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Reliability Measure of a Clinical Test: Appreciation of Music in Cochlear Implantees (AMICI)

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Abstract

Purpose—The goals of this study were (1) to investigate the reliability of a clinical music perception test, Appreciation of Music in Cochlear Implantees (AMICI), and (2) examine associations between the perception of music and speech. AMICI was developed as a clinical instrument for assessing music perception in persons with cochlear implants (CIs). The test consists of four subtests: (1) music versus environmental noise discrimination, (2) musical instrument identification (closed-set), (3) musical style identification (closed-set), and (4) identification of musical pieces (open-set). To be clinically useful, it is crucial for AMICI to demonstrate high test-retest reliability, so that CI users can be assessed and retested after changes in maps or programming strategies.

Research Design—Thirteen CI subjects were tested with AMICI for the initial visit and retested again 10–14 days later. Two speech perception tests (consonant-nucleus-consonant [CNC] and Bamford-Kowal-Bench Speech-in-Noise [BKB-SIN]) were also administered.

Data Analysis—Test-retest reliability and equivalence of the test's three forms were analyzed using paired t-tests and correlation coefficients, respectively. Correlation analysis was also conducted between results from the music and speech perception tests.

Results—Results showed no significant difference between test and retest ($p > 0.05$) with adequate power (0.9) as well as high correlations between the three forms (Forms A and B, $r = 0.91$; Forms A and C, $r = 0.91$; Forms B and C, $r = 0.95$). Correlation analysis showed high correlation between AMICI and BKB-SIN ($r = -0.71$), and moderate correlation between AMICI and CNC ($r = 0.4$).

Conclusions—The study showed AMICI is highly reliable for assessing musical perception in CI users.

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Keywords

Cochlear implants; music perception; test-retest reliability; speech perception

Cochlear-implant (CI) devices have advanced rapidly in the past three decades. Currently, most modern CI users have good speech perception in quiet (Hamzavi et al, 2001; Anderson et al, 2002; Frijns et al, 2002; Parkinson et al, 2002; Rauschecker and Shannon, 2002; Ramsden, 2004). However, research has shown that music perception has not experienced the same improvements as speech perception (Gfeller and Lansing, 1991; Fujita and Ito, 1999; Gfeller et al, 2000; Stordahl, 2002; Leal et al, 2003; Gfeller et al, 2005; Wilson et al, 2005; Vongpaisal et al, 2006; Spitzer et al, 2008). According to Gfeller and colleagues (2000), the majority of CI users are dissatisfied with their music listening experience after implantation. To address this disappointing outcome, recent research has focused on assessing in greater detail music perception by CI users, and CI manufacturers have been striving to improve their implant devices for music appreciation purposes. Similarly, on the clinical side, clinicians are becoming aware of the need to have a standard clinical music test to assess CI users' music perception and determine the extent to which different processing strategies have an impact on outcomes. Results from clinical music tests may also help clinicians discuss with CI users expectations in different listening situations and offer guidance regarding rehabilitation plans.

Motivated by these concerns, a clinical test for music perception, Appreciation of Music in Cochlear Implantees (AMICI), was developed by Spitzer and Mancuso (2006) to assess several aspects of music perception: discrimination of music versus environmental noise, identification of musical instruments (closed-set), identification of musical styles (closed-set), and recognition of individual musical pieces (open-set). For AMICI, all musical excerpts were taken from commercially available music material heard in everyday situations. The rationale behind this approach was to offer a realistic understanding of how CI users may perform in common listening situations. Moreover, given different levels of CI users' musical abilities, Spitzer and colleagues (2008) designed AMICI so it would show a progression of difficulty throughout the subtests. The initial version of the test served as a trial stage to allow better understanding of the difficulty and appropriateness of each item. After a preliminary test was conducted on 34 normal-hearing (NH) subjects, item analysis was carried out, resulting in the elimination of items with a high error rate, leading to modification of the test into its current three forms, A, B and C. Using the newly modified AMICI, a further study was then performed on 15 NH subjects (Cheng et al, 2007), with results showing no significant difference between test and retest ($\alpha = 0.05$) and significant correlation between each form (Forms A and B, $r = 0.91$; Forms B and C, $r = 0.92$; Forms C and A, $r = 0.91$). As for AMICI performance, the total average score was 96.7% with standard deviation of 3.99 (see Table 1).

