Song Recognition by Children and Adolescents With Cochlear Implants

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Purpose: To assess song recognition and pitch perception in prelingually deaf individuals with cochlear implants (CIs).

Method: Fifteen hearing children (5–8 years) and 15 adults heard different versions of familiar popular songs—original (vocal + instrumental), original instrumental, and synthesized melody versions—and identified the song in a closed-set task (Experiment 1). Ten CI users (8–18 years) and age-matched hearing listeners performed the same task (Experiment 2). Ten CI users (8–19 years) and 10 hearing 8-years-olds were required to detect pitch changes in repeating-tone contexts (Experiment 3). Finally, 8 CI users (6–19 years) and 13 hearing 5-year-olds were required to detect subtle pitch changes in a more challenging melodic context (Experiment 4).

Results: CI users performed more poorly than hearing listeners in all conditions. They succeeded in identifying the original and instrumental versions of familiar recorded songs, and they evaluated them favorably, but they could not identify the melody versions. Although CI users could detect a 0.5-semitone change in the simple context, they failed to detect a 1-semitone change in the more difficult melodic context.

Conclusion: Current implant processors provide insufficient spectral detail for some aspects of music perception, but they do not preclude young implant users' enjoyment of music.

KEY WORDS: cochlear implants, auditory processing, music recognition

Music and speech are similar in the sense that they consist of sound patterns that unfold over time. They differ drastically in their processing demands (Patel, Peretz, Tramo, & Labreque, 1998; Zatorre, Belin, & Penhune, 2002), however, because of differences in the relative priority of acoustic cues in speech and musical sequences. For example, speech involves very rapid articulation. Aspects of the signal change continuously, and the rate of typical conversational English, including pauses, averages 12.5 perceptible sounds per second (Miller, 1981). Music unfolds at a considerably slower rate, with individual pitches sustained for 200–600 ms (Drake & Bertrand, 2003).

Variations in fundamental frequency, or pitch, tend to show the opposite pattern, with more fine-grained information in music than in speech. In general (i.e., for languages other than tone languages), pitch changes that signal important linguistic contrasts (e.g., statements vs. questions) are relatively large, on the order of 6 semitones (half an octave). In fact, because of continuous variations in amplitude and formant frequency that obscure pitch changes, running speech has approximately three or four distinguishable pitch intervals per octave (Hart, Collier, &

Cohen, 1990). By contrast, much smaller changes (e.g., 1 semitone) play a significant role in music (e.g., distinguishing major and minor chords), and successive notes in melodies are typically separated by 1 or 2 semitones (Vos & Troost, 1989). Redundant cues in speech make it possible to decode messages in the context of severely degraded spectral cues provided the temporal cues are intact (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995). In Western music, however, pitch cues are critical to melody identification (Hébert & Peretz, 1997), even though temporal cues also play a role. Although effective speech processing can occur in the context of coarse spectral cues but precise temporal cues, effective music processing depends on precise spectral cues.

Because of differences in the relative importance of spectral cues to the perception of speech and music, spectral processing limitations are likely to have differential consequences in speech and musical domains. For example, individuals with tone deafness, or *amusia,* have normal phonetic and prosodic processing abilities, but they are unable to recognize or produce simple melodies, including those that are universally known within a culture (e.g., *Happy Birthday;* Ayotte, Peretz, & Hyde, 2002; Foxton, Dean, Gee, Peretz, & Griffiths, 2004; Hyde & Peretz, 2004; Murayama, Kashiwagi, Kashiwagi, & Mimura, 2004; Stewart & Walsh, 2002). Amusic individuals' difficulties in melodic processing and their characteristic indifference to music (Peretz & Hyde, 2003) stem from an inability to discriminate very small pitch differences that are relevant to music but not to speech (Hyde & Peretz, 2004).

Cochlear implant (CI) users have difficulties in pitch perception that exceed those of amusic individuals. The processing algorithms used in conjunction with CIs extract temporal-envelope cues from the auditory input at the expense of fine-grained pitch cues (Wilson, Sun, Schatzer, & Wolford, 2004). For postlingually deafened adults, the typical outcome is relatively good speech perception under favorable listening conditions (i.e., quiet) but very poor music perception (Dorman, Basham, McCandless, & Dove, 1991; Gfeller et al., 2005). For example, adult CI users have difficulty identifying instrumental versions of familiar melodies (i.e., tone sequences or tunes) unless distinctive rhythmic cues are available (Fujita & Ito, 1999; Gfeller et al., 2000; Kong, Cruz, Jones, & Zeng, 2004; Leal et al., 2003; Looi, McDermott, McKay, & Hickson, 2004). They also perform very poorly on pitch-discrimination tasks that necessitate pitch-direction judgments, with successful performance requiring differences of 4–12 semitones (Fujita & Ito, 1999; Green, Faulkner, & Rosen, 2004; Looi et al., 2004; Vandali et al., 2005).

Studies of temporal processing among CI users highlight deficits that vary in magnitude depending on the complexity of the task. In very simple tasks, such as those involving tempo discrimination in the context of drum sequences, adult CI users perform equivalently to normal-hearing (NH) controls (Kong et al., 2004). They also notice whether the rhythm of two monotonic sequences is the same or different (Gfeller & Lansing, 1991), in some cases performing equivalently to NH controls (Gfeller, Woodworth, Robin, Witt, & Knutson, 1997). Nevertheless, they show impairments on more difficult tasks such as specifying the location of a shortened interpulse interval in a six-pulse sequence (Gfeller et al., 1997) or matching the rhythm of a sequence to a visual display (Kong et al., 2004).

It comes as no surprise that adult CI users report greatly reduced interest (or total disinterest) in music after their acquired hearing loss, a situation that is commonly exacerbated by implantation (Gfeller et al., 2000; Leal et al., 2003). Relatively little information is available on the musical experiences of child CI users. The findings from adult CI users may not generalize to children because of differences in the users' history of hearing and music listening (Gfeller, Witt, Spencer, Stordahl, & Tomblin, 1998). For example, adults' experience with music prior to hearing loss may make degraded musical input less acceptable than it would be otherwise. Moreover, evidence of enhanced development of the central auditory system in early- relative to late-implanted children (Sharma, Dorman, & Kral, 2005; Sharma, Dorman, & Spahr, 2002) may have favorable implications for music processing, as it does for speech processing (Harrison, Gordon, & Mount, 2005; Purdy, Kelly, & Thorne, 2001; Robinson, 1998).

In one study (Stordahl, 2002), implanted children had difficulty recognizing familiar songs on the basis of pitch alone, and their appraisals of music tended to be more negative than those of hearing children. Although the findings from children are consistent with those from adults (Gfeller et al., 2000; Leal et al., 2003), they are difficult to reconcile with CI children's participation in a variety of musical activities (Gfeller et al., 1998; Stordahl, 2002). Because of CI users' difficulty with pitch resolution, their reliance on timbre and timing cues may be greater than is the case for listeners with normal hearing. Thus, the use of unfamiliar renditions of familiar songs (e.g., instrumental versions of sung material) may underestimate implanted children's and adults' ability to recognize songs. In other words, CI users might recognize songs more readily in the context of multiple cues, particularly if those cues were available in familiar recordings (e.g., pop songs, television themes). This perspective is in line with the encoding-specificity principle (Tulving & Thompson, 1973), in which memory for a stimulus is better if cues at the time of retrieval match those at the time of encoding. Because of limitations in current implant technology (e.g., atypical representations of pitch and timbre), cues at encoding and retrieval would have to be sufficiently distinctive to permit CI users to differentiate the target songs from other songs.

