structure information appears to be important for music perception and for listening in more difficult acoustic environments.[35,37,46,47,64,75] This is in part substantiated by research into combining acoustic and electric stimulation to aid music perception. The acoustic mode of stimulation would allow for the partial preservation of the fine-structure information present in the original stimulus. Theoretically, this fine-structure information should aid the perception of complex sounds; however, how much of this additional detail would be perceived by a CI user is still a matter of conjecture.[42,47]

In considering the results of the aforementioned studies looking at pitch perception of subjects using hybrid devices, it is worthwhile mentioning that a study by Reiss et al[80] reported that the pitch perceived through such a device can change over time, with the time course varying from one subject to another. With these hybrid devices being comparatively new technology this could become more of an issue as time and research progresses.

SUMMARY OF CI RECIPIENTS' PERCEPTUAL ABILITIES FOR MUSIC

Current research indicates that adult CI recipients are significantly poorer than NH listeners at frequency-based music tests, such as tasks involving pitch perception, instrument identification, or melody recognition. Emerging research also suggests that adult recipients scored poorer than HA users with similar levels of hearing loss at pitch perception and melody recognition assessments. Collectively these findings suggest that the electrical stimulation of hearing, as enabled by a CI, often has an adverse impact on pitch-related music perception tasks when compared with acoustically stimulated hearing. That is, an adult's perception of music post-CI surgery would probably be significantly different from their perception of music presurgery. This is an important issue to address in pre-CI counseling, and a factor for potential CI recipients to consider, particularly those with an interest in music. There is, and will continue to be, ongoing research to improve CI technology to enable better music perception. However, two pertinent findings for current CI users to consider are that the use of a simultaneous HA in conjunction with the CI may benefit music listening for those with aidable levels of residual acoustic hearing, and that music training may be of benefit.

The "news" regarding music perception for recipients, though, is not all negative. Although technological improvements have yet to demonstrate significant benefits for recipients' music appreciation, there is an increasing body of research demonstrating that music training may go some way toward remediating some of the difficulties experienced, even with the limitations imposed by the device. Music training is something that can be offered to current recipients with current technology who are interested in music.

MUSIC TRAINING FOR CI USERS

Given the aforementioned difficulty that most CI recipients have in perception of pitch and timbre, the goal of music enjoyment may seem unreachable. It is well accepted, however, that there are large degrees of variability among recipients for both perceptual accuracy and enjoyment of music. Furthermore, there are individual CI recipients whose perceptual acuity exceeds expectations, as well as those who have learned to enjoy music through training. Although there is no definitive explanation as to why some recipients have been able to reestablish music enjoyment, one potential contributing factor is brain plasticity and the capacity for auditory learning through training.

Although the topic of music training is relatively recent in relation to hearing devices, (i.e., HAs, CIs) there exists a more extensive body of work regarding auditory learning and aural rehabilitation methods, much that focuses on enhancing speech perception of persons with hearing impairments. The following overview of general concepts and approaches associated with auditory learning and training provides a foundation for discussing studies of music training reviewed later in this article.

Auditory Learning and Training

For the purpose of this article, auditory learning refers to any change in a listener's ability to perform an auditory perceptual task contingent upon observed or known experience.[81] The term, "adaptation" refers to auditory learning that occurs as a result of everyday experiences. The term, "training" is used to describe auditory learning that occurs as the result of focused, systematic exposure to particular auditory stimuli; it is intended to promote a listener's ability to perform specific auditory perceptual tasks.[82]

According to Arthur Boothroyd,[83] changes in hearing occur as a result of a hearing loss after the acquisition of a hearing device (CI, HA) when HAs are reprogrammed and when CIs are remapped. Adaptation to that change, a process through which the listener acquires new knowledge and modifies skills, is influenced by a whole range of factors related to both the patient (e.g., status of the auditory system, cognitive abilities, environmental circumstances, etc.) and the device (e.g., type, sound processing features, etc.). Active training may provide greater or more accelerated auditory learning than more passive adaptation (incidental exposure).[81–83] Formal training can enhance perceptual processing skills as the listener spends time on perceptual tasks without the demands, constraints, and uncertainties associated with everyday communication. The ultimate goals are restoration of effective communication, reduced levels of activity limitations, and participation restrictions, along with an improved quality of life.[83]

Successful training, however, is dependent upon active engagement (attention and arousal); consequently, components that promote motivation and compliance are important elements in training.[81,83–85] For example, in relation to training stimuli and parameters for presentation, protocols should include sufficient repetition to promote learning, a reasonable balance between success and learning opportunity, accommodation of changes in the central processing of older listeners, feedback on performance, and varied stimuli that are interesting, meaningful, and rewarding. Other components take into account the social nature of communication and successful interactions as a motivating factor. Socially oriented factors could be addressed through training tasks that take advantage of social and situational context, teaching strategies for controlling the listening environment, and helping the listener to establish realistic expectations.[81–83,85] The following section describes training parameters that have been examined in relation to formal training.