Previous research has shown that rhythm perception in CI users is close to that of NH listeners, since CIs can provide accurate temporal information (Gfeller and Lansing, 1991; Gfeller et al, 1997; Kong et al, 2004). However, when CI users were presented with more challenging rhythmic tasks, (i.e., adding quarter, eighth, and sixteenth notes into rhythmic

patterns), they performed more poorly than NH subjects, suggesting that rhythm perception by CI users is also task specific (Kong et al, 2004). In general, pitch, melody, and timbre perception posed more difficulty for CI users, with these difficulties mainly due to reduced spatial resolution and absence of temporal fine-structure information from the CIs (Qin and Oxenham, 2003; Drennan and Rubinstein, 2008). Previous studies have shown that CI users have poorer performance than NH listeners for pitch-direction discrimination and pitch-pattern identification (Gfeller and Lansing, 1991; Gfeller et al, 1997; Laneau et al, 2004). Similarly, for melody perception, Gfeller et al (2002a) found that the average melody recognition performance for CI users was 19% while NH listeners achieved an average of 83% accuracy. In order to examine the influence of rhythmic cues in melody recognition tasks, Kong et al (2004) tested a group of CI users and NH listeners with 12 familiar songs heard either with or without rhythmic cues. For melodies with rhythmic cues, the NH group was able to achieve an almost 100% accuracy rate while the CI group averaged 63% correct. As for melodies without rhythmic cues, the CI group performed below chance levels. Consistent with the previously mentioned studies, Leal et al (2003) examined the influence of lyrics by testing CI users with nursery songs with and without lyrics. CI users scored much higher when melodies were presented with lyrics, while melody recognition without lyrics was difficult for most CI users (only 3% of the participants obtained 50% accuracy).

Cochlear implant patients also generally perform more poorly than NH listeners on timbre perception tasks. In a study by Gfeller et al (2002b), 48 CI users and 11 NH listeners were asked to identify the sounds of eight musical instruments (trumpet, trombone, flute, clarinet, saxophone, violin, piano, and cello). Implant users performed significantly poorer than NH listeners, with a mean score of 46.5% compare to NH listeners' mean score of 90.9%. As for CI users' subjective ratings of music, past research has shown that CI users do not enjoy music as much as NH listeners. Using the Iowa Musical Background Questionnaire with 65 CI users, Gfeller et al (2000) found that 75% of CI users enjoyed music before cochlear implantation, but 83% reported a decrease in musical enjoyment after implantation. Similarly, Mirza et al (2003) surveyed 35 CI users regarding the enjoyment of music, with the result showing that only 46% listen to music after implantation. Furthermore, when CI users were asked to rate the enjoyment of music, results showed a mean of 8.7 (on a 10-point scale) pre-implantation but only 2.6 post-implantation. Finally, Brockmeier et al (2002) used the Munich Music Questionnaire (MUMU) to survey 103 CI users' subjective ratings on music, finding that 51% of CI users described music sounds as pleasant, and only 31% said that music sounded natural. These results indicate that CI users' subjective ratings of music are generally lower after implantation. In summary, the above findings also show that adult CI users are generally comparable to NH listeners in the area of rhythm perception (except more complex rhythm tests), while pitch perception, melody recognition, and timbre perception remains challenging for most CI users. These disadvantages can lead to a lack of enjoyment of music and, to a certain extent, diminished quality of life.

In addition to examining music perception by CI users, past research also examined the association between music and speech recognition, both in quiet and in noise. In a study by Gfeller et al (2002b), the authors investigated the relationship between music perception and speech recognition. Specifically, they examined CI users' timbre perception and speech recognition in noise using the Hearing in Noise Test (HINT) and the Iowa Consonant (in

quiet and in noise) and consonant-nucleus-consonant (CNC) tests. The results showed moderate to strong correlations between timbre recognition and the two speech-in-noise tests (the Iowa Consonant test in noise and HINT). However, correlations were not significant between timbre recognition and speech-in-quiet tests (CNC and the Iowa Consonant test in quiet). Furthermore, in their 2007 study, Gfeller et al tested CI users' familiar melody recognition (without lyric) and their speech recognition thresholds in two noise conditions, two-talker babble and white noise. Their results showed moderate correlations for both masker types. In a study by Kang et al (2009), the authors tested CI users' pitch perception, and melody and timbre recognition. They found that all tests (pitch, melody and timbre) showed statistically significant moderate correlation with the CNC monosyllabic word recognition test (Peterson and Lehiste, 1962) in quiet. To investigate the relationship between music perception and speech-in-noise recognition, the authors administered speech recognition thresholds (both in noise and two-talker babble) and found significant moderate correlations with pitch perception and melody and timbre recognition. Finally, Won et al (2010) found pitch perception to be significantly correlated with speech perception. In particular, they found pitch discrimination thresholds to be moderately correlated with CNC recognition in quiet. For speech recognition in noise (both two-talker babble and steady noise), they found significant moderate correlations with pitch-direction thresholds.