The purpose of the present study was to shed light on the music-processing abilities of young CI users. Of particular interest were differences in song-identification strategies between NH controls and CI users who were congenitally or prelingually deaf. Previous studies of musical abilities in CI users have focused primarily on postlingually deafened adults (e.g., Gfeller, Christ, Knutson, Witt, & Mehr, 2003; Gfeller et al., 1997, 2005; Kong et al., 2004; Leal et al., 2003). We hypothesized that implanted children would be more likely to recognize familiar musical materials when the acoustic cues at test time closely matched those available during prior listening experiences. Accordingly, our stimuli included standard renditions of songs that were familiar to all participants, namely contemporary pop songs for which there were canonical, or unique, recordings. Our stimuli also included renditions that eliminated specific cues from the recordings (e.g., lyrics, timbre), a strategy aimed at specifying the cues required for successful song recognition. We created a forced-choice task to assess listeners' ability to identify familiar songs in three different conditions. In one condition, the stimuli comprised the original commercial recordings. A second condition had identical stimuli except for the absence of vocals (i.e., commercially available instrumental recordings). In a third condition, the stimuli were piano versions of the main melodies (i.e., the tune that one would sing or hum along with the recording).

For NH listeners, we expected the familiar recordings to be almost as recognizable without the words as with them (Experiment 1). Although piano renditions of the tunes provided far fewer acoustic cues than the original recordings, they are sufficient for adults' identification of familiar musical materials (Hébert & Peretz, 1997). As such, they should be identified reasonably well by younger listeners provided these listeners can generalize across substantial transformations in musical texture and timbre.

In principle, CI listeners could succeed on the original versions by relying exclusively on vocal cues. Although adult CI users can decode sung lyrics in the context of instrumental accompaniment (Fujita & Ito, 1999), child users have difficulty doing so, especially with novel materials and open-set tasks (Vongpaisal, Trehub, & Schellenberg, 2005). If melodies are imperceptible to young CI listeners (Stordahl, 2002), as they are to adults (Fujita & Ito, 1999; Gfeller et al., 2000; Kong et al., 2004; Leal et al., 2003; Looi et al., 2004), then versions with the original instrumental cues might still be identifiable on the basis of multiple timbre or timing cues. Although the melodic stimuli maintained the pitch and temporal patterning of the melodies from the original recordings, they were expected to pose considerable difficulty because of the importance of pitch cues for melody identification (Hébert & Peretz, 1997) and because of CI users' reported inability to perceive the requisite pitch differences (Fujita & Ito, 1999; Green et al., 2004; Vandali et al., 2005). In sum, we expected CI children to perform poorly compared to NH children across conditions, perhaps at chance levels in the most challenging melody condition (Experiment 2).

We also explored the source of CI users' difficulty with music recognition. CI users might be able to detect simple pitch changes even if they were unable to perceive pitch relations such as intervals (i.e., pitch distances between simultaneous or successive tones) or contours (i.e., pattern of directional changes in pitch). If this were the case, then they might be able to detect pitch changes in simple contexts (Experiment 3) but not in the context of a melody (i.e., a tone sequence with varied pitches; Experiment 4).

Experiment 1

The purpose of the first experiment was to evaluate the efficacy of our song-identification task by testing NH children (ages 5–8 years) who were younger than the CI listeners to be tested in Experiment 2. If younger children succeeded in identifying familiar songs, then we could consider our task well within the ability of older NH children and perhaps within the ability of some CI participants. To ascertain the upper range of performance on this task, we also tested NH adults. We expected that both age groups would identify the original, instrumental, and melody versions at well above chance levels. We also expected that adults would perform better than young children in all three testing conditions.

Method

Participants. The participants were 15 children 5–8 years of age (M = 6;11 [years;months], SD = 1;5) from the local community and 15 university students 17–22 years of age. One requirement for inclusion in the sample was no personal or family history of hearing problems, according to parental report in the case of children and self-report in the case of university students. Another requirement was familiarity with the pop songs in our stimulus set. Because the experiment necessitated familiarity with the songs, participants were required to achieve an accuracy score of .75 or higher (see *Results and Discussion*) on the original recordings. A number of additional children (two 5-year-olds, one 6-year-old, one 7-year-old, and one 8-year-old) were excluded for failing to meet this criterion.

Apparatus and stimuli. Testing took place in a double-walled sound-attenuating booth (Industrial Acoustics Corporation) 3 m × 2.5 m. Stimuli were presented with an iMac computer and two loudspeakers (Bose LSPP 20234783) at a sound level of approximately 70 dB (A scale). An interactive computer program

Table 1. Popular song selections for Experiments 1 and 2.

Artist/band	Song title
Britney Spears	Baby One More Time
	Oops, I Did it Again
	Lucky
	I'm a Slave for You
	Stronger
	Crazy
Backstreet Boys	Larger Than Life
	The One
	I'll Never Break Your Heart
	Quit Playing Games
	As Long as You Love Me
'N Sync	Pop
	It's Gonna Be Me
	Bye, Bye, Bye

presented the musical selections, after which it displayed response options consisting of images of the artists along with the song titles. The program also recorded responses and provided encouraging but noncontingent feedback (a 3-s cartoon) after each response. The stimulus set consisted of 14 pop songs (see Table 1) that were familiar to many CI children (as well as NH children and adults), as determined from a questionnaire completed by potential participants or their parents. There were three versions of each song, each saved as a CD-quality sound file: (a) the original recording, (b) an instrumental version that was identical to the original recording except for the absence of vocals, and (c) a 20–30 s unaccompanied (monophonic) melody version of the song performed with a synthesized piano timbre. The instrumental versions were taken from commercial sources (i.e., B-sides of singles). The melody versions were produced by an experienced musician who performed and recorded the vocal melody of the chorus with a Roland JV-90 mulitimbral synthesizer. The melody versions maintained the original pitch relations (intervals), tempo, and rhythm of the vocal melody.

Procedure. Participants were tested individually. At the beginning of the test session, they selected the songs that they knew best—three (n = 13) or five (n = 2) different songs in the case of children and five songs for adults.

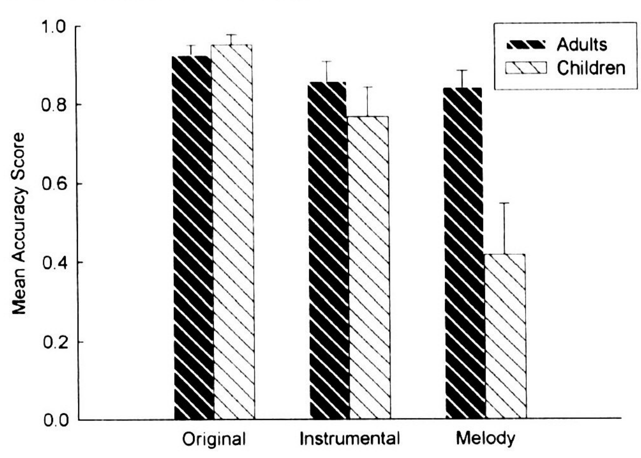
Participants were told that their task was to identify each song that was played. The three conditions were presented in fixed order: original recordings, instrumentals, and melodies. In each condition, each song was presented twice, with songs presented in random order, constrained so that no song was presented twice in a row. For the first two conditions, participants were instructed to press a key on the computer keyboard when they recognized the song, which terminated its presentation, and then to identify the song by clicking on one of the on-screen selections. Participants who required further exposure to the song before making their choice were able to resume listening. In the melody condition, the entire stimulus was presented before listeners made their selection. No feedback was provided for correct performance. Instead, the computer automatically provided visual feedback after each response as a form of encouragement.