Training Parameters

Auditory training can vary on several parameters, including frequency (how often), duration (length of sessions), and delivery method. Although clear-cut guidelines have yet to emerge, spaced rehearsal is generally superior to massed practice, as is training over a longer time frame.[81,82,86] However, training protocols also need to account for a trainee's lifestyle and personal commitments.[66,85] Furthermore, the method of delivery must be sufficiently accessible for training to be sustained. For some, computer-assisted self-instruction used in the home may be a suitable option that they could incorporate into their own personal schedule. However, for others, individual or group training with a clinician or (re)habilitationist may provide social reinforcement and personal interaction that better fosters compliance.[83,85]

Auditory training also may vary on the type of stimuli used (e.g., computer-generated or naturalistic sounds), perceptual tasks (e.g., recognition, discrimination, etc.), and task difficulty. According to Moore and Amitay,[81] training on one type of task may generalize to other types of stimuli that require similar perceptual processes, or even radically different stimuli (e.g., visual stimuli as part of auditory training) if auditory learning is the result of priming or contextual cues that modify the listener's attention to the signal.[81,82,87] However, other studies have revealed that some listening tasks (e.g., spectrally complex aspects of speech or music) may require more specific types of training stimuli (e.g., sufficiently complex stimuli).[88,89] Training tasks that are too easy may fail to produce optimal learning, whereas robust learning can occur on extremely difficult tasks.[81]

Task difficulty can be modified by using adaptive or fixed-level training. In adaptive training, the program begins with stimuli that are easily discriminable, and the task difficulty is adjusted as a function of the trainee's responses.[90] Fixed-level algorithms can maintain the same difficulty level (i.e., there is no change in difficulty level regardless of the trainee's response) or use stimuli that maintain a constant difference in difficulty.[84,91]

Two general approaches to training have been documented in the auditory training literature: analytic, which emphasizes bottom-up perceptual processes; and synthetic, which emphasizes top-down cognitive processes.[81,82,86]

Analytic approaches expose the listener to increasingly difficult contrasts in acoustic features (e.g., speech phonemes; isolated pitches or timbres, often presented using an adaptive algorithm), and are intended to increase perceptual efficiency in hearing small changes. This can facilitate more efficient processing throughout the auditory system and may generalize to tasks reliant upon similar processing skills.[81,82]

Synthetic approaches are designed to promote more efficient central (cognitive) processing (e.g., enhanced attention, use of contextual cues, priming), which can assist the listener in extracting sufficient useable information from the signal.[82,85,86] Synthetic approaches are also more likely to use stimuli that are more naturalistic (e.g., real voices or instruments as opposed to computer-generated pure tones or harmonic complexes) and connected. Connected stimuli in speech training would include complete sentences or paragraphs, as opposed to brief acoustical stimuli such as isolated phonemes. In music training, connected stimuli would include complete musical phrases, songs, or excerpts from longer musical compositions, as opposed to brief pitch contours or isolated pitch or timbre contrasts. Connected stimuli can be made up of either computer-generated stimuli (e.g., melodies created using MIDI technology) or recordings of actual singers and musical instruments (naturalistic). Both analytic and synthetic approaches can be differentially beneficial, depending upon the listening circumstances, the auditory stimuli, listener capabilities, and hearing history and age.[81,82,85,86]

Having addressed various concepts and parameters associated with auditory learning, the following sections focus more specifically on the rationale for music training of CI recipients and extant research regarding their auditory learning of musical sounds.

WHY MUSIC TRAINING?

A Sociocultural Rationale

From an evolutionary perspective, for those reliant upon oral communication, speech and language are essential to successful functioning in many aspects of daily life; consequently, improved speech perception has been a clear objective in the development of hearing devices and auditory training. There is considerable debate, however, regarding the impact of music in relation to basic human needs.[92,93] Thus the question may arise: Is music training worthwhile for CI recipients? From a sociocultural perspective, music is a pervasive form of communication that exists in all known cultures. Music is an emotionally expressive and a culturally significant acoustic phenomenon that helps regulate mood, connects us with important memories, and fosters social cohesiveness throughout the life span.[94] In daily life, we hear music on the television and radio, in places of business, at worship, at sporting events, concerts and dances, and at home to name just a few environmental situations.[92–97] Americans spend more money each year on music (concerts, iPods (Apple), musical instruments, etc.) than on prescription drugs,[93] and American adolescents listen to an average of 105,000 hours of music each year.[98] As music is such a pervasive acoustic phenomenon, CI recipients are likely to be exposed to music on a regular basis. Thus, training that improves understanding and enjoyment of music can assist with their orientation to the environment, along with enhancing the quality and quantity of their social interactions.

From the perspective of CI recipients themselves, music is an important aspect of well-being and social life.[48] Therefore, it is unfortunate that poor music perception through the CI has limited many recipients' access to, and enjoyment of, this important social and cultural phenomenon.[48,99] Music training has clinical relevance in relation to quality of life, enhanced participation within society, and subjective CI benefit.