Overall, the findings of aforementioned studies indicate at least a moderate correlation between perception of music and speech in noise. On the other hand, the relationship between music perception and speech recognition in quiet remains less clear, with more variation in correlation magnitudes and significance across studies. This finding is not surprising since previous studies have shown that current CIs are still limited at providing pitch information due to reduced spatial resolution and lack of temporal fine-structure information. In particular, reduced temporal fine-structure information may result in both poor music perception and speech perception in noise due to greater challenges in segregating the speech signal from surrounding competing noise (Qin and Oxenham, 2003; Nelson and Jin, 2004; Gantz et al, 2005; Kong et al, 2005; Drennan and Rubinstein, 2008; Moore, 2008). In summary, there is generally a significant relationship between music perception and speech in noise and, to certain extent, speech in quiet.

Aside from AMICI, several other clinical music perception tests have been independently developed to assess music perception by CI users. These are the Clinical Assessment of Music Perception (CAMP) test, the Korean version of the CAMP (K-CAMP), and the Musical Sounds in Cochlear Implants (Mu.S.I.C.). Developed by researchers at University of Washington (Nimmons et al, 2008), CAMP consists of four subtests designed to examine three different aspects of music perception: timbre perception, pitch-direction discrimination, timbre identification and melody recognition. K-CAMP (Jung et al, 2010) consists of the same pitch-direction discrimination and timbre identification tests. However, for melody recognition, due to cultural differences, 10 of the 12 melodies from CAMP have been replaced with popular Korean melodies. Developed by Brockmeier et al (2011), Mu.S.I.C. consists of six subtests assessing rhythm discrimination, pitch discrimination, melody discrimination, chord discrimination, instrument detection, instrument identification, and two subjective subtests, which are dissonance rating and emotion rating. These clinical music perception tests are, to a certain extent, different from each other. For example, in

CAMP's melody recognition subtest, all melodies are manipulated and administered in an isochronous manner (Kang et al, 2009) such that lyrics and rhythmic elements have been removed to avoid any potential influence on melody recognition. However, for AMICI, the melodies were all taken from commercially available music materials without removing lyrics and rhythmic elements, thus, making them more representative of music CI patients are likely to encounter in everyday life. As for the Mu.S.I.C. test, the main difference that separates it from CAMP, K-CAMP, and AMICI is that it consists of two additional subjective tests that examine CI users' ability to judge the emotional quality of the music and their harmony perception. In terms of administration time, CAMP, K-CAMP, and AMICI can be administered in a short period of time (~30 min), while Mu.S.I.C. takes longer to administer (~90 min). Aside from these methodological differences, there are differences in goals as well. For AMICI, the test focuses on addressing real-life clinical needs by using unaltered and unprocessed musical excerpts and providing results that can be used to predict and counsel CI users' music ability in everyday life, while CAMP, K-CAMP, and Mu.S.I.C. concentrate on more specific aspects of musical elements (e.g., rhythm, melody, timbre, pitch perception, and chord discrimination). Furthermore, CAMP was designed with the intention of universal usage, whereas AMICI is only suitable for users who are familiar with Western culture music.

For a clinical test such as AMICI, it is crucial to demonstrate acceptable test-retest reliability. This would allow for repeated assessments of CI users' music perception after changes in maps or programming strategies, thus ensuring that test performance changes can be attributed to clinical manipulation rather than test variability. Equivalency of forms is also needed to minimize learning effects in retesting and permit multiple assessments over time. In the current study, additional correlations between music and speech perception (both in quiet and in noise) were also examined to investigate whether AMICI lead to a similar pattern of associations in the perception of speech and music by CI users as shown with previous tests of music perception. Finally, in order to take into consideration past musical training and listening experience, a music questionnaire was administered to further understand CI users' subjective experience of music.

The purpose of the present study was to investigate the reliability of AMICI using test-retest and demonstrate equivalency of forms using a parallel-form testing method. Based on previous AMICI findings with normal hearing listeners (Cheng et al, 2007), it was expected that (1) there would be no significant difference between test and retest performance on CI users, indicating test reliability; (2) the different AMICI test forms would have similar levels of difficulty, demonstrated by equal accuracy and high intercorrelations across the three test forms; and (3) there would be significant correlations between AMICI scores and measures of speech perception abilities.