Results and Discussion

Because participants were tested on different numbers of songs (three or five), accuracy scores (proportion correct) were corrected for different chance levels of responding (33% or 20% for three or five songs, respectively). This proportion was subtracted from both the numerator (the proportion of songs identified correctly) and the denominator (perfect performance). The resulting accuracy score had a value of 1 for perfect responding and 0 for chance-level performance. Negative values indicated performance at below-chance levels.

Figure 1 illustrates performance achieved by NH children and adults across the three conditions. One-sample t tests comparing performance with chance levels (M = 0) confirmed that performance was better than chance for both groups in each of the three conditions (original, instrumental, and melody, respectively): adults, $ts(14)$ = 38.90, 17.66, and 20.38, $ps < .001$; children, $ts(14)$ = 35.55, 10.21, and 3.24, $ps < .01$. In other words, even young children were successful in the most challenging (melody) condition. Performance was not consistently at ceiling levels either, as evidenced by reliable differences between age groups and conditions. Specifically, a mixed-design analysis of variance (ANOVA) revealed that adults were better than children at identifying songs, $F(1, 28) = 6.87, p = .014$, as predicted. The main

Figure 1. Mean accuracy scores for normal hearing (NH) children and adults in the three testing conditions of Experiment 1. Error bars represent standard errors.



effect of condition was also significant, $F(2, 56) = 12.24$, $p < .001$. As shown in Figure 1, performance declined monotonically for both groups across the three testing conditions. Both main effects were qualified by a significant interaction between age group and condition, $F(2, 56) = 6.94$, $p = .002$. To explore the interaction further, age differences were examined separately for each condition. The two groups did not differ on the original or the instrumental versions, but adults performed better than children in the melody condition, $t(28) = 3.15, p = .004$.

In short, NH children and adults successfully recognized familiar songs from stimuli that contained either multiple cues to their identity or relatively few cues, as in the melody condition. It was reasonable to expect, then, that this task would be suitable for the older NH and CI children who were to be tested in Experiment 2. The task was also sensitive to age differences in performance, as seen in the melody condition. The response patterns indicated that adults were relatively flexible in their processing of musical information. As such, they generalized across substantial transformations of musical stimuli, including those that eliminated many of the original acoustic cues. By contrast, young children performed at high levels only when there was a reasonable match between the test stimuli and the recordings they had experienced previously.

Experiment 2

In Experiment 2, we used a matched-pairs design to compare the song-identification abilities of CI participants 8–18 years of age with their NH peers. We expected NH listeners to perform at very high levels in the original and instrumental conditions because of the popularity of the artists in our stimulus set among this age range. In the more challenging melody condition, we anticipated more modest performance, somewhere between that of the NH children and adults in Experiment 1. We also predicted that CI participants would perform similarly, in some respects, to the young NH children in Experiment 1: highest with stimuli that retained all or most of the original acoustic cues (i.e., original recordings and instrumental renditions) and lowest with test stimuli that had the fewest original cues. Given their difficulties in tracking pitch relations in melodies (Stordahl, 2002), CI participants might perform relatively poorly, possibly at chance levels, in the melody condition, even though the temporal aspects of the melody were preserved.

Method

Participants. CI users were recruited from the greater Toronto area on the basis of congenital or prelingual deafness (pure-tone average exceeding 90 dB), regular use of a cochlear implant for at least 1 year, successful use of the implant (i.e., ability to comprehend speech and carry on a conversation), absence of other disabilities or health problems, and English as their first language. As in Experiment 1, participants were required to reach an accuracy score greater than or equal to .75 on the original renditions.

Table 2. Age and duration of cochlear implant (CI) use for individual CI participants in Experiments 2, 3, and 4 (years;months).

Participant	Age	Duration of CI use
1[a,b]	15;11[a], 17;2[b]	12;8[a], 13;11[b]
2[a]	17;1	1;11
3[a,b,c]	18;3[a], 19;5[b,c]	6;0[a], 7;2[b,c]
4[a,b,c]	9;11[a], 10;10[b,c]	2;0[a], 2;11[b,c]
5[a,b]	8;7[a], 9;1[b]	6;6[a], 6;12[b]
6[a,b]	13;7[a], 14;4[b]	4;2[a], 4;11[b]
7[a,b,c]	9;1[a], 10;2[b,c]	4;3[a], 5;2[b,c]
8[a,b]	8;6[a], 9;1[b]	1;0[a], 1;7[b]
9[a]	17;3	13;0
10[a]	10;0	4;8
11[b]	16;11	2;2
12[b,c]	10;0[b,c]	1;3[b,c]
13[b,c]	11;1[b,c]	8;3[b,c]
14[b]	8;3	3;3
15[b]	9;7	5;9
16[c]	9;5	3;4
17[c]	7;5	4;5
18[c]	6;8	5;3

[a]Experiment 2. [b]Experiment 3. [c]Experiment 4.

The final sample of CI participants (see Table 2) consisted of 10 children or teens 8–18 years of age (M = 12;10, SD = 4;0) who had used their implant for 1–13 years (M = 5;9, SD = 4;3). CI participants used either the Nucleus 22 implant (with SPEAK strategy) or the Nucleus 24 (with ACE or SPEAK strategy). All participants had hearing parents and communicated exclusively by auditory–oral means, which reflects local clinical practices (i.e., individual auditory–oral support; no use of sign language unless parents are deaf or request it or unless the child has failed to benefit from sustained auditory–oral intervention). Most CI users had used bilateral hearing aids prior to implant surgery, sometimes with the principal goal of maintaining activity in the auditory pathways while awaiting surgery, even if no functional hearing benefits were apparent. At the time of testing, all participants were in regular classrooms at age-appropriate grade levels. Additional CI children were excluded from the song-identification task because of disinterest in the task (n = 2) or for failure to achieve an accuracy score of at least .75 on the original versions (n = 2). The sample of NH participants consisted of 10 children or teens (M = 12;11, SD = 4;3) from the community who were selected on the basis of their age match (within 10 months) to a CI participant, their familiarity with the musical materials, and the absence of a family or personal history of hearing loss.

Apparatus and stimuli. The apparatus and stimuli were identical to those of Experiment 1.

Procedure. Participants were tested individually. At the beginning of the test session, they selected the songs that they knew best—three (n = 7) or five (n = 3) different songs in the case of CI participants and three (n = 2) or five (n = 8) different songs in the case of NH participants. The procedure was identical to that of Experiment 1 except that we also recorded CI participants' affective responses to the musical stimuli. Following their song-selection response, they were asked to rate how much they liked each song by clicking a rating on a 5-point Likert-type scale (1 = *not at all,* 3 = *indifferent,* 5 = *very much*).