Structural Characteristics of Music in Relation to Neural Plasticity

In addition to music's sociocultural significance, a growing body of research with NH listeners suggests that the structural characteristics of music, with its perceptual demands, may enhance processing at various levels of the auditory system, particularly for individuals with more extensive music training.[100,101] Both music and speech take advantage of the dynamic modulations of acoustic parameters. Extended music experience (listening, singing, playing), which requires heightened fine-grained frequency discrimination, may improve rapid spectro-temporal processes and can foster the development of perceptual skills that may generalize to perception of more complex spectrally based speech tasks (e.g., speech perception in noise, talker identification, recognition of emotional prosody, tonal language perception, etc.).[102–104] The acoustical richness of musical stimuli activates a widespread bilateral network of brain regions related to attention, working memory, semantic and syntactic processing, motor functions, and emotional processing.[100–102,105] Music training also has been attributed with arousal and social factors that can increase motivation and thus persistence in careful listening.[101,105]

Such findings with NH listeners have prompted speculation whether similar outcomes would be observed in people with hearing loss.[100,101] On one hand, greater experience with spectrally complex sounds, such as music, may enhance cortical responses and improve those aspects of speech perception for which spectral features are particularly salient. It is possible, however, that the CI signal, which transmits primarily the temporal envelope, lacks sufficient fine-structure information to support training of spectrally complex sounds. Furthermore, a host of extraneous variables related to both the recipient as well as the device and its signal processing may influence the efficacy of specific forms of music training.

As noted previously, the benefits of music training also are associated with factors such as longer-term music training[104] as well as attention, arousal, and motivation.[101,105] These factors may be different for CI users than for NH listeners. Only a small proportion of CI users are likely to have had extensive music training prior to deafness.[48] After implantation, one may question whether a recipient would persist with music training, given the degraded representation of pitch and timbre information, and/or whether they would actually benefit from training. Even if formal music training can accelerate or enhance perceptual accuracy more than incidental exposure, how much training is required, and will training on music generalize to other spectrally complex listening tasks?

Systematic evaluation of music training is required to better assess the potential benefit to CI recipients and factors that influence outcomes. The next section reviews a small but growing body of research documenting the effects of training on various aspects of music perception, particularly pitch patterns, melodies, timbre, and enjoyment.

MUSIC TRAINING OF ADULT CI RECIPIENTS

Pitch-Based Structures: Melodic Contours and Melodies

A variety of perceptual tasks are required for real-world music listening; consequently, training that enhances music enjoyment in real life is likely to require a variety of stimuli and response tasks as well as assessment materials to determine training benefit. Some of the pitch-based perceptual tasks trained and tested to date are melodic contour identification (MCI; short sequential patterns of pitch changes) and familiar melody recognition (FMR). FMR involves the perception not only of the melodic contour, but also the exact magnitude of intervallic change from one pitch to the next; mental comparison of the melody being heard to one's recall of the familiar melody's structure is also required. Thus, FMR has considerable ecological validity in reflecting real-world listening experiences. A disadvantage of FMR, however, is the requirement of prior exposure to and recall of the specific melodies. Thus, prior listening experiences and the use of contextual cues are important considerations for FMR. Different pitch-based tasks target different aspects of music listening, but also present specific benefits or challenges within training and perceptual testing of CI users.

Galvin et al[106] examined the effect of computer-based training on both MCI and FMR. Prior to training, 11 adult CI users were tested on a closed-set MCI task that required the listener to identify the pitch contour of five-note sequences: either rising, falling, flat, rising-falling, or falling-rising. The stimuli in this study consisted of computer-generated tones (harmonic complexes) over three octaves, with the interval between successive notes varying from five semitones to one semitone. Baseline pretraining data revealed large intersubject variability in MCI performance, with the best performers achieving >90% correct on the MCI for the two semitone interval. The worst performers identified <40% correct of the sequences with five semitone intervals. The CI users also were tested on a closed-set FMR test in which commonly known melodies were presented in two conditions: rhythmic cues preserved and rhythmic cues removed. Mean FMR performance was 58% when the rhythmic cues were preserved, and 29% correct when the rhythmic cues were removed.

To determine whether training could improve MCI, six of the 11 participants trained on the MCI for 30 minutes per day, 5 days a week. Both auditory and visual feedback were provided. The time course of training was not explicitly controlled as an experimental parameter; trainees were "allowed to continue training as long as they liked."[106(p311)] As a result, the duration of training ranged from 1 week to nearly 2 months. The trainees had repeated exposure to the five melodic contours, using an adaptive computer-generated algorithm that increased the level of difficulty by introducing smaller intervals when the trainee achieved a criterion level of 80% correct. This regime, which used stimuli and response tasks consistent with an analytic approach, required the listener to attend to increasingly difficult contrasts (i.e., smaller pitch intervals), with an objective of increasing their ability to hear smaller changes. To examine the generalizability of the training to similar yet untrained acoustic stimuli, training was completed at a frequency range different from the test items.

Mean MCI performance improved significantly (28.3%; $p = 0.004$), with the amount of improvement ranging from 15.5 to 45.4%. Intersubject variability also was reduced. However, even the best performers were unable to correctly identify MCI contours made up of one-semitone intervals. Although not trained directly on melody recognition, four of the six trainees were tested after training on the FMR as well as the MCI. Mean FMR performance without rhythm cues improved 20.8% ($p = 0.02$) and with rhythm cues by 9.1%. Anecdotal reports from trainees suggested improvement for music perception and appreciation.

This study suggests that analytic training using specific-pitch contours can generalize to untrained music listening tasks with similar or somewhat different perceptual requirements. This study did not explicitly control the time course of training, but at least for some participants, measurable improvement occurred with as little as 1 week of training.