MATERIALS AND METHODS

Subjects

Thirteen CI subjects were tested (7 females and 6 males). The age range of the group was from 21 to 77 yr (mean age was 48, and standard deviation was 18.2). Table 2 shows detailed background information of the CI subjects. All subjects were postlingually deafened

and had more than 1 yr of implant experience. Seven subjects were implanted on the right, five on the left, and one bilaterally who chose to use his right implant for this study. For each subject, the nonimplanted ear was plugged with an E-A-R Classic earplug. There was no minimal musical background required, but there were eight subjects who had some musical instrument training prior to implantation (<3 yr of musical training) and five subjects with none. In addition, all subjects were native speakers of American English. Finally, all subjects showed no signs of decreased mental status, having all passed the Mini-Mental State Exam with a passing score of 28 (Folstein et al, 1975).

Procedures

Before the experiment, each subject was given an opportunity to review and sign a consent form and was screened for general cognitive abilities using the Mini-Mental State Exam (Folstein et al, 1975). During testing, each subject was seated in an audiometric test suite, facing a single Lifeline loudspeaker (model LLF-50) at 0° azimuth at a distance of 1 m. The warble-tone hearing test involved obtaining CI-aided hearing thresholds in the sound field with a plugged nonimplanted ear if residual hearing was present (or currently utilizing a hearing aid). The pure-tone hearing test included test frequencies ranging from 250 to 8000 Hz.

The study required two visits for each subject. During the first visit, each subject was tested with two of the three forms of AMICI. For the second visit (after a 10–14 day interval), the subject was tested with two more AMICI forms, with a retest on one of the forms from the previous session, and two speech tests. A Madsen Orbiter 922 clinical audiometer was used for both the music test and the speech test. For both the music and speech tests, stimuli were played on a CD player and presented via the audiometer and calibrated speaker. The presentation level for all tests was set at 70 dB (A).

Stimuli

Music Test: AMICI—AMICI has three forms (Forms A, B, and C), with each form divided into four subtests based on the music perception task listeners needed to perform (Spitzer et al, 2008). The first subtest, noise versus music discrimination, contains 25 items, 20–30 sec each, selected from a wide variety of royalty-free recordings. The noise stimuli consist of everyday environmental noise such as the sound of footsteps or running water. For the second subtest, identification of instruments, there are 30 musical excerpts, 20–30 sec each. Altogether, 10 target instruments are included in this task: trumpet, tympani/drum, flute, tuba, guitar, violin/strings, piano, saxophone, female vocal, and male vocal either with or without accompaniment. Excerpts with the accompaniment were selected so that the intensity level of the accompaniment is much lower than the principal instrument. The third subtest is identification of musical style. For this part, 25 items of 20–30 sec selections are identified in the categories of (1) classical, (2) Latin, (3) country western, (4) jazz and (5) rock 'n' roll/popular. Finally, for the last subtest, open-set recognition of musical pieces, 20 musical excerpts of 20–30 sec each were chosen from the American cultural mainstream, which includes popular and classical music. Subjects were given a set of written instructions for each test section, along with the foils that were used for the closed-set portions of the test. For subtests 1 through 3, a verbal response was required after each stimulus. For subtest

4, recognition of musical pieces, acceptable responses include song name, composer, a context in which it was used (such as a movie or advertisement), or singing or humming the rest of the melody. Responses were recorded by the examiner on a score sheet.

Speech Tests: CNC and BKB-SIN—Speech perception was evaluated in terms of recognition of 200 NU-6 CNC words in quiet and Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN; Bench et al, 1979) in the presence of a four-talker speech-babble masker. Four lists of ten sentences from the BKB-SIN test (Etymotic Research, 2005) were used. Across each list, the signal-to-noise ratio (SNR) decreased in 3 dB steps from 21 to –6 dB. Based on the number of the 124 key words (31 words $\times$ 4 lists) correctly repeated, results were converted to the metric SNR-50, the normalized estimated SNR needed for 50% correct response.

Survey: MUMU—The MUMU (Munich Music Questionnaire, Brockmeier et al, 2002) was administered to assess CI subjects' subjective previous musical experience and ratings of musical sounds before and after cochlear implantation.

RESULTS

General Description of Results: Overall Means and Standard Deviations

Results are presented in Table 3 and Figure 1. Table 3 shows the mean score for the three forms and one retest form as well as the standard deviation (SD) for each subtest. Scores are presented as number of items correct, which can also be read as percent correct as there are 100 items in each form. The mean total score for Form A was 67.08% (SD = 14.99%; range = 48–95%). The mean total score for Form B was 66.92% (SD = 15.23%; range = 45–97%). The mean total score for Form C was 67.54% (SD = 15.66%; range = 50–94%). For the retest, the mean total across the forms was 66.62% (SD = 16.87%; range = 45–96%).