Results and Discussion

Accuracy scores were generated, as in Experiment 1. Means and standard errors for CI and NH listeners in each of the three conditions are shown in Figure 2. Figure 3 shows individual performance grouped by CI–NH age-matched pairs. Comparisons with chance levels of responding revealed that performance of NH listeners was perfect for the original recordings, almost perfect for the instrumentals, $t(9) = 58.50$, $p < .001$, and reliably better than chance for the melodies, $t(9) = 14.50$, $p < .001$. For the CI group, performance exceeded chance levels for the original and instrumental conditions, $ts(9) = 21.94$ and 4.33, respectively, $ps < .002$, but not for the melody condition. As shown in Figure 2,

Figure 2. Mean accuracy scores of NH and CI children and teens in the three testing conditions of Experiment 2. Error bars represent standard errors.

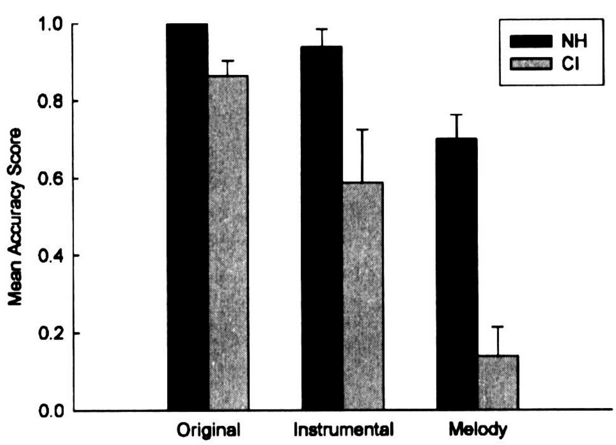
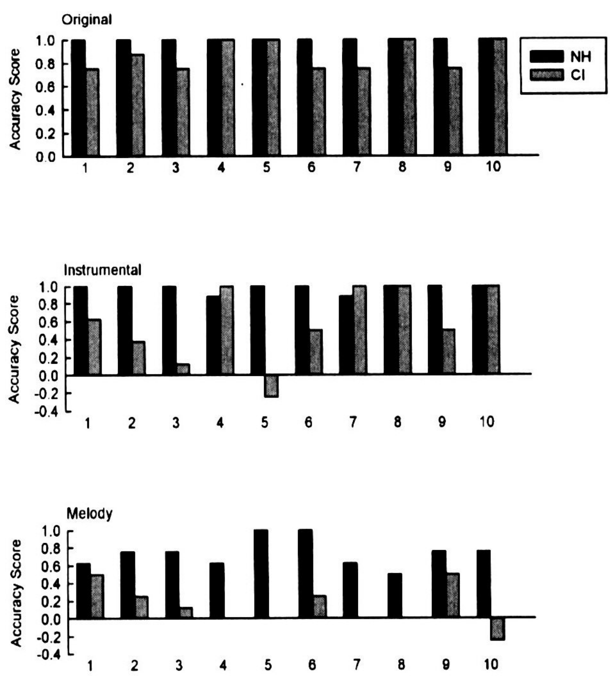


Figure 3. Accuracy scores of individual age-matched NH and CI children and teens in the three testing conditions of Experiment 2.



the NH group outperformed the CI group across conditions, and both groups exhibited a monotonic decrease in performance across conditions. Because there was no variance for the NH group in the original condition, group differences in this condition were tested with a nonparametric (sign) test. The NH group outperformed the CI group (p = .031). Performance in the instrumental and melody conditions was examined with a two-way (Group × Condition) ANOVA, which confirmed that the NH group outperformed the CI group in these conditions, $F(1, 9) = 29.73$, $p < .001$, and that both groups found the melodies more challenging to identify than the instrumentals, $F(1, 9) = 12.02$, $p = .007$. There was no two-way interaction.

Marked differences among individuals in the CI group are highlighted in Figure 3. Only 2 CI participants (CI 1 and CI 9) performed reasonably well in the difficult melody condition. Two others (CI 3 and CI 5) appeared to be guessing in all but the original condition, whereas four others (CI 4, CI 7, CI 8, and CI 10) performed perfectly with the instrumental stimuli but poorly in the melody condition. CI participants in Pairs 1, 5, 8, and 10 claimed to be avid fans of the artists in the stimulus set. On the basis of their frequent, deliberate listening to the recordings, one might have expected better performance from these listeners than from other CI listeners who reported simple familiarity with the recordings. As shown in Figure 3, however, there was no evidence that the avid fans had systematic performance advantages.

Turning now to the appraisals of the CI group, comparisons of mean ratings in each condition with the midpoint of the Likert scale (i.e., 3 = *indifferent*) revealed that ratings were significantly higher (i.e., more favorable) than the midpoint in the original (M = 4.14, SD = 0.71) and instrumental (M = 4.13, SD = 0.81) conditions, $ts(9)$ = 5.08 and 4.42, respectively, $ps < .002$, but not in the melody condition (M = 3.7, SD = 1.0). Although a one-way ANOVA did not reveal reliable differences across conditions, a direct comparison of the melody with the other two conditions was on the cusp of statistical significance, $F(1, 18) = 4.23$, $p = .054$. In short, positive appraisals were evident for stimuli with multiple acoustic cues (i.e., original and instrumental conditions) but not for the melodies.

In sum, NH participants were more accurate at song identification than same-age CI users, as one would expect. Nonetheless, CI users were able to identify original and instrumental versions of recordings at levels that were better than chance. Although the deficits of the CI participants extended across the various testing conditions, those deficits could stem from pitch- and spectral-processing difficulties. Stimuli with multiple acoustic cues—some involving pitch, others involving temporal and timbral factors—such as those in the original and instrumental conditions, were identified successfully but less accurately than they were by NH listeners. When the task relied more heavily on pitch information, as in the melody condition, performance fell to chance levels, and CI listeners appraised the stimuli less favorably.

In the two experiments that follow, we tested CI users' pitch-processing abilities in more detail. Specifically, we examined the pitch-discrimination performance of CI and NH listeners in different contexts: a pitch displacement in a monotonic (repeating tone) sequence (Experiment 3) and a pitch displacement in a melodic (varying tone) sequence (Experiment 4).

Experiment 3

Pitch processing is fundamental to music perception. Recognizing a melody requires elementary pitch discrimination, such as noticing changes in pitch between successive tones, as well as higher order abilities, such as perceiving the global pattern of pitches. In the present experiment, we examined simple pitch discrimination by comparing CI and NH listeners' ability to detect a pitch change in the context of a repeating tone. A number of investigators have reported the pitch resolution of postlingually deafened adult CI users as 4 semitones or more (Fujita & Ito, 1999; Gfeller et al., 2002) although better resolution is evident in some users (Gfeller et al., 2002). Because young CI users often experience better ultimate speech perception and production outcomes than adult CI users (e.g., Purdy et al., 2001), they may enjoy better outcomes in the music domain as well. By virtue of the limitations of CI processors, we predicted that CI listeners would have more difficulty than NH listeners with simple pitch discrimination. It is possible, however, that they would have better pitch resolution than that of adult CI users by virtue of greater cerebral plasticity in the early years (Harrison et al., 2005; Sharma et al., 2005) and its association with enhanced outcomes.

