Identification of TV Tunes by Children with Cochlear Implants

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INTRINSIC PITCH PROCESSING LIMITATIONS OF cochlear implants constrain the perception of music, particularly melodies. We tested child implant users' ability to recognize music on the basis of incidental exposure. Using a closed-set task, prelingually deaf children with implants and hearing children were required to identify three renditions of the theme music from their favorite TV programs: a flute rendition of the main (sung) melody, a full instrumental version without lyrics, and the original music. Although child implant users were less accurate than hearing children, they successfully identified all versions of songs at above-chance levels—a finding that contradicts widespread claims of child and adult implant users' difficulties with melody identification. We attribute their success primarily to timing cues that match those of the original music.

Received July 7, 2008, accepted January 27, 2009.

Key words: cochlear implants, children, music, melody, recognition

Much is known about the challenges of music listening when the signal is transmitted electrically (i.e., by cochlear implants) rather than acoustically. Current signal processing schemes provide implant users with more information about temporal-envelope modulations than about temporal fine-structure or spectral details (Loizou, 1998; Rosen, 1992). One consequence of these device limitations is that differentiation of pitch patterns is typically poor, even for users who demonstrate good speech understanding in favorable listening conditions (Galvin, Fu, & Nogaki, 2007; Gfeller, Woodworth, Robin, Witt, & Knutson, 1997; Kong, Cruz, Jones, & Zeng, 2004; Leal et al., 2003). For example, implant users have problems discriminating changes in pitch direction (Cooper, Tobey, & Loizou, 2008; Fujita & Ito, 1999) and recognizing familiar melodies in the absence of distinctive rhythmic cues (Galvin et al., 2007; Gfeller et al., 1997; Kong et al., 2004). Tempo perception is normal, and rhythm perception is adequate but poorer than that of hearing listeners (Cooper et al. 2008; Kong et al., 2004; McDermott, 2004). Temporal envelope cues, which are critical to timbre perception, are preserved in the electrical input, but spectral shape, which is also important, is degraded. As a result, cochlear implant users often exhibit confusion within and between classes of instruments (Gfeller, Witt, Woodworth, Mehr, & Knutson, 2002; McDermott, 2004).

Unlike postingually deafened implant users, who are often disappointed with the musical input provided by their prostheses (Gfeller et al., 2000; Lassaletta et al., 2007; Leal et al., 2003), congenitally or prelingually deaf children have no knowledge or representations of music in its acoustic form. Moreover, implantation early in life may facilitate adaptation to cochlear stimulation (Kral & Tillein, 2006). These factors may underlie implanted children's favorable evaluations of music and their participation in a variety of musical activities, including instrument lessons, dancing, and even singing (Gfeller, Witt, Spencer, Stordahl, & Tomblin, 1998; Nakata, Trehub, Mitani, & Kanda, 2006; Vongpaisal, Trehub, & Schellenberg, 2006). It is telling, however, that their singing preserves the rhythms but not the pitch contours (i.e., patterns of rising and falling pitches) of the target songs (Nakata et al., 2006), which reflects the pitch perception problems that they share with adult implant users (Fujita & Ito, 1999; Cooper et al., 2008).

What is known about the music perception skills of child implant users? In one study, 8- to 15-year-old implanted children had difficulty recognizing instrumental renditions of well-known songs (e.g., *Happy Birthday; Row, Row, Row Your Boat; Star Spangled Banner*) despite their claims of knowing these songs (Stordahl, 2002). In an extension of that study, adult implant users were found to be considerably more accurate at identifying instrumental renditions of well-known songs in a four-alternative forced-choice task than were postlingually deaf children (9-18 years) who, in turn, were more accurate than prelingually deaf children (8-18 years) (Olszweski, Gfeller, Froman, Stordahl, & Tomblin, 2005). Unlike the child implant users, their

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adult counterparts showed substantial benefit from the availability of distinctive rhythmic cues. It is likely that the postlingually deaf adults and some of the postlingually deaf children had rich representations of music that could be used to their advantage after becoming deaf. Also of interest is the fact that music training facilitated performance for the postlingually deaf children, which implies that the music processing difficulties of cochlear implant users can be ameliorated to some extent by appropriate interventions.