Average overall performance for each subject in each subtest is shown in Figure 2. The variability between subjects was the lowest in the first subtest, music vs. noise discrimination. It is apparent that variability increased and accuracy decreased as CI subjects progressed from one subtest to the next, with the widest range of variability and poorest performance in subtest 4, the recognition of musical pieces. Moreover, there was a steady decline in performance as subjects moved through each subtest.

Test and Retest Results

As mentioned previously, one of the main purposes of this study was to investigate AMICI test and retest reliability, with the hypothesis that there would be no significant change between test and retest scores within the short interval period between the two tests and the absence of change in CI processing strategy. For test-retest, paired *t*-test analyses were used to examine possible change in scores for the retest. Furthermore, Pearson correlation analysis was used to determine the correlation between test and retest.

The results of paired *t*-test showed no significant difference between test and retest ($p > 0.05$), indicating the absence of any learning or adaptation effects. In addition, the high Pearson correlation between test and retest was significant ($r = 0.97$, $p < 0.05$). To ensure the

result was not affected by small sample size, a post hoc power analysis was conducted, and results showed a sample size of 13 subjects is adequate for detecting a target power level of 0.90.

Form Equivalency

Another objective of this study was to investigate equivalency between Forms A, B, and C of AMICI. For parallel-form testing, Pearson correlation analysis was used to examine the relationship between each form. The results showed a significant ($p < 0.05$) correlation of 0.91 for Forms A and B, 0.95 for Forms A and C, and 0.91 for Forms B and C.

Music versus Environmental Noise Discrimination

The mean score for this subtest was 97% with SD of 4.56% (range 92–100%). The result shows that this discrimination task was not difficult for the CI subjects and that there is a clear distinction between music versus everyday noise (i.e., environmental sounds) for CI subjects.

Identification of Musical Instruments

CI subjects achieved a mean score of 70% correct (SD of 13.6%, range = 50–89%) for this subtest; responses were analyzed to obtain percent-correct accuracy for each individual instrument. Table 4 shows instrument confusion matrix with the total percent correct for each instrument along with other cells showing the total percentage of inaccurate responses (i.e., when subjects misidentified the target instrument as another instrument). As indicated in Table 4, all ten instruments can be further divided into five instrumental families: (1) string families, (2) brass family, (3) woodwind family, (4) percussive family, and (5) voice. This grouping reveals that CI subjects often misidentified instruments from different families, especially between the brass and woodwind families. Among the 10 instruments, percussive family had the highest accuracy with the drum being perceived with no errors at all. Within the same family, the piano had the second highest accuracy rate of 87%. Conversely, the two woodwind instruments (flute and saxophone) had the lowest accuracy with flute showing the lowest accuracy rate of 39%. This is consistent with other CI timbre perception studies that also found flute to be among the most difficult instrument to identify (Gfeller et al, 2002b; Nimmons et al, 2008). It is also important to note that male vocal has a higher percentage rate (75%) compared to female vocal (53%). Similarly, within the brass family, the trumpet's accuracy was 55% while tuba obtained a much higher accuracy (74%). It is possible that CI subjects were less likely to identify incorrectly an instrument with a lower frequency range.

Identification of Musical Styles

In this subtest, CI subjects achieved a mean score of 50% correct (SD of 24.5%, range = 27–98%). Table 5 shows the total percent correct for each style along with other cells indicating the total percentage of inaccurate responses (i.e., when CI subjects misidentified the target style as another). Based on Table 5, the classical style had the highest accuracy score (81%), with Latin showing the lowest (44%). The Latin style was commonly confused with Jazz style as well as pop/rock. It is possible that similar combination of instruments (vocal,

guitar, drums and brass band) shared by Latin, pop/rock, and country western style was one of the reasons why CI subjects were more likely to be confused with these styles than with classical excerpts since in classical styles there are less similar ensemble combinations than in other styles.

Recognition of Musical Pieces (Open-Set)

In this subtest, CI subjects only achieved a mean score of 37.95% correct (SD of 29.05%, range = 6.25–90%), the lowest of all subtests. Among the 34 different melodies presented to CI subjects, the most recognized melody was “Do Re Mi” sung by Julie Andrews in the movie *The Sound of Music*. This melody achieved an accuracy of 71%. The second highest accurate melody was “Unforgettable,” sang by Nat King Cole; this melody achieved 65% correct. As for the least recognized melodies, there were three melodies that scored 0%, these were (1) “Memories” by Barbara Streisand, (2) “The Way We Were” by Barbara Streisand, and (3) “Wind Beneath My Wings” by Bette Midler. These results were unexpected since all three melodies contain lyrics, and it was surprising that CI subjects were not able to use lyrics as cues when they attempted to identify these melodies.