Although Galvin et al's[106] study represents analytic and adaptive methods of training, an experiment by Gfeller et al[63] more closely resembled synthetic training in that the program used connected (i.e., complete MIDI generated melodies and recorded excerpts from longer musical compositions) as well as some naturalistic (real musical instruments or human voices) musical stimuli. To promote top-down processing, trainees were prompted to listen for particular structural features (e.g., pitch, melody, rhythm, timbre, song lyrics) and encouraged to use contextual cues derived through listening experiences prior to hearing loss. The training was undertaken at home on a computer, using a fixed-level presentation of stimuli. Twenty-four experienced adult CI users were randomly assigned to a music training or control (no training) group.

The program included 48 lessons, 20 minutes each, taken over a period of 12 weeks. The training program included two types of melodies: computer-generated melodies (CGM), and real-world melodies (RWM). The CGM were full-length melodies, all created using the piano setting of the MIDI software. The CGM condition permitted considerable control over the structural elements (frequency range, spectrum, tempo, duration, and amplitude) of each melody. Recognition required perception of the overall melodic contour and the direction and magnitude of sequential pitch changes. Rhythmic cues also were available. The RWM stimuli were excerpts from recordings of pop, country, and classical genres. In contrast with the CGM, the RWM presented a more diverse pool of stimuli with regard to stimulus features, including numerous combinations of timbral blends of instruments and voices, melodies with accompanying harmonies and rhythmic patterns, and lyrics—for example, musical sounds heard in real life. Both types of training items included highly familiar melodies as well as newly composed and unfamiliar tunes; this permitted examination of whether trainees could learn new melodies. To examine the generalizability of training to nontrained stimuli, two versions (program A and program B) of the program were created; half of the group trained on each version. All participants were tested pre- and posttraining on both the trained and untrained items.

The results indicated that formal training can improve some aspects of melody perception. For the control group, there were no significant improvements from pre- to posttest in recognition or appraisal on any of the tests. The training group (i.e., combined data from program A and program B) showed significant improvement on the RWM from pre- to posttesting on recognition ($p < 0.0001$; including recognition of some previously unfamiliar melodies) and appraisal (liking; $p < 0.0001$). Most trainees showed greater improvement on those items directly trained in their version of the program, thus it appears that change in accuracy was not the result of improvement in a fundamental perceptual ability but rather a matter of developing compensatory strategies for recognition.

On the CGM, improvement between the pre- and posttest sessions were 10.9% for the training group and 2.3% for the control group; neither improvement was statistically significant. Thus, this fixed-level synthetic approach was effective in improving recognition and sound quality of the real-world tunes, but only modest learning occurred on the CGM. It is possible that the unique timbral blends, rhythmic patterns, and song lyrics comprising the real-world items provided auditory stimuli more readily perceptible through the CI than the pitch sequences presented in the CGM. The availability of more auditory information in the real-world stimuli may have provided more suitable stimuli for training. As is typical with the CI population, there was considerable inter- and intraparticipant variability.

These studies suggest that both analytic and synthetic approaches to training may assist in pitch-based tasks, though in these particular studies, the analytic approach yielded greater generalizability to untrained tasks. Both studies documented considerable individual variability with regard to performance on specific tasks.

Training of Timbre

As discussed earlier in this article, timbre perception, including appraisal (sound quality ratings), is relatively poor for CI recipients. Furthermore, many CI recipients find that timbre perception does not improve as a result of incidental exposure over time.[2] Because most people listen to music for entertainment or aesthetic pleasure, the poor timbral quality transmitted through the CI has a negative impact on music enjoyment.[48] Fortunately, a small body of research suggests that timbre recognition and appraisal can be improved with systematic training.

Gfeller et al[18] examined whether synthetic, fixed-level training could improve recognition and appraisal of musical instruments. Twenty-four CI recipients (concurrently involved in melody training discussed earlier in this article[63]) with at least 12 months of experience were randomly assigned to a training or control (no training) group. Pretraining scores confirmed no significant differences between the groups for recognition or appraisal at baseline.

Training consisted of 48, 10-minute sessions delivered via a computer at home, over a 12-week time period. The protocol included direct instruction (DI) of eight musical instruments representing four instrumental families (woodwind, brass, string, pitched percussion) played in three frequency ranges (low, medium, high). Naturalistic and connected training stimuli were used. The stimuli were recorded excerpts of solos played by musicians in a sound recording studio. Because timbre varies considerably for one instrument, depending upon the manner that it is played (e.g., style, articulation, etc.), the excerpts for each instrument were selected to represent a variety of sounds and musical styles associated with each instrument (e.g., solos of a clarinet playing Dixieland jazz, classical, pop music; a trombone playing a glissando, etc.).

The timbral excerpts were accompanied by computer-screen text that introduced each instrument (DI; e.g., "Here is a video of a person playing a trombone. Trombones are members of the brass family and change pitches by using a metal slide. The trombone uses this metal slide to "slide" from one note to the next."). Visual cues (e.g., videotapes, icons, etc.) and on-screen prompts drew the trainee's attention to particular characteristic features. Contextual cues related the training stimuli to predeafness listening experiences (e.g., "The trumpet often plays fanfares. Listen to this fanfare played during the Olympic ceremonies.").

To evaluate training benefit, both the control and training group were tested at the same time points (pretest at baseline; posttest after training or after 3 months for the control group) on timbre recognition and appraisal tests. The test stimuli were recordings of a standardized seven-note melody played on each of the eight instruments within its most typical frequency range. The recognition test was a closed-set task in which participants indicated which instrument they had heard. In the appraisal test, the participants rated the sound quality of each instrument using a visual analog scale of 0 to 100 points anchored with bipolar descriptors. Each item was rated for overall sound quality (like very much, dislike very much) along with scales for three descriptors of sound quality: thin-full, dull-brilliant, and scattered-compact.