One factor precluding unambiguous interpretation of these findings is the fact that prelingually and postlingually deaf children knew half as many of the nine test songs as did the adult implant users and hearing children. In fact, some implanted children knew only one of the songs on which they were tested. Scores were adjusted to exclude trials with unfamiliar songs, but those scores could still overestimate children's song recognition, especially if some of the children (e.g., the older ones) responded strategically by choosing the known song on every trial. In general, however, substantial divergence between the instrumental test materials used in most studies with implant users and the usual vocal renditions experienced in daily life could underestimate the music recognition skills of this population.

Vongpaisal et al. (2006) investigated the possibility that child implant users would recognize familiar music when the test materials preserved all or some of the features available during exposure or familiarization. For that purpose, they used popular recordings (e.g., by Britney Spears or Backstreet Boys) that the children listened to regularly. Child implant users were relatively accurate at identifying excerpts of the original versions with lyrics. They also performed above chance levels on instrumental excerpts that preserved the original timbre and timing cues but omitted the lyrics. Their performance was at chance levels, however, on piano renditions of the main melody that preserved the rhythm, tempo, and relative pitch patterning of the original tune. Such piano renditions are relatively abstract in the sense that they carry the gist or essence of the melodies while omitting other distinctive performance cues that may be critical to implant users' recognition of music.

Children with cochlear implants also recognize songs heard incidentally while watching engaging television programs, but only when the renditions preserve the original vocal as well as instrumental cues (Mitani et al., 2007; Nakata et al., 2005). Their failure to identify instrumental renditions may stem from the incidental context of exposure to TV theme songs, in contrast to the deliberate context of exposure to pop songs (as in Vongpaisal et al., 2006). Such differences also could arise from lesser overall exposure to the TV music. In Japan, where the TV studies were conducted, the theme songs of children's programs typically change after 3-12 months (Trehub, Schellenberg, & Nakata, 2008), which contrasts with the long-term availability of popular recordings or theme songs from children's TV programs in North America.

The goal of the present study was to determine whether child implant users could recognize altered versions of familiar songs heard incidentally while watching their favorite TV programs. It was necessary, first, to establish that the children could recognize the music in its original form. For those able to recognize the original versions, it was of particular interest to determine whether the songs were recognizable without the lyrics, as they were for child implant users in Vongpaisal et al. (2006) but not for those in Mitani et al. (2007) and Nakata et al. (2005). It was also of interest to determine whether child implant users could recognize simple melodic versions of familiar music because of design limitations of studies addressing this issue (Olszewski et al., 2005; Stordahl, 2002). Although engaging audiovisual contexts are thought to facilitate the encoding and retention of auditory cues (Schellenberg & Trehub, 2003; Trehub et al., 2008), those cues would have to be perceptible and distinctive for child implant users to take advantage of them.

Method

Participants

Inclusion in the study was limited to children who demonstrated their familiarity with at least four television programs in our stimulus set. Although parents reported that their children were regular viewers of particular television programs, the children had to meet specific recognition criteria, as described below. The participants were 17 children (M = 8.4 years, SD = 2.2, range = 4.7-11.7; see Table 1) with cochlear implants (CIs) who were recruited from the greater Toronto area. All of the children were prelingually deaf (most being congenitally deaf). The CI children received Nucleus 24 implants (with ACE or SPEAK processing strategy) at least 3 years prior to testing (M = 5.7, SD = 2.0, range = 2.9-9.7), and all but two were implanted by 3 years of age (M = 2.7, SD = 1.0, range = 1.0-5.0). When tested with their implants, absolute thresholds for tones within the speech range were within normal limits (10-15 dB). The CI children communicated exclusively by auditory-oral means (i.e., no sign language), and they were in

TABLE 1. Age at Testing, Age at Implantation, and Implant Experience for Cochlear Implant (CI) Participants.