Correlation: Music and Speech

Overall, high correlation was found between the AMICI total (the total score of all four subtests) and BKB-SIN ($r = -0.71$, $p < 0.05$); however, only a moderate correlation was found between the AMICI total and CNC ($r = 0.41$, $p < 0.05$). In addition, the correlation between each of the AMICI subtests and the two speech tests also showed higher correlation with BKB-SIN than CNC (Table 6). Correlations varied among the four AMICI subtests but were all in the moderate to high range for BKB-SIN, while they were in the low range for the first three AMICI subtests and CNC, reaching moderate levels for subset 4 (recognition of musical pieces).

Survey

In this study, subjects were asked to complete a musical background survey using the Munich Music Questionnaire (Brockmeier et al, 2002). When asked to rate musical quality in terms of how natural music sounds, almost half of the group rated music sound quality as unnatural (46.5%), despite having at least a year of experience with their implants. Moreover, when asked to rate how pleasant music sounds, 38% rated music as unpleasant (23% rated neutral, 39% rated pleasant). In the same survey, subjects were also asked how often they listen to music with their CI; about 38.5% reported they listen to music often, 38.5% reported listening sometimes, and 23% reported listening rarely or very rarely. Spearman’s rho correlation analysis, used to avoid the assumption of normally distributed data collected from the survey, revealed no significant association between subjective ratings of musical quality (both natural and pleasant) and other measures (music and speech perception).

An additional analysis was performed by separating subjects into musically trained (eight subjects) and non-musically trained groups (five subjects). A Mann-Whitney U-test was used to determine if there was a significant difference between the two groups in terms of music or speech perception. Post hoc analysis showed that musically trained subjects (mean

= 74.4, SD = 14.68) performed significantly better ($p < 0.05$) than non-musically trained subjects (mean = 55.25, SD = 6.74) in the AMICI total ($p < 0.05$) and the AMICI musical style identification subtest ($p < 0.05$). However, no significant difference between the two groups was detected in either speech test. Finally, the effect of side of implantation on music and speech perception was evaluated with Mann-Whitney U analysis. Results showed no significant difference between the side of implantation with AMICI ($p = 0.71$, $\alpha = 0.05$), BKB SIN ($p = 0.94$, $\alpha = 0.05$), and CNC ($p = 0.61$, $\alpha = 0.05$).

DISCUSSION

The present findings demonstrate that cochlear implants considerably limit the quantity and the quality of acoustic information used in perceptual processing of music. As vocoder-based processors with a relatively small number of independent information channels relative to a healthy cochlea, most CI devices reduce spectral resolution and eliminate temporal fine structure cues, which have been shown to have an important role in music perception (Drennan and Rubinstein, 2008; Heng et al, 2011). Similarly, in the present study, CI listeners' average score of AMICI was 66%, which is significantly ($p < 0.01$) lower than NH listeners' 96.7% average previously reported by Cheng et al (2007). This result is consistent with most other music perception studies in which CI users performed more poorly than NH listeners in music perception tasks, especially in pitch perception, timbre perception, and melody recognition. In line with results from Galvin et al (2009), musically trained CI users performed significantly better than non-musically trained CI users, indicating that strong previous musical experience may provide CI users advantages in music perception.

Present findings demonstrated the considerable difficulty of CI users in the perception of timbre. An important component of music perception, perception of timbre is affected by spectral resolution (Kong et al, 2011; Macherey and Delpierre, 2013), while temporal fine structure is also a significant contributor to the ability to segregate sources of acoustic information in auditory scenes, such as, for instance, with multiple concurrent talkers, musical instruments, or other environmental sound sources (Apoux and Healy, 2011; Sheft et al, 2012). Therefore, consistent with previous findings (Gfeller et al, 2000; McDermott and Looi, 2004; Nimmons et al, 2008; Heng et al, 2011), limiting spectral and fine-grained temporal information has a detrimental effect on music perception in CI listeners. However, CIs are able to transmit accurately dynamic envelope cues, and consequently, as indicated by the present findings, percussive instruments like drum and piano were identified with greater accuracy than others, while wind instruments like flute were more difficult to identify (Gfeller et al, 2002b; McDermott and Looi, 2004; Nimmons et al, 2008; Brockmeier et al, 2010; Jung et al, 2010; Heng et al, 2011). In addition, the availability of reliable temporal envelope cues may affect the relative perceptual weight of spectral and temporal cues in instrument identification.