Method

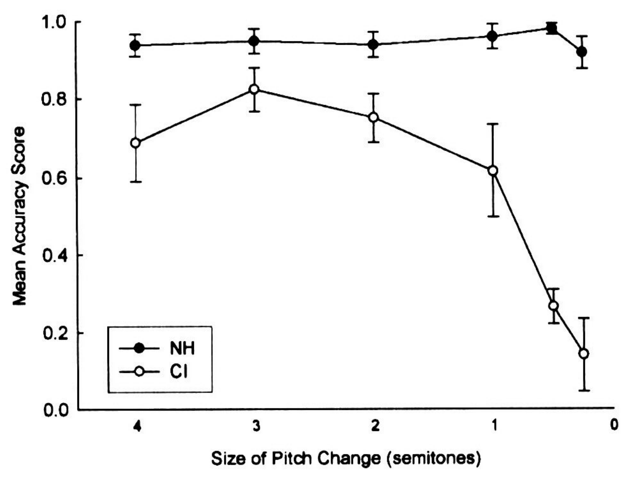
Participants. Twelve child and teen CI users from 8 to 19 years of age (M = 12;2, SD = 3;9) participated in the current experiment, 7 of whom had participated in Experiment 2 (see Table 2). All CI users had a congenital or prelingual hearing loss, and the average length of implant use was 5 years, 3 months (SD = 3;7). Twelve NH children were recruited from the local community to serve as a control group. Because we expected the task to be relatively easy for NH children, we recruited only 8-year-olds (M = 8;6, SD = 0;3), the same age as the youngest CI participant.

Apparatus and stimuli. The apparatus was identical to that of Experiments 1 and 2, except that a Roland JV-90 multitimbral synthesizer was used to generate piano tones. The stimuli were adapted from Hyde and Peretz's (2004) test of pitch discrimination for amusic adults. To enhance the likelihood of successful performance among CI users, we modified their stimuli to provide tones with larger pitch changes and longer duration, tones within the typical musical range (rather than outside that range) and only upward (rather than upward and downward) pitch shifts. The sequences comprised five equal-duration and equal-amplitude piano tones, each 200 ms with intertone onsets of 350 ms. Standard (or nonaltered) sequences consisted of a single repeating tone (C_4 = 262 Hz). Altered sequences were identical except that the fourth tone was displaced upward in pitch by 7, 6, 5, 4, 3, 2, 1, 0.5, or 0.25 semitones.

Procedure. To reduce the effects of fatigue and assess the appropriateness of further testing, we scheduled two test sessions. Each condition in both sessions had 16 trials, with each condition having an equal number of standard and altered sequences presented in random order. Participants were required to detect the presence or absence of a pitch change in one tone of the sequence by clicking on "Yes" or "No" buttons on the monitor. Correct responses were followed by the appearance of a star on screen; there were no consequences for incorrect responding. This yes–no task was much simpler than Fujita and Ito's (1999) task, which required CI adults to judge whether the first or second of two tones was higher in pitch.

The first condition in the first session had a 4 semitone pitch change. Participants who achieved a score equal to or greater than chance (50% correct) proceeded to the next level of difficulty (i.e., smaller pitch change). Those who performed below chance were tested on a much larger pitch change, 7 semitones. Pitch displacements were 7, 6, 5, 4, 3, 2, and 1 semitone in the first test session, and 0.5 and 0.25 semitones in the second session. In both sessions, a score of 50% or greater in each condition was required to proceed to the next level of increased difficulty. Testing was discontinued when participants failed to achieve this criterion. To proceed to the second test session, participants needed to score greater than 50% correct in the 1 semitone condition.

Figure 4. Mean accuracy scores of NH 8-year-olds and CI listeners 8–19 years of age in the six testing conditions of Experiment 3. Error bars represent standard errors.



Results and Discussion

Only 1 CI participant failed to achieve the continuation criterion at 4 semitones in the first condition of the first test session. After successfully detecting pitch changes of 7 semitones, this participant successfully achieved the continuation criterion thereafter and completed testing for all levels. The score from the second (i.e., successful) 4 semitone condition was used in the analyses. Four other CI children did not proceed to the second session because they failed to achieve the continuation criterion ($n = 2$) at the 1 semitone level, or they were not available for further testing ($n = 2$). All 12 NH controls completed all testing conditions.

Accuracy scores were generated by subtracting false-alarm rates (proportion of "yes" responses for standard sequences) from hit rates (proportion of "yes" responses for altered sequences). As in Experiments 1 and 2, a score of 1 indicated perfect performance and a score of 0 indicated chance responding. Figure 4 depicts accuracy scores separately for the two groups of participants for each condition. Preliminary analyses revealed that the NH group was reliably better than chance in each condition, ts (11) = 32.57, 29.18, 28.72, 29.92, 69.71, and 22.00 in the 4, 3, 2, 1, 0.5, and 0.25 semitone conditions, respectively, $ps < .001$. The CI group also performed better than chance in the 4, 3, 2, and 1 semitone conditions, ts(11) = 7.02, 14.56, 12.19, and 5.22, respectively, $ps < .001$. Performance of the smaller CI sample that completed the second testing session was above chance levels for the 0.5 semitone change, $t(7) = 4.82, p = .002$, but not for the 0.25 semitone change.

A two-way mixed-design ANOVA (2 groups × 6 pitch changes) that included only the CI children who were tested in all six conditions (i.e., the best performers) revealed a significant main effect of group, $F(1, 18) = 68.64, p < .001$; a significant main effect of pitch change, $F(5, 90) = 14.32, p < .001$; and a significant interaction between group and pitch change, $F(5, 90) = 13.98$, $p < .001$. For NH controls, performance was uniformly high and did not vary as a function of the magnitude of pitch change ($F < 1$). For CI listeners, performance varied with the magnitude of pitch change, $F(5, 35) = 11.16, p < .001$. As shown in Figure 4, performance declined monotonically from 3 to 0.25 semitones. It is likely that the initial dip in performance in the first (easiest) condition stemmed from CI listeners' unfamiliarity with the task.

In sum, CI listeners were impaired relative to NH controls across conditions, as one would expect. Whereas NH listeners' detection of a pitch change was not influenced by the size of the change (0.25–4 semitones), CI users were much better at detecting larger compared to smaller changes in pitch. Presumably, larger pitch changes provided other cues (spectral or timbral) that made the task easier.

Nonetheless, the performance of CI users differed from that of previous studies. Note, however, that previous studies of musical pitch discrimination included the more challenging response of judging the direction of pitch change (Fujita & Ito, 1999; Gfeller et al., 2002). Of particular relevance to music perception was the ability of CI users in the present study to detect a 1 semitone pitch change at well above chance levels. In fact, in the simple, idealized context provided by the present stimuli and task, the average pitch-discrimination threshold (defined here as the smallest pitch difference detected above chance levels) for the CI users was between 0.5 and 0.25 semitones. The relatively successful performance of pediatric CI recipients in this context highlights the impact of stimulus and task parameters on this population. It also has implications for stimulus and task selection in instructional and rehabilitative contexts.

We have chosen to emphasize the ability of the CI group to exceed chance responding, in contrast to Hyde and Peretz (2004), who emphasized the impairment of congenitally amusic listeners relative to controls. To put the two studies in perspective, the performance of their amusic listeners on 1 semitone pitch shifts was much better (i.e., mean accuracy score of approximately .9) than the performance of our CI listeners (M = .61) despite stimulus alterations that were designed to make our task easier than theirs.