Participant	Age (years)	Age at implantation (years)	Implant experience
1	7.2	2.8	4.4
2	11.7	2.8	8.9
3	9.0	6.0	3.0
4	5.4	1.0	4.4
5	7.5	2.1	5.4
6	9.7	2.7	7.0
7	6.7	1.9	4.8
8	9.8	4.9	4.9
9	10.8	2.9	7.9
10	11.5	2.9	8.6
11	5.9	2.1	3.8
12	7.7	2.8	4.9
13	4.7	1.0	3.7
14	9.0	2.5	6.5
15	9.5	2.4	7.1
16	11.6	1.8	9.8
17	7.0	2.9	4.1

age-appropriate classes with hearing peers. Three additional CI children were excluded from the sample because of their failure to demonstrate recognition of original versions of the music. Specifically, they scored at or below chance levels on the original versions, either because of poor music perception in general or insufficient familiarity with the test music.

For a comparison group, we recruited 39 normal-hearing (NH) 4-to 6-year-old children (M = 5.2, SD = 1.0; range = 4.0-6.7) from the local community, whose average age approximated that of the youngest child in the CI group. The NH children had no personal or family history of hearing problems.

Apparatus and Stimuli

Testing took place in a double-walled sound-attenuating booth (Industrial Acoustics Corporation) 3 m × 2.5 m. An interactive computer program (customized for an iMac computer) presented stimuli and recorded response selections. All stimuli were played through high-quality loudspeakers (Bose LSPP 20234783) at a sound level of approximately 70 dB (A).

The 30 stimuli consisted of 10 musical excerpts, with each excerpt presented in three different versions: *melody, instrumental,* and *original*. The originals were taken directly from theme songs played at the beginning of popular children's television programs (see Table 2) by re-recording the audio track of videotapes

TABLE 2. Selection of Theme Songs from Children's Television Programs.

Television Theme Song
1. Arthur
2. Barney
3. Bob the Builder
4. Caillou
5. Clifford the Big Red Dog
6. Franklin
7. Dragon Tales
8. Magic School Bus
9. Teletubbies
10. Zaboomafoo

as digital sound files. Instrumental and melody versions were created by a professional musician in a recording studio. The instrumental versions duplicated the timbre and timing of the original recordings, with the original vocal portions (i.e., the sung melody) replaced by a synthesized flute, as in Mitani et al. (2007) and Nakata et al. (2005). The melody versions consisted of the same flute melodies but without instrumental accompaniment. All excerpts were approximately 10 s in duration.

Procedure

All participants were tested individually. Before the test session began, participants selected four TV shows that they knew best from the available materials. Pictures of the main character(s) from each program were displayed on the computer monitor along with program titles beside each image. On each trial, participants were instructed to listen to the entire excerpt before identifying the appropriate TV program from the four images on the monitor. The three conditions were blocked and presented in order of decreasing difficulty: melodies first, instrumentals second, and originals last. Each excerpt was presented three times in each condition with the 12 stimuli (4 songs × 3 repetitions) in random order constrained to exclude successive presentations of the same excerpt. Participants received no feedback about response accuracy. Instead, the experimenter provided noncontingent verbal encouragement throughout the session. After providing their response on each trial, children were asked to rate how much they liked each excerpt by clicking on a Likert-type scale consisting of five ice-cream cones varying in size (smallest = 1 or 'not at all' to largest = 5 or 'very much').

Results

Because preliminary analyses revealed that performance did not vary as a function of age in either group, age was not considered further. For the CI group, duration of implant use had no association with performance and was therefore excluded from further consideration.