Previous studies have also shown that musical instrument identification by CI listeners involves both dynamic envelope information in the attack time and spectral shape characteristics, which can be used to distinguish the timbre of different instruments (Pressnitzer et al, 2005; Carlyon et al, 2007; Macherey and Delpierre, 2013). Consistent with

previous research by McDermott (2004) and Gfeller et al (1998), the present findings also indicate frequent instrument confusions across the boundaries of instrument families. It is possible that due to signal distortions that result from CI processing, idiosyncratic electrode configurations, and variable strength of memory representations for musical instruments, CI listeners rely on a different set of acoustic cues in music listening than NH listeners. This conclusion is supported by previous work by Heng et al (2011) and Kong et al (2004), who showed that CI listeners relied on temporal envelope cues in judgments of timbre (cf., Macherey and Delpierre, 2013). Thus, the confusion of instruments across instrument families might be partly due to similarities in the perceptually salient temporal envelope cues used by CI patients, combined with lesser influence of the spectral information available to NH listeners in instrument identification.

In our study, we also found high correlation between AMICI and BKB-SIN scores using Pearson's correlation analysis. This finding further confirms a relationship between perception of speech and music. The moderate-to-strong correlations between music perception and speech perception in noise and in quiet have been also reported in previous work (Gfeller et al, 2002b; Gfeller et al, 2007; Kang et al, 2009; Won et al, 2010). These consistent patterns of correlations are especially remarkable because of the variety of materials and procedures used in music and speech perception tests. A number of factors are likely to contribute to the link between music and speech processing. Both music and speech represent heterogeneous and complex acoustic patterns used to transmit informationally rich affective and semantic content. As such, both music and speech involve sensory-cognitive interactions between low-level bottom-up and high-level top-down factors (Strait and Kraus, 2011). Since both rely on sufficiently robust basic auditory ability to process low-level peripheral sensory patterns, previous research has also demonstrated that perception of both speech and music is associated with spectral and temporal pattern processing (Drennan and Rubinstein, 2008; Won et al, 2010; Sheft et al, 2012). Similar associations have also been reported for other complex meaningful sounds such as familiar environmental sounds. As with music, previous research demonstrated that the ability to perceive familiar environmental sounds in CI patients is consistently associated with speech perception (Tyler et al, 1989; Reed and Delhorne, 2005; Inverso and Limb, 2010; Shafiro et al, 2011). Indeed, music may be considered a specific instance of nonlinguistic sound perception (Inverso and Limb, 2010), while perception of timbral processing of musical instruments can also be linked to the perception of naturally produced common environmental sounds.

The results of the music survey revealed that for at least one-third of our CI subjects, music does not sound pleasant and that less than half of the CI subjects listen to music often. Close to 50% of CI subjects find music sounds unnatural. In addition, no association was found between self-reported musical enjoyment ratings and music perception skills. These results are consistent with earlier findings that music perception scores and music appraisal may not be related (Gfeller et al, 2008; Lassaletta et al, 2008) and that current CI users do not seem to be able to enjoy music to the same extent as their normal-hearing peers.

Limitations of the Current Study

Unlike CAMP, which is designed for universal usage (Jung et al, 2010), AMICI is a culturally specific test, with all music stimuli derived from the Western musical culture. For example, jazz and country western styles are well-known by Western culture; however, they may not be as well-known by some individuals in other parts of the world, such as the Middle East or Asia. Therefore, clinicians must be aware of these factors when administering AMICI to implant users who are not familiar with or are not part of the American cultural mainstream. Furthermore, it is important to note that implant users with very early onset deafness or younger CI users may have greater difficulty with subtests 2, 3, and 4 due to lack of exposure to musical instruments, styles, and popular melodies.

CONCLUSIONS

The present investigation has shown that AMICI is a reliable clinical test, suitable for testing different aspects of music perception as well as demonstrating individual differences. The demonstrated reliability, both test-retest and interform, allows AMICI to be used to investigate the impact of changes in CI strategies or programming approaches. More insight into music perception by CI users can stimulate further improvements in electrode design and signal processing optimization for music perception. With future research, it may be possible to develop age- and culture-specific versions of a music perception test for young CI users.

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Abbreviations

AMICI	Appreciation of Music in Cochlear Implantees test
BKB-SIN	Bamford-Kowal-Bench Speech-in-Noise
CI	Cochlear implant
CNC	consonant-nucleus-consonant

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Figure 1.
Overall correct scores for Forms A, B, C and retest (N = 13).

Figure 2.
The average (bars) and individual (symbols) performance on each subtest.