For the posttest results, the training group's recognition scores were significantly higher than those of the control group ($p < 0.002$). In addition, the training group showed a significant increase between the pre- and posttest scores for the recognition task ($p < 0.0001$); there was no significant change for the control group. The appraisal ratings for the training group also improved from pre- to posttest ($p < 0.02$); there was no significant change for the control group. These results indicate that CI recipients can improve in both recognition and appraisal of instrumental timbre as a result of at least 12 weeks of synthetic, fixed-level computer-based training.

Although Gfeller et al[18] established that significant auditory learning can occur over 12 weeks in clinical practice, 12 weeks may be an unrealistic time commitment for some recipients. What duration of training is sufficient to achieve significant and sustainable benefit? Driscoll and colleagues[107] conducted an experiment that tracked change in timbre recognition as a function of synthetic fixed-level training at three points in time: 3 weeks, 5 weeks, and 2 weeks after training was completed. In addition to examining rate of learning, this study also compared the effectiveness of three different types of training input for timbre recognition: repeated exposure to the stimuli with no feedback (RE only), repeated exposure with feedback on accuracy (RE + FB), and DI (similar to that used in the Gfeller et al[18] study). All training conditions presented the same recorded excerpts of musical instruments playing solo repertoire that reflected prototypical features of each instrument (e.g., fanfares played by trumpets); the number of exposures to each instrumental excerpt was consistent across all training conditions.

The participants in the study were NH adults who listened to CI simulations of the instrumental recordings used in the training program. Testing a NH sample facilitated the recruitment of a larger sample of participants and also reduced individual variance among participants with regard to hearing history and auditory system status (or integrity). Trainees participated in three training sessions per week over 5 weeks. The training was delivered via a password protected Web site and completed in the participant's home. Closed-set instrument recognition tests, using the same stimuli as that incorporated into training, were performed at four points in time: prior to training, week 3, week 5, and 2 weeks after the completion of training.

The RE only group showed modest though nonsignificant improvement only at week 3; no further improvement was noted. In contrast, the RE + FB and DI groups showed significant ($p < 0.001$) improvement in week 3 and continued improvements at week 5. Those assigned to the DI group showed the greatest improvement at week 3 ($p < 0.002$) and over the entire training period, as well as sustained improvement at week 7. These results suggest that auditory learning from repeated exposure to musical sounds without feedback (which occurs in many incidental listening situations such as music on the radio) is less efficient than if feedback and/or DI is provided. This study also indicates that feedback as well as DI can be beneficial in "relearning" instrumental sounds through a CI. Significant improvements can occur with as little as 3 weeks of instruction, however, further and sustained benefits can be observed with longer training (5 weeks). This study, however, did not examine outcomes with similar stimuli not directly trained or the generalization of training to different types of stimuli.

In summary, these studies indicate that timbre recognition and appraisal can improve as a result of as little as 3 weeks of synthetic training. However, longer training provides greater improvement and supports sustained improvement posttraining. Further study is needed regarding learning on untrained but similar stimuli and generalization to other stimulus categories.

Psychosocial Considerations in Music Training

As the aforementioned studies indicate, formal training can enhance auditory perception for pitch-based and timbral elements in music. However, auditory learning requires repeated exposure, thus clinical benefit will not occur unless trainees persevere with training protocols. Consequently, characteristics such as motivation, engagement, and cognitive factors should be taken into account when considering training parameters and program content.[81,83] According to Arthur Boothroyd, motivation to engage in formal training comes from the learner, usually in response to specific life-changing events.[83] For CI recipients, this may include dissatisfaction with musical sound quality and a desire for improved music listening.

In relation to music training protocols, several studies have examined attitudes of CI recipients regarding music training and those components that they would find most beneficial.[66,108,109] Looi and She[66] surveyed 100 adult CI recipients about various aspects of music listening and factors that affected their music enjoyment. Fifty-four percent indicated interest in a music training program if available. The skills they considered most important were ability to recognize previously known tunes, musical instruments, and pitch changes; all tasks related to enhanced pitch or timbre perception. Sixty-five percent of this sample recommended that training should include a wide range of musical styles. When queried about optimal length of sessions and frequency of training, the most common recommendations were 30-minute sessions for two to three times a week.

Philips et al[108] surveyed 40 postlingually deaf adult CI recipients. Only 28% of this sample stated that they appreciated music with their CI, and 82% described music as sounding unnatural. Thirty-three percent of the group reported "having received a form of musical training during rehabilitation," and 45% reported "practicing listening at home."[108(p816)] The authors provided no description of what constituted training or home practice. Those respondents who practiced music listening at home found that it improved tracking rhythm, but not melody. Seventy percent of the bimodal listeners in the group noted the benefit of using HAs when listening to music. The authors reported that 65% were convinced that learning to listen to music during rehabilitation was useful. Fifty-two percent of the 40 patients surveyed indicated the importance of being able to enjoy music again, and 35% noted that music was significant for their social life.