For ease of interpretation, identification accuracy (number correct out of 12) was converted to percent-correct scores separately for each child for each condition. Summary statistics are illustrated in Figure 1. One-tailed, one-sample *t*-tests compared performance with chance levels of responding (25% correct; below-chance levels of accuracy are not interpretable). For the CI group, performance exceeded chance for the melodies ($M = 37\%$, $SD = 20\%$), the instrumentals ($M = 38\%$, $SD = 25\%$), and the originals ($M = 65\%$, $SD = 21\%$), $t(16) = 2.50$, 2.18, and 7.93, respectively, $p < .05$. A repeated-measures analysis of variance (ANOVA) confirmed that identification accuracy differed across conditions, $F(2, 32) = 14.13$, $p < .001$, with better identification of the originals than either the melodies or the instrumentals, $t(16) = 4.46$ and 3.98, respectively, $p < .001$, which did not differ from each other.

Performance of individual CI children is illustrated in Figure 2. Note the large individual differences, with some CI children performing well above chance levels across conditions and others performing at or near chance levels. In the melody condition, 10 of the 17 CI children performed above 25% correct. Based on average scores in the melody and instrumental versions, we observed that two (CI-4 and CI-13) of the three best performers (including CI-16) received their implant at 1 year of age, well before the other children. Note that the rank ordering of performance differed across melody and instrumental conditions, which implies that there were individual differences in the use of cues to tune identity.

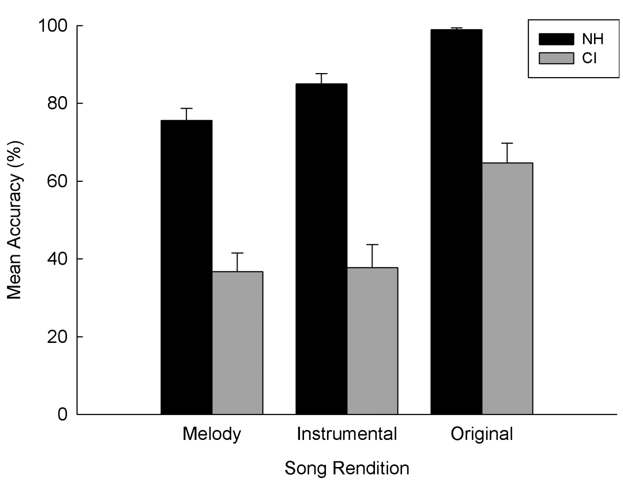

FIGURE 1. Mean accuracy (percentage correct) for normal hearing (NH) and children with cochlear implants (CI) across song conditions. Error bars represent standard errors.

For NH children, performance exceeded chance levels for the melody ($M = 76\%$, $SD = 19\%$) and instrumental ($M = 85\%$, $SD = 16\%$) versions, $t(38) = 16.35$ and 22.77, respectively, $p < .001$, reaching ceiling levels for the originals ($M = 99\%$, $SD = 3\%$) (see Figure 1). As with CI children, identification accuracy varied across conditions, $F(2, 76) = 36.22$, $p < .001$, with better identification of the originals than the melody or instrumental versions, $t(38) = 7.45$ and 5.45, respectively, $p < .001$. In contrast to the CI children, however, NH children exhibited a significant advantage for instrumental over melody versions, $t(38) = 3.69$, $p < .001$. A two-way (condition X group) mixed-design ANOVA (original condition excluded because of ceiling performance for the NH group) confirmed that the difference between NH children and CI children was highly significant, $F(1, 54) = 73.00$, $p < .001$, but the interaction between condition and group was only marginal, $F(1, 54) = 2.88$, $p = .09$. Substantial between-group differences and large individual differences in the CI group may have masked more subtle differences in response patterns between CI and NH children.