Experiment 4

In contrast to the monotonic stimulus sequences of Experiment 3, music almost always involves tones that vary in pitch. In the present experiment, we tested whether CI listeners could detect a 1 semitone pitch change in a melodic context. Specifically, CI users and NH controls were tested on their ability to discriminate two melodic sequences that differed by a 1 semitone displacement to one of the component tones. Because the sequences were not transposed, both absolute and relative pitch cues were available. In other words, when the standard and comparison sequences differed, one tone was shifted in pitch (i.e., an absolute pitch change), which means that its pitch distance from the preceding and subsequent tones was also altered (i.e., relative pitch changes). Hearing infants and young children readily detect such pitch changes (Trehub, Cohen, Thorpe, & Morrongiello, 1986). Despite these additional cues involving pitch relations, we expected this task to be much more difficult for CI listeners than the simple pitch-discrimination task of Experiment 3. Aside from the increased information-processing demands of a multi-tone sequence, poor discrimination of pitch and pitch direction would interfere with the representation of multiple pitches.

Method

Participants. CI listeners included 8 children and adolescents ranging in age from 6 to 19 years (M = 10;3, SD = 4;1). One had participated in Experiment 2, 1 in Experiment 3, and 2 in Experiments 2 and 3 (see Table 2). All CI listeners were congenitally or prelingually deaf, and their average length of implant use was 5 years, 2 months (SD = 1;9). A control group included 13 NH 5-year-olds (M = 5;5, SD = 0;5) who were younger than the youngest CI participant.

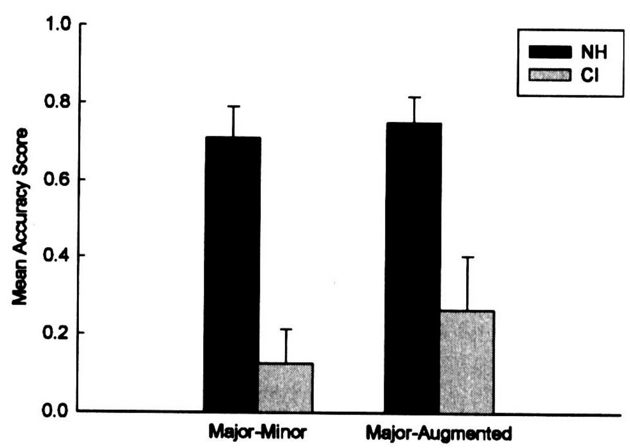
Apparatus and stimuli. The apparatus was identical to that of Experiment 3. Standard and comparison tone sequences were generated with a sequencer (Cakewalk Pro Audio 9) and recorded in Musical Instrument Digital Interface (MIDI) format. The standard sequence comprised three piano tones from the C *major* triad presented in ascending-descending order (C_4-E_4-G_4-E_4-C_4, or 262, 330, 392, 330, and 262 Hz). On "same" trials, the comparison sequence was identical to the standard. On "different" trials, the comparison sequence also comprised three different tones, except that the second and fourth tones (i.e., the middle pitch) were displaced downward by 1 semitone (i.e., forming a C *minor* triad, C_4-$E\flat_4$-G_4-$E\flat_4$-C_4, or 262, 311, 392, 311, and 262 Hz), or the third tone (i.e., the highest pitch) was displaced upward by 1 semitone (forming a C *augmented* triad, C_4-E_4-$G\#_4$-E_4-C_4, or 262, 330, 415, 330, and 262 Hz). Each note was 500 ms in duration, and the interonset interval was 600 ms. A silent interval of 1.5 s separated the standard and comparison sequences.

Procedure. There were 12 trials, with each possible pair of standard and comparison sequences (major–major, major–minor, major–augmented) presented four times in random order. After listening to each pair, participants were required to judge whether the standard and comparison sequences were the same or different. No feedback was provided.

Results and Discussion

Each participant had two outcome scores, one representing performance with major–minor comparisons, the other representing performance with major–augmented comparisons. Both scores were calculated as

Figure 5. Mean accuracy scores of NH 5-year-olds and CI listeners 6–19 years of age in the two testing conditions of Experiment 4. Error bars represent standard errors.



hit rate (proportion of "different" responses on major–minor or major–augmented trials) minus false alarm rate (proportion of "different" responses on major–major trials). As in the previous experiments, scores of 1 and 0 represented perfect and chance performance, respectively. Descriptive statistics are shown in Figure 5. Preliminary analyses confirmed that the NH children performed well above chance levels for the major–minor and major–augmented comparisons, $ts(12) = 8.97$ and 11.05, respectively, $ps < .001$, but the CI group was at chance levels for both comparisons. A two-way mixed-design ANOVA revealed a main effect of group, with NH children outperforming CI users, $F(1, 19) = 21.61, p < .001$. The difference between conditions was not reliable and there was no two-way interaction. In short, the findings revealed that CI users had marked deficits in the detection of 1 semitone pitch changes in a melodic context.

General Discussion

The aim of the current study was to shed light on the music-recognition abilities of deaf children and adolescents who used cochlear implants (CIs). In Experiment 1, the performance of normal hearing (NH) children provided a baseline for evaluating CI listeners' recognition of familiar songs. NH children identified the original recordings, instrumental versions, and melody versions at above-chance levels. In fact, they performed as well as NH adults on the original and instrumental versions but not on the melody versions. In Experiment 2, the same stimulus materials were used to compare CI users with age-matched NH controls. The CI users exhibited performance deficits across conditions, although their deficits were relatively small for the original recordings with vocals. Most notably, performance of the CI group was at chance levels for the melody versions and intermediate for the instrumental versions. Like young NH children, CI users performed best when the acoustic cues in the test stimuli were identical or very similar to those heard in the course of previous recreational listening, presumably because the stimuli included structural features that were transmitted effectively by the CI. As the disparity increased between the cues available at familiarization (i.e., previous exposure to the original materials) and test, recognition became progressively poorer. Although NH children were poorer at identifying the songs from melodic cues than NH adults were, they still performed well above chance levels. By contrast, CI users' performance fell to chance levels under comparable circumstances.

Identifying pop songs with lyrics may not seem particularly challenging because of the occurrence of song titles in the lyrics. It is important to note, however, that CI children have difficulty decoding the lyrics of unfamiliar songs, even when the songs are unaccompanied (Vongpaisal et al., 2005). Thus, CI children's successful identification of the original versions confirms their familiarity with the music. If we are correct in our view that children's performance is influenced by the match between cues in the recordings heard at home and those heard in the laboratory, then CI children may be unable to identify full vocal-and-instrumental performances of familiar songs by different vocalists and instrumentalists (i.e., cover versions). With respect to the instrumental versions, CI listeners' success probably stems from the preservation of multiple, nonvocal cues from the original performances.

We know that hearing adults have detailed representations of familiar pop recordings. For example, they can identify recordings from 100-ms excerpts in which words or pitch changes are imperceptible (Schellenberg, Iverson, & McKinnon, 1999). It is highly unlikely that CI listeners would be able to identify music from samples of such extreme brevity. Aside from hearing listeners' detailed representation of specific performances, they have abstract or general representations of specific pieces of music that permit them to identify familiar tunes played on different instruments and at different pitch levels and speeds. These abstract representations, which involve relational pitch and timing cues, have been documented much more extensively (e.g., Hébert & Peretz, 1997) than listeners' representations of specific performances (e.g., Schellenberg & Trehub, 2003). Undoubtedly, CI users' abstract representations of music differ substantially from those of hearing individuals, with pitch relations playing a central role for hearing individuals and a minimal role for CI users. As a result, CI users fail to recognize tunes that they have heard repeatedly over the years (e.g., *Happy Birthday*) unless very distinctive timing cues are available (Fujita & Ito, 1999; Gfeller & Lansing, 1991; Kong et al., 2004; Leal et al., 2003). In the present study, deficient abstract representations of pitch patterns would have prevented CI listeners from recognizing the songs from the melody versions.