Using qualitative research methodology (grounded theory), Hughes et al[109] investigated CI users' attitudes toward and experiences of music and music rehabilitation. Data were gathered through an anonymous questionnaire surveying users' experiences of music pre- and postimplantation. The questionnaire was sent to all adult recipients implanted in their center within the past 3 years. Fifty-four percent ($n = 7$) returned the survey. Next, a focus group was organized and five adult CI recipients and one hearing partner ($n = 6$) enrolled. The focus group was used to pilot various approaches to music rehabilitation (group discussions, technical update, analytic listening tasks, listening to different musical excerpts). The authors did not describe the length, frequency, or duration of the focus groups.

All group discussions within the focus group were transcribed for analysis. A post–focus group questionnaire was sent to all the participants to elicit their impressions of the focus group; the clinicians facilitating the group also were asked for feedback. The questionnaires and transcripts were coded and analyzed to identify key concepts or ideas.

The key themes that emerged from this study included: (1) CI users who listened to and valued music preimplant were more likely to listen to and value music postimplant; (2) familiar melodies provided "memory hooks" and boosted confidence when beginning to listen to music postimplant; (3) analytical listening activities revealed variability among individuals in perception of musical structures (e.g., pitch, loudness, notes, chords, scales, etc.); (4) group learning was considered valuable by clinicians and recipients, although persons with congenital hearing losses may have different musical needs than postlingually deafened adults; and (5) recipient expectations of the implant were central to their musical enjoyment; how patients "reframe their perception of musical enjoyment"[109(p72)] was identified as an area for consideration.

These studies suggest that many CI recipients are interested in music training, have sufficient motivation to enroll in training, and have specific ideas regarding those musical skills that they wish to improve. Expectations regarding reasonable outcomes are an important variable in perceived benefit. This suggests the need for counseling CI users on realistic expectations for music perception and enjoyment. However, the initial desire for training will dwindle if the training protocol is not well suited to the needs and characteristics of the learner.

One such factor that needs to be accounted for is age-related changes. A sizeable proportion of adult CI recipients are likely to be 45 years or older; consequently, physical, cognitive, mental, and social changes associated with age should be accounted for in the development of music training programs for adults.[85] According to Gfeller,[85] training components that can support the older learner include (1) training materials that account for possible visual limitations associated with more advanced age (e.g., larger print and images with clear resolution, reduced visual clutter), (2) strategies that accommodate slower information processing (e.g., self-paced instruction, anticipatory information, ample repetition), and (3) meaningful information that has obvious applicability to listener situations in real life (e.g., strategies to enhance listening at home and in social situations).

The efficacy of addressing characteristics of older learners was documented in the music training program developed by Gfeller and colleagues that trained adult CI recipients (ages 38 to 75, mean age 56.6) on melodies and timbre (melody and timbre training described previously, Gfeller et al[18,63,99]). In addition to listening exercises for melodies and timbre, the program included more socially oriented components through computer screens that: (1) conveyed practical strategies for controlling music listening situations (e.g., using FM input at a concert, requesting seating near the performer to improve/provide visual cues); (2) described listening exercises that could be applied to real-life listening situations (e.g., listening for different musical styles on radio stations), and (3) practical strategies for music listening that had been gleaned from other CI users who enjoy music listening (social support).

The training group showed not only significant perceptual improvements (e.g., recognition and appraisal of RWM and timbre), but also gave positive evaluations of the program's content, organization, and ease of use (mean rating of 3.64 out of 4 possible points). In response to the question, "Would you recommend this training program to other CI recipients?" all trainees responded with ratings of 4 (strongly agree). Despite the relatively lengthy training protocol (12 weeks), online data revealed strong program compliance and persistence, with 92% completing the entire 12-week music training program.

Although the aforementioned studies describe music training designed for postlingually deaf adults, there is a growing interest in music training for pediatric CI recipients. Because prelingually deaf individuals differ on hearing history, do not have a "normal hearing" representation of music to compare with, and have different cognitive, behavioral, and social characteristics from adults, music training for adults cannot be presumed to be suitable for pediatric patients. Further, the results of the adult studies cannot be generalized to children.[110,111] The following section describes some key issues associated with pediatric training and summarizes the few training studies that have been conducted with pediatric CI recipients.

MUSIC TRAINING PROGRAMS FOR CHILDREN

Musical play is a natural part of early childhood, consequently, involvement in music experiences is a suitable developmental choice for pediatric CI recipients. Several studies indicate that many pediatric CI users are involved in various types of music at school and at home, and many children do enjoy music, despite having less accurate perception for pitch and timbre than their NH peers.[110–113] As is the case for adults, there is considerable variability among children, with a small subset of children showing remarkable accuracy in some aspects of music perception.[111]

Successful involvement in educational and community music programs can foster social integration and personal mastery in avocational pursuits.[111,112] Recently, there has been interest in the potential habilitative benefits of music for pediatric CI recipients. As noted earlier, for NH listeners, long-term music listening experience alters the temporal and spectral relationships between sound stimuli and the resulting patterns of synchronous activation in auditory centers in the brain stem.[114] Based upon these findings with NH listeners, a growing number of clinicians, professional Web sites, and advocacy groups[102,115,116] have recommended the implementation of music-based training for children with communication disorders in early childhood, a time of optimal neural plasticity.