The above-chance performance of CI children in the melody condition motivated us to compare their performance directly with that of Japanese CI children of similar age. In the Japanese study, CI children had performed at chance levels on a comparable melody-recognition task (Mitani et al., 2007) except for the reverse order of conditions (originals, instrumentals, melodies). To facilitate cross-study comparisons, we adopted the scoring method of Mitani et al. (2007), which corrected for differences in the number of response alternatives (i.e., 3, 4, or 5 in Mitani et al. versus 4 in the present study). An independent-samples *t*-test confirmed that CI children in the present study performed significantly better than those in Mitani et al. (2007), $t(27) = 2.09$, $p < .05$. Because the reverse order of testing (i.e., originals first) was likely to prime performance of the Japanese CI children—inflating scores in the melody condition rather than depressing them—our test of the performance advantage of the current CI sample was conservative. Indeed, Japanese CI children who were retested with the same order of conditions as those used in the present study also performed at chance levels on the instrumental and melody excerpts (T. Nakata, personal communication, February, 2007), which implies that

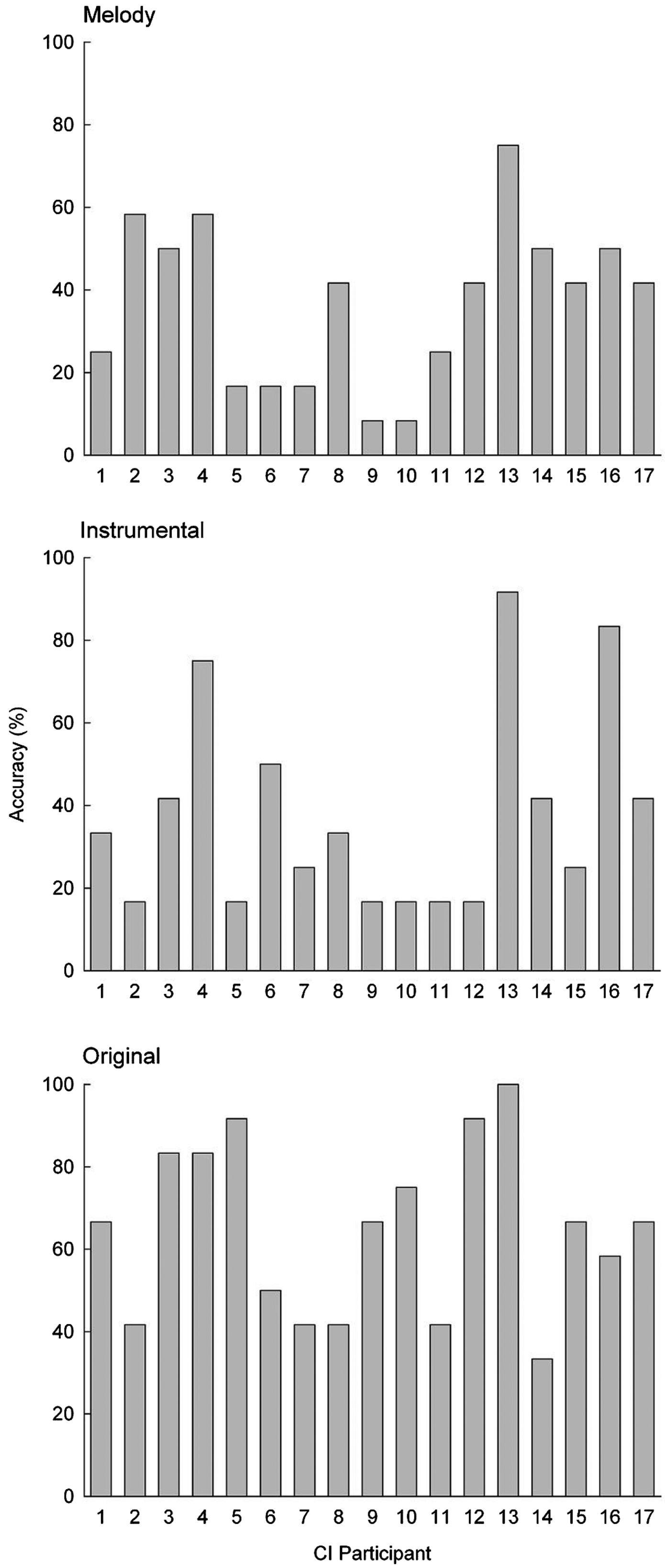

FIGURE 2. Individual scores (percentage correct) of cochlear implant (CI) children in each song condition: (A) melody, (B) instrumental, and (C) original.