Despite their difficulties relative to same-age hearing listeners, CI children and teens had song-recognition skills that were better in some respects than those reported previously for CI children (Stordahl, 2002) and adults (Fujita & Ito, 1999; Gfeller et al., 2005; Kong et al., 2004; Looi et al., 2004). Their success may be attributable, in part, to restrictive candidacy criteria and intensive follow-up associated with the publicly funded implants in the present study, to test stimuli that preserved many acoustic cues from the familiar recordings, and to game-like tasks. It remains to be determined whether early age of implantation conferred other benefits. There are recent indications that early life is a period of enhanced perceptual flexibility, when very young children may be more sensitive than adults to some nuances of novel musical patterns (e.g., Hannon & Trehub, 2005).

The pitch-processing deficits of CI listeners are likely to underlie their music-recognition deficits. Although CI users performed poorly compared to younger NH controls, they still detected a very small pitch change (0.5 semitones) in the context of a single repeating tone (Experiment 3). For most hearing listeners, the altered tone would be perceived as higher or lower than the surrounding pitches. That may not be the case for implanted listeners, for whom the difference may indicate a change in tone quality or timbre but not one of pitch direction. As noted, adult CI listeners' perception of pitch is so distorted that the direction of change only becomes evident for pitch differences as large as 4 to 12 semitones (Fujita & Ito, 1999; Looi et al., 2004; Vandali et al., 2005). Such insensitivity to pitch direction would render the contour, or pattern of directional changes in melodies, largely inaccessible because most note-to-note changes in pitch are smaller than 4 semitones (Vos & Troost, 1989). As a result, melodies would be unrecognizable unless they had very distinctive rhythmic cues (Fujita & Ito, 1999; Gfeller & Lansing, 1991; Kong et al., 2004; Leal et al., 2003). It is not surprising, then, that the CI listeners in Experiment 4 had difficulty detecting 1 semitone differences in the context of variable tones—a task that was relatively easy for hearing 5-year-olds.

Individuals with congenital amusia reportedly dislike music or are indifferent to it (Peretz & Hyde, 2003), perhaps because they fail to appreciate the nuances of melodies. For postlingually deafened adults with CIs, it is clear that music would lack the richness that it once had. Why, then, is music enjoyable for young, prelingually deaf CI users? It is possible that the pitch patterning they receive is so limited that they ignore it, focusing largely on the timing cues, which enable them to synchronize their dancing, tapping, and clapping with others. Such synchronous activity is thought to strengthen interpersonal bonds (Benzon, 2001; McNeill, 1998). Positive appraisals in all but the melody condition are consistent with CI users' inability to derive meaning or pleasure from simple pitch patterns or melodies. If CI children's and adolescents' appraisals of the musical samples were influenced primarily by social desirability (Heyman & Legare, 2005), or responding in socially appropriate ways, they would have appraised all music favorably, including the melody versions.

Finally, CI users' difficulties in pitch-pattern processing have implications that extend well beyond music recognition. In a number of languages, including Thai, Vietnamese, and Chinese, tones signal contrastive lexical meaning. For example, Cantonese has six contrastive tones that are defined by their pitch level and pitch contour: high-level, high-rising, mid-level, low-falling, low-rising, and low-level. CI listeners have considerable difficulty perceiving and producing these tones and the tones of other languages (Ciocca, Francis, Aisha, & Wong, 2002; Peng, Tomblin, Cheung, Lin, & Wang, 2004). They also have difficulty differentiating voices, a skill that depends on the perception of differences in fundamental frequency and formant frequencies (Cleary & Pisoni, 2002; Cleary, Pisoni, & Kirk, 2005; Fu, Chinchilla, & Galvin, 2004). Reduced spectral cues also impede CI users' ability to perceive speech in the context of noise, especially when that noise involves competing talkers (Fu & Nogaki, 2005).

In sum, we documented marked deficits in song-recognition abilities among children and teens with CIs. At the same time, we confirmed that they could recognize original recordings, instrumental versions of recordings, and small pitch changes in the context of a repeating tone. Their inability to recognize typical pitch changes in a melodic context appears to stem from the limitations of CI processors (i.e., speech processing strategies) that also give rise to music perception problems in general, problems discriminating lexical tone contrasts in tone languages, voice discrimination problems, and problems perceiving speech in noise. Future modifications of CI processors could help users perceive complex auditory patterns that are fundamental to communication and well-being.

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References

Ayotte, J., Peretz, I., & Hyde, K. (2002). Congenital amusia: A group study of adults afflicted with a music-specific disorder. *Brain, 125,* 238–251.

Benzon, W. L. (2001). *Beethoven's anvil: Music in mind and culture.* New York: Basic Books.

Ciocca, V., Francis, A. L., Aisha, R., & Wong, L. (2002). The perception of Cantonese lexical tones by early-deafened cochlear implantees. *Journal of the Acoustical Society of America, 111,* 2250–2256.

Cleary, M., & Pisoni, D. B. (2002). Talker discrimination by prelingually deaf children with cochlear implants: Preliminary results. Annals of Otology. *Rhinology, and Laryngology, Supplement, 111*(5, Suppl.), 113–118.

Cleary, M., Pisoni, D. B., & Kirk, K. I. (2005). Influence of voice similarity on talker discrimination in children with normal hearing and children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 48,* 204–223.

Drake, C., & Bertrand, D. (2003). The quest for universals in temporal processing in music. In I. Peretz & R. J. Zatorre (Eds.), *The cognitive neuroscience of music* (pp. 21–31). Oxford, United Kingdom: Oxford University Press.

Dorman, M., Basham, K., McCandless, G., & Dove, H. (1991). Speech understanding and music appreciation with the Ineraid cochlear implant. *The Hearing Journal, 44,* 32–37.

Foxton, J. M., Dean, J. L., Gee, R., Peretz, I., & Griffiths, T. D. (2004). Characterization of deficits in pitch perception underlying "tone deafness". *Brain, 127,* 801–810.

Fu, Q. J., Chinchilla, S., & Galvin, J. J. (2004). The role of spectral and temporal cues in voice gender discrimination by normal-hearing listeners and cochlear implant users. *Journal of the Association for Research in Otolaryngology, 5,* 253–260.

Fu, Q. J., & Nogaki, G. (2005). Noise susceptibility of cochlear implant users: The role of spectral resolution and smearing. *Journal of the Association for Research in Otolaryngology, 6,* 19–27.

Fujita, S., & Ito, J. (1999). Ability of Nucleus cochlear implantees to recognize music. *Annals of Otology, Rhinology, and Laryngology, 108,* 634–640.

Gfeller, K., Christ, A., Knutson, J. F., Witt, S., & Mehr, M. (2003). The effects of familiarity and complexity on appraisal of complex songs by cochlear implant recipients and normal hearing adults. *Journal of Music Therapy, 40,* 78–112.