Extant publications regarding music training/therapy for children often recommend active and playful engagement in music making and listening, which are linguistically, behaviorally, and psychosocially age-appropriate forms of activity.[110–112] Pedagogical methods for young children, such as Orff, Kodaly, Dalcroze, Suzuki, and YAMAHA, employ multidimensional and multisensory musical experiences that emphasize exploration of sounds through playing keyboards or percussion instruments, singing, listening, and moving to music within a social context (e.g., group music, family music).[112] For younger (e.g., preschool) children in particular, the emphasis is typically on exploration and enjoyment of sound rather than perceptual acuity.[110,112] A clinical session is likely to be shaped by the behavioral and cognitive capabilities as well as the auditory skills of each individual child. Flexibility in implementing a session is often required to sustain the child's attention and engagement. Playful music making does not readily lend itself to the highly controlled and neatly ordered training parameters that were previously described in association with many training programs for adults.

The issue of training and evaluating music perception in young children is challenging for several reasons. Even for NH children, the development of particular musical skills (perception and production) tends to vary not only as a function of perceptual abilities, but also due to differences in cognitive maturity, personal motivation and attentiveness, and environmental influences.[117] Unlike language arts, which are typically required in all schools, music instruction may be optional, unaffordable, or unavailable for many children. Consequently, children are likely to differ considerably in their experiences with music, including familiarity with musical terms that may be used in testing. For example, some musical terms/structures such as pitch (e.g., high versus low; which pitch is higher than another) are conceptually difficult to understand, even for younger NH children.[110] Thus, one could not expect complete competency on tasks such as pitch ranking or contour identification by young pediatric CI users, whose conceptualization of pitch will also be influenced by prior exposure (or lack of) to musical concepts, cognitive maturity, hearing history, status of their auditory system, as well as having a hearing device that presents a degraded representation of pitch.[110]

A handful of studies with young prelingual CI users have examined the use of socially oriented active music making as a form of habilitation.[118–120] In 2001, Abdi et al[118] investigated the use of music as a means of habilitation with 23 pediatric CI users (aged 2.5 to 12.5 years). Group music sessions (four children per class) were held once a week and children participated in Orff methodology[112] and lessons on a Se-tar, a traditional Iranian stringed instrument. Details regarding the session format or content were not provided. The length of participation (between 3 to 12 months) differed across the sample, depending upon the interest/motivation and availability of each child and their parents. Musical skill development for a variety of tasks and enthusiasm for music were documented using teacher ratings (1 to 10); the rating outcomes themselves were not documented in the article. Rather, the results were presented as individual case studies (narratives of approximately one paragraph per child) reporting general progress in musical skills, familial interest, and enthusiasm toward music. The authors concluded that all the children showed appreciable progress in instrument playing and parents expressed satisfaction with perceived benefits of the program; however, no perceptual data were reported. Although no direct comparisons with NH children were included in the study, the authors estimated that CI users required approximately three times more instruction to learn specific music skills in comparison with an NH child.

Yucel et al[119] instituted family oriented music training that took place in the child's home over a 2-year time period. The authors hypothesized that if music abilities of the children could be improved, musical enjoyment and speech perception also may improve. Nine pediatric CI recipients (chronological age at testing not provided) completed home-based music training implemented by the parents. The parents were given a manual that outlined the training tasks. Each child was expected to complete 10 minutes of music training each day. The primary training tasks included (1) listening to pairs of pitches and rhythm patterns played on a keyboard (discrimination tasks) and responding same or different (the discrimination tasks became increasingly difficult over time) and (2) listening to the pitches and rhythms in children's songs played on an electronic keyboard and trying to recognize the songs. The stimuli were produced on the keyboard by the child's parents. After listening to the discrimination exercises played by the parents, the children were encouraged to explore sounds by playing on the keyboard. Diary entries of the parents indicated that the children logged a total of 116.87 to 175.42 minutes of music training over the 2-year time frame.

The parents evaluated their child's responses to music at 12 and 24 months using a Musical Stage Profile (MSP). Using this questionnaire, the parents rated their child's abilities on (1) sound awareness and general reaction to music, (2) voluntary participation in music outside of the training exercises, (3) discrimination and identification of pitch and rhythm patterns, and (4) emotional responses to music. The 26 questions in the questionnaire used a Likert-type scale (1 to 5 points) of never, rarely, occasionally, frequently, or always. No measures of pitch or rhythm perception were taken. Speech perception measures were also collected, included the Ling 6 Sound Detection-Identification Test, the Word Identification Test (in Turkish), the Mr. Potato Head Task, and the Daily Sentences in Turkish Task (see Yucel et al[119] for detailed description of the speech measures). The scores of the nine children who participated in training were compared with a control group of nine children who did not participate in music training. However, all participants (training and control) were also enrolled in an auditory-verbal learning training program as part of their normal routine.

The results showed a wide range of performance by the children on all the speech measures. For the first 12 months, the results on the MSP were similar for both groups. After 12 months, the music group was rated as having greater interest in MSP items related to music exposure in daily life and awareness of musical elements. By the end of the 24 months, the children in the music group were rated by the parents as being more attentive to music, and more competent on all aspects measured by the MSP. No significant differences were found at the end of 24 months on any of the speech measures. The authors concluded that music training helped appreciation of music, fostered a closer parent-child relationships, and may enhance progress in other auditory domains.