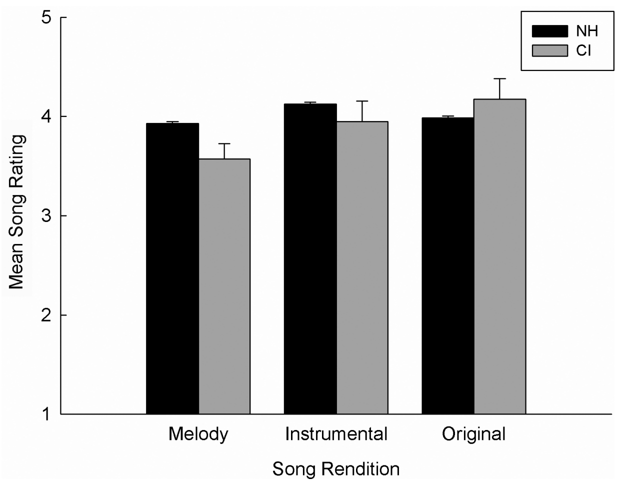

FIGURE 3. Mean liking ratings of normal hearing (NH) and cochlear implant (CI) children for each song condition.

performance differences between Japanese and Canadian children were not attributable to such order differences. Moreover, all but three deaf children in the current study received their implants before 3 years of age, whereas most deaf children in Mitani et al. (2007) received their implants after 3 years of age even though they were all congenitally deaf.

Figure 3 illustrates descriptive statistics for the liking ratings. To determine whether the excerpts were rated favorably or unfavorably, we compared mean ratings with the midpoint of the rating scale (3 = 'indifferent'), separately for CI and NH children in each of the three testing conditions. In all instances, the mean ratings were significantly higher than the mid-point, $p < .005$, indicating that CI and NH children gave positive ratings to all musical renditions. Group differences in song ratings were examined with a mixed-design (group X condition) ANOVA. The analysis revealed a main effect of condition, $F(2, 108) = 6.30, p < .005$, and a significant interaction between group and condition, $F(2, 108) = 3.81, p < .05$. Ratings from CI children varied across conditions, $F(2, 32) = 5.80, p < .01$, but those from the NH children did not. Specifically, CI children assigned lower ratings to the melody versions than to the instrumental and original versions, $t(16) = 2.25$ and 2.86, respectively, $p < .05$, but their ratings of instrumental and original versions did not differ.

Discussion

Deaf children with cochlear implants were much poorer than young hearing children at recognizing TV theme songs. Nevertheless, they performed significantly above chance levels on monophonic versions (i.e., sequences of single notes) of the main melodies and on instrumental versions of the theme songs that retained all of the original cues except for the vocals. Although the instrumental versions provided many more differentiating cues than the melody versions, CI children performed no differently in these contexts. Moreover, they rated all versions positively, with the monophonic (i.e., melody) versions rated less positively than the instrumental and original versions. The implication is that CI children found the instrumental versions richer but no more distinctive than the melody versions.

CI children's success on the melody and instrumental versions in the present study is at odds with the findings of CI children's failure to identify those versions of TV music in the Japanese study (Mitani et al., 2007; Nakata et al., 2005) and with Canadian CI children's failure to identify the melodies of familiar pop songs (Vongpaisal et al., 2006). As noted, implant users in the present study probably had greater exposure to the target TV programs and accompanying music than did Japanese implant users, which may be the principal source of these performance differences. It is also possible that the current implant listeners had more exposure to the target music than did the pop fans in Vongpaisal et al. (2006). Only by controlling such exposure, perhaps through the use of novel materials, can the issue be resolved definitively.