Table 1

Mean Items Correct and Standard Deviation for AMICI (Normal Hearing Listeners): Four Subtests and Total Score

		Subtest 1 (Max = 25)	Subtest 2 (Max = 30)	Subtest 3 (Max = 25)	Subtest 4 (Max = 20)	Total (Max = 100)
Form A	Mean	25	29.73	23.80	17.00	95.53
	SD	0	0.59	1.61	3.33	4.49
Form B	Mean	25	29.72	24.13	18.53	97.4
	SD	0	0.59	1.85	2.13	3.56
Form C	Mean	25	29.67	24.33	17.93	96.93
	SD	0	0.62	1.35	2.63	4.32
Retest	Mean	25	29.93	24.13	17.73	96.80
	SD	0	0.26	1.25	2.25	3.59
Mean		25	29.76	24.1	17.80	96.67
	SD	0	0.52	1.52	2.59	3.99

Table 2

Biographical Information for the CI Users Who Participated in This Study

Subject	Age	CI Experience	CI Ear	CI Make	CI Internal Device	CI External Device	Processing Strategy
CI 1	43	2	Right	Advanced Bionics	HiRes90k	Auria	HiRes
CI 2	22	10	Left	Cochlear	Nucleus 24 Contour	Freedom	ACE
CI 3	31	2	Left	Cochlear	Freedom	Freedom	ACE
CI 4	66	7	Right	Advanced Bionics	HiRes90k	Auria	HiRes
CI 5	77	14	Right	Advanced Bionics	Clarion II	Platinum BTE	ACE
CI 6	21	9	Right	Advanced Bionics	Clarion II	Platinum BTE	SAS
CI 7	53	4(R), 2(L)	Both (Test Right)	Cochlear	Freedom	Freedom	ACE
CI 8	68	8	Left	Cochlear	Freedom	Freedom	ACE
CI 9	71	1	Right	Cochlear	Freedom	Freedom	ACE
CI 10	39	3	Right	Cochlear	Freedom	Freedom	ACE
CI 11	40	6	Right	Cochlear	Nucleus 24 Contour	ESPrnt 3G	ACE
CI 12	49	4	Left	Cochlear	Freedom	Freedom	ACE
CI 13	49	9	Left	Advanced Bionics	Clarion II	Auria	MPS

Table 3

Mean Items Correct and Standard Deviation for AMICI (CI Listeners): Four Subtests and Total Score

		Subtest 1 (Max = 25)	Subtest 2 (Max = 30)	Subtest 3 (Max = 25)	Subtest 4 (Max = 20)	Total (Max = 100)
Form A	Mean	24.31	21.15	14.07	7.54	67.08
	SD	0.95	4.52	5.82	5.66	14.99
Form B	Mean	24.15	20.38	15.23	7.76	66.92
	SD	1.28	4.4	6.04	5.92	15.23
Form C	Mean	24.15	21.38	14.54	7.62	67.54
	SD	1.28	4	6.85	5.84	15.66
Retest	Mean	24.37	21.3	13.54	7.46	66.62
	SD	1.03	4.95	7.01	5.8	16.87
Mean		24.25	21.05	14.35	7.59	67.04
SD		1.14	4.47	6.44	5.81	15.69

Table 4

Confusion Matrix for Musical Instruments

Response	Instrument Presented											
	(String Family)			(Brass Family)			(Woodwind Family)			(Percussive Family)		
	Violin	Guitar	Trumpet	Tuba	Flute	Saxophone	Piano	Drums	F. Vocal	M. Vocal	Total	Total
Violin	74	2	5	3	6	3	1	1	5	0	100	100
Guitar	5	58	2	0	1	2	21	11	0	0	100	100
Trumpet	7	0	55	2	16	11	2	0	7	0	100	100
Tuba	1	6	6	74	0	3	1	5	2	2	100	100
Flute	37	0	6	0	39	4	5	0	8	1	100	100
Saxophone	2	1	23	6	6	56	1	0	4	1	100	100
Piano	2	7	0	0	1	3	87	0	0	0	100	100
Drums	0	0	0	0	0	0	0	100	0	0	100	100
F. Vocal	0	0	11	0	13	0	2	0	53	21	100	100
M. Vocal	5	2	2	0	0	0	0	0	16	75	100	100

Table 5

Confusion Matrix for Musical Styles

Response	Musical Style Presented					Total
	Latin	Jazz	Pop/rock	Classical	Country western	
Latin	44	20	20	7	9	100
Jazz	12	54	18	4	12	100
Pop/rook	7	10	49	12	22	100
Classical	9	4	2	81	4	100
Country western	10	17	10	11	52	100

Table 6

Correlations between AMICI Subtests and Speech Tests

	CNC	BKB-SIN
Subtest 1: Discrimination between Music vs. Noise	0.25	−0.49
Subtest 2: Identification of Musical Instruments	0.14	−0.87
Subtest 3: Identification of Musical Styles	0.28	−0.67
Subtest 4: Recognition of Musical Pieces	0.65	−0.81
AMICI Total	0.41	−0.71