A training study using YAMAHA music instruction examined the impact of formal music instruction on pitch perception.[120] Twenty-seven congenital or prelingually deaf CI recipients (ages 5 to 14 years; mean of 6.7) participated in the study. The children's age at implantation varied from 17 to 163 months; duration of CI use varied from 10 to 69 months. The children participated in YAMAHA music instruction for 2 to 36 months (mean of 13.2 months). The authors described the training as consisting of "listening, singing, score reading, and instrument playing."[120(p794)] The children were tested on a pitch-ranking task played on the piano by the test administrator. A 2AFC task was used in which the test administrator played two sequential piano tones, ranging from C (256 Hz) to B (495 Hz). A total of 49 tone pairs were presented in testing; interval sizes ranging from prime (same note) to a major seventh interval (11 semitones) in ascending and descending direction of pitch change. The children were tested individually and asked to identify the pitch relationship between the two tones (same, higher, or lower that the first pitch). No feedback was given on accuracy.

The outcome was reported in percent correct scores for the 49 test items (pitch pairs). Individual performance varied from 9.5 to 92.5%. Accuracy of pitch perception was examined as a function of training duration, pitch interval size, current age, age of implantation, gender, and type of CI. The duration of training was positively correlated with pitch perception accuracy ($r^2 = 0.389$, $p = 0.045$). There were no significant correlations between pitch accuracy and age at implantation, gender, or type of CI. Children older than 6 years were more accurate than those younger than 6. The authors noted that the younger children may have had more difficulty understanding the test itself. This is consistent with our previous observation that younger children may have difficulty with the conceptualization of higher and lower pitch.[110]

Together, these studies suggest that pediatric CI recipients can participate successfully in some aspects of music training based upon naturalistic music learning experiences. The programs described were developmentally suitable, and provided opportunities for motivating yet challenging listening experiences. Based on models of brain plasticity, it is clear that a rich auditory environment is needed to promote development of the auditory system.[102,105]

Naturalistic training protocols, however, do not allow strict control over structural parameters (e.g., choice of stimuli, frequency and duration of training, specific perceptual tasks, etc.). Consequently, it is difficult to determine what aspects of training may have contributed to observed changes in perception or enjoyment. Furthermore, assessment protocols that are developmentally suitable for young children, yet reliable and valid in measuring training outcomes, present significant challenges. Evaluations based upon teacher or parent reports alone also can be susceptible to Hawthorne effect or rater bias. Several non-training factors (e.g., hearing history, musical experiences outside of training, cognitive development) also can influence results.[110–112,117] These considerations suggest the importance of thoughtful interpretation of study outcomes.

A host of questions remain regarding pediatric music training. Does formal music training accelerate or result in greater perceptual accuracy than incidental exposure or other types of environmental stimulation? Are there optimal developmental periods when music training may be most beneficial? Are some forms of training more efficacious than others? How much training is required to achieve significant and sustained benefit? Does music training of CI users generalize to speech perception tasks? Will music training benefit tonal language speakers when pitch changes provide linguistic information? Given the considerable challenges involved in research protocols that are developmentally suitable for young children, these questions will likely require a collective effort of many clinical research teams over the coming decades.

SUMMARY

As this growing body of research indicates, music appraisal as well as perception is suboptimal for CI recipients. Fortunately, several factors, including bimodal stimulation, suitable listening conditions, listening to music postimplant, and music training can improve music perception and appreciation (appraisal). Improved pitch and timbre perception (including appraisal) have obvious implications for music enjoyment, which can in turn impact on social integration and quality of life. Further research is needed, however, to better understand the variability that CI recipients show in response to music training and factors that may enable greater degrees of training benefit—factors related to the recipient themselves (e.g., hearing history, listening modes, age, etc.), hearing devices (e.g., device types, processing strategies, BMS, etc.), as well as those related to the training parameters (e.g., training approach, duration and frequency, presentation mode, etc.).

In recent years, there has been increasing speculation that music training also may enhance speech perception by CI recipients.[100,101,103] At present, this is based primarily on research with NH listeners with long-term participation in music instruction and performance,[101,121–125] which suggests that extended music experience can improve some aspects of cognitive linguistic functioning such as auditory attention, phonological processing, and speech perception in background noise.[100,101,121–123] However, given that some aspects of speech perception are pitch-based (e.g., prosodic cues, emotional status of the speaker, lexical tone perception for tonal languages), along with the fact that some of the cues used for perceiving speech in noise are similar to those required for accurate pitch perception (e.g., temporal fine-structure information and spectral specificity), the transference of skills acquired in music training to speech perception is not an unreasonable hypothesis. At present, correlational data show strong relationships between music perception and some measures of spectrally complex speech, such as speech perception in noise, talker identification, and tonal language perception.[76,100,103] This suggests that enhanced perception of music may generalize to speech perception of CI recipients. However, until systematic refereed studies are available, the generalization of studies with NH listeners to CI recipients should be made with caution.

Regardless, it is well accepted that music is an important auditory stimuli for both pediatric and adult CI recipients and that currently both perceptual accuracy and satisfaction levels for music listening is generally low. Although research continues into how the device itself and/or the speech processing strategy implemented may be developed to better transmit the features of musical sounds, it would seem that music training is an intervention that could be offered now to current recipients, regardless of their current musical abilities, device/strategy used, or experience with the implant, to potentially improve their music perception and appreciation.

NOTE

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