Gfeller, K., Christ, A., Knutson, J. F., Witt, S., Murray, K. T., & Tyler, R. S. (2000). Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. *Journal of the American Academy of Audiology, 11,* 390–406.

Gfeller, K., & Lansing, C. (1991). Melodic, rhythmic, and timbral perception of adult cochlear implant users. *Journal of Speech and Hearing Research, 34,* 916–920.

Gfeller, K., Olszewski, C., Rychener, M., Sena, K., Knutson, J. F., Witt, S., & Macpherson, B. (2005). Recognition of "real world" musical excerpts by cochlear implant recipients and normal-hearing adults. *Ear and Hearing, 26,* 237–250.

Gfeller, K. E., Turner, C., Woodworth, G., Mehr, M., Fearn, R., Knutson, J., et al. (2002). Recognition of familiar melodies by adult cochlear implant recipients and normal hearing adults. *Cochlear Implants International, 3,* 29–53.

Gfeller, K., Witt, S. A., Spencer, L. J., Stordahl, J., & Tomblin, B. (1998). Musical involvement and enjoyment of children who use cochlear implants. *Volta Review, 100,* 213–233.

Gfeller, K., Woodworth, G., Robin, D. A., Witt, S., & Knutson, J. F. (1997). Perception of rhythmic and sequential pitch patterns by normally hearing adults and adult cochlear implant users. *Ear and Hearing, 18,* 252–260.

Green, T., Faulkner, A., & Rosen, S. (2004). Enhancing temporal cues to voice pitch in continuous interleaved sampling cochlear implants. *Journal of the Acoustical Society of America, 116,* 2298–2310.

Hannon, E. E., & Trehub, S. E. (2005). Tuning in to musical rhythms: Infants learn more readily than adults. *Proceedings of the National Academy of Sciences, USA, 102,* 12639–12643.

Harrison, R. V., Gordon, K. A., & Mount, R. J. (2005). Is there a critical period for cochlear implantation in congenitally deaf children? Analyses of hearing and speech performance after implantation. *Developmental Psychobiology, 46,* 252–261.

Hart, J. 't, Collier, R., & Cohen, A. (1990). *A perceptual study of intonation: An experimental-phonetic approach to speech melody.* Cambridge, United Kingdom: Cambridge University Press.

Hébert, S., & Peretz, I. (1997). Recognition of music in long-term memory: Are melodic and temporal patterns equal partners? *Memory & Cognition, 25,* 518–533.

Heyman, G. D., & Legare, C. H. (2005). Children's evaluation of sources of information about traits. *Developmental Psychology, 41,* 636–647.

Hyde, K. L., & Peretz, I. (2004). Brains that are out of tune but in time. *Psychological Science, 15,* 356–360.

Kong, Y.-Y., Cruz, R., Jones, J. A., & Zeng, F.-G. (2004). Music perception with temporal cues in acoustic and electric hearing. *Ear and Hearing, 25,* 173–185.

Leal, M. C., Shin, Y. J., Laborde, M.-L., Calmels, M.-N., Verges, S., Lugardon, S., et al. (2003). Music perception in adult cochlear implant recipients. *Acta Oto-Laryngologica, 123,* 826–835.

Looi, V., McDermott, H., McKay, C., & Hickson, L. (2004). Pitch discrimination and melody recognition by cochlear implant users. *International Congress Series, 1273,* 197–200.

McNeill, D. (1998). The nature and function of gesture in children's communication. In J.M. Iverson & S. Goldin-Meadow (Eds.), *The nature and function of gesture in children's communication. New directions for child development* (pp. 11–27). San Francisco, CA: Jossey-Bass.

Miller, G. A. (1981). *Language and speech.* San Francisco: Freeman.

Murayama, J., Kashiwagi, T., Kashiwagi, A., & Mimura, M. (2004). Impaired pitch production and preserved rhythm production in a right brain-damaged patient with amusia. *Cognition, 56,* 36–42.

Patel, A. D., Peretz, I., Tramo, M., & Labreque, R. (1998). Processing prosodic and musical patterns: A neuropsychological investigation. *Brain & Language, 61,* 123–144.

Peng, S. C., Tomblin, J. B., Cheung, H:, Lin, Y. S., & Wang, L. S. (2004). Perception and production of Mandarin tones in prelingually deaf children with cochlear implants. *Ear and Hearing, 25,* 251–264.

Peretz, I., & Hyde, K. L. (2003). What is specific to music processing? Insights from congenital amusia. *Trends in Cognitive Sciences, 7,* 362–367.

Purdy, S. C., Kelly, A. S., & Thorne, P. R. (2001). Auditory evoked potentials as measures of plasticity in humans. *Audiology & Neuro-Otology, 6,* 211–215.

Robinson, K. (1998). Implications of developmental plasticity for the language acquisition of deaf children with cochlear implants. *International Journal of Pediatric Otorhinolaryngology, 46,* 71–80.

Schellenberg, E. G., Iverson, P., & McKinnon, M. C. (1999). Name that tune: Identifying popular recordings from brief excerpts. *Psychonomic Bulletin & Review, 6,* 641–646.

Schellenberg, E. G., & Trehub, S. E. (2003). Good pitch memory is widespread. *Psychological Science, 14,* 262–266.

Shannon, R. V., Zeng, F.-G., Kamath, V., Wygonski, J., & Ekelid, M. (1995). Speech recognition with primarily temporal cues. *Science, 270,* 303–304.

Sharma, A., Dorman, M. F., & Kral, A. (2005). The influence of a sensitive period on central auditory development in children with unilateral and bilateral cochlear implants. *Hearing Research, 203,* 134–143.

Sharma, A., Dorman, M. F., & Spahr, A. J. (2002). Rapid development of cortical auditory evoked potentials after early cochlear implantation. *Neuroreport, 13,* 1365–1368.

Stewart, L., & Walsh, V. (2002). Congenital amusia: All the songs sound the same. *Current Biology, 12,* 420–421.

Stordahl, J. (2002). Song recognition and appraisal: A comparison of children who use cochlear implants and normally hearing children. *Journal of Music Therapy, 39,* 2–19.

Trehub, S. E., Cohen, A. J., Thorpe, L. A., & Morrongiello, B. A. (1986). Development of the perception of musical relations: Semitone and diatonic structure. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 295–301.

Tulving, E., & Thompson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 352–373.

Vandali, A. E., Sucher, C., Tsang, D. J., McKay, C. M., Chew, J. W., & McDermott, H. J. (2005). Pitch ranking ability of cochlear implant recipients: A comparison of sound-processing strategies. *Journal of the Acoustical Society of America, 117,* 3126–3138.

Vongpaisal, T., Trehub, S. E., & Schellenberg, E. G. (2005, March). *Challenges of decoding the words of songs.* Poster presented at the 10th Symposium on Cochlear Implants in Children, Dallas, TX.

Vos, P., & Troost, J. (1989). Ascending and descending melodic intervals: Statistical findings and their perceptual relevance. *Music Perception, 6,* 383–396.

Wilson, B. S., Sun, X., Schatzer, R., & Wolford, R. D. (2004). Representation of fine structure or fine frequency information with cochlear implants. *International Congress Series, 1273,* 3–6.

Zatorre, R. J., Belin, P., & Penhune, V. B. (2002). Structure and function of auditory cortex: Music and speech. *Trends in Cognitive Sciences, 6,* 37–46.

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