Age of implantation may also be implicated. On average, deaf children in the present sample received their implant at a younger age than Japanese children tested in previous studies of music recognition and Canadian children in Vongpaisal et al. (2006). The best performers in the present study (i.e., combined performance on melodies and instrumentals) were two congenitally deaf children who received their implants at 1 year of age. Advantages of such early implantation have been documented for language development (Connor et al., 2006; Nicholas & Geers, 2006). These "stars" were also the youngest participants—4 and 5 years of age—which means that they had less implant experience than many other CI participants in our sample.

All other things being equal, deliberate musical exposure, as for the implanted children tested on familiar recordings of pop songs (Vongpaisal et al., 2006), should generate better performance than incidental musical exposure, as in the present study. Unfortunately, all other things were not equal. In addition to differences in the age of implantation and potential differences in amount of exposure, there were other differences in the stimuli (e.g., flute vs. piano renditions of melodies) and context of exposure. There are suggestions that piano tones, which were used in Vongpaisal et al. (2006), pose particular difficulty for implant users (Cooper et al., 2008;

Fujita & Ito, 1999). With respect to contextual factors, the dynamic audiovisual stimuli may have generated deeper encoding of the TV theme music and, consequently, greater memory for musical details. Indeed, emotionally engaging stimuli and contexts enhance learning and performance in infants (Kuhl, Tsao, & Liu, 2003; Thiessen, Hill, & Saffran, 2005; Volkova, Trehub, & Schellenberg, 2006), preschool children (Schellenberg, Nakata, Hunter, & Tamoto, 2007), school-age children (Schellenberg & Hallam, 2005), and adults (Schellenberg & Trehub, 2003; Thompson, Schellenberg, & Husain, 2001). Determining the relative contribution of amount of exposure, context of exposure, and optimal timbral cues is of particular importance.

Unquestionably, distinctive timing cues facilitate music recognition in general and melody recognition in particular. The melodies in the present study, like those in Mitani et al. (2007), Nakata et al. (2005), and Vongpaisal et al. (2006), retained the original timing cues, specifically, the rhythm and tempo. Although those cues proved insufficient for melody identification in previous studies with child implant users (Mitani et al., 2007, Nakata et al., 2005; Vongpaisal et al., 2006), they could be largely, if not entirely, responsible for the successful identification of melody and instrumental versions in the present study. Kong et al. (2004) found that CI adults could identify melodies in a closed-set task, but only when the melodies retained the rhythms of the original music. In contrast to the present study, Kong et al. (2004) provided a practice session preceding the test session as well as feedback about response accuracy on all practice and test trials. As a result, it is not clear that CI adults' performance was based on long-term representations of the music.

The contribution of timing cues to song identification can be illustrated by tapping or clapping the rhythm of various familiar songs. Note that the rhythmic cues of *London Bridge is Falling Down* are distinguishable from those of *Twinkle, Twinkle, Little Star* but not from those of *Mary Had a Little Lamb*. In general, lively musical pieces, like the theme songs of children's TV programs, are more rhythmically distinctive than slow or soothing musical pieces. Even if the timing cues were sufficient for identification with the closed response set of the current study, it is unlikely that they would suffice in the context of open-set responding. For adults with normal hearing, pitch cues make a considerably greater contribution to song identification than do temporal cues (Hébert & Peretz, 1997). Future research could determine whether child implant users are able to identify TV music on the basis of rhythmic cues alone, even with closed-set responding.

In short, prelingually deaf implant users can recognize melodic themes from familiar TV programs when those themes retain the original timing cues. We attribute their success on this task to some combination of early implantation, amount of exposure, and contextual factors at the time of encoding that promote heightened arousal and positive affect. Our findings have implications for music perception and memory in special populations. Moreover, they could help guide the design of training strategies to enhance learning and rehabilitation in children with cochlear implants.

Author Note

This research was funded by the Canadian Institutes for Health Research and the Natural Sciences and Engineering Council of Canada. We thank Drs. Blake Papsin and Karen Gordon for their cooperation, and Cam MacInnes for preparing the stimulus materials.

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