Published in final edited form as:

J Am Acad Audiol. 2012 May ; 23(5): 350–379. doi:10.3766/jaaa.23.5.6.

Music Perception and Appraisal: Cochlear Implant Users and Simulated CI Listening

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Abstract

Background—The inability to hear music well may contribute to decreased quality of life for cochlear implant (CI) users. Researchers have reported recently on the generally poor ability of CI users' to perceive music, and a few researchers have reported on the enjoyment of music by CI users. However, the relation between music perception skills and music enjoyment is much less explored. Only one study has attempted to predict CI users' enjoyment and perception of music from the users' demographic variables and other perceptual skills (Gfeller et al., 2008). Gfeller's results yielded different predictive relationships for music perception and music enjoyment, and the relationships were weak, at best.

Purpose—The first goal of this study is to clarify the nature and relationship between music perception skills and musical enjoyment for CI users, by employing a battery of music tests. The second goal is to determine whether normal hearing (NH) subjects, listening with a CI-simulation, can be used as a model to represent actual CI users for either music enjoyment ratings or music perception tasks.

Research Design—A prospective, cross-sectional observational study. Original music stimuli (unprocessed) were presented to CI users, and music stimuli processed with CI-simulation software were presented to twenty NH listeners (CIsim). As a control, original music stimuli were also presented to five other NH listeners. All listeners appraised twenty-four musical excerpts, performed music perception tests, and filled out a musical background questionnaire. Music perception tests were the Appreciation of Music in Cochlear Implantees (AMICI), Montreal Battery for Evaluation of Amusia (MBEA), Melodic Contour Identification (MCI), and University of Washington Clinical Assessment of Music Perception (UW-CAMP).

Study Sample—Twenty-five NH adults (22 – 56 years old), recruited from the local and research communities, participated in the study. Ten adult CI users (46 – 80 years old), recruited from the patient population of the local adult cochlear implant program, also participated in this study.

Data Collection and Analysis—Musical excerpts were appraised using a 7-point rating scale and music perception tests were scored as designed. Analysis of variance was performed on appraisal ratings, perception scores, and questionnaire data with listener group as a factor.

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Presented at: Portions of this research were presented at American Academy of Audiology, AudiologyNOW!! 2009, Dallas, TX

Correlations were computed between musical appraisal ratings and perceptual scores on each music test.

Results—Music is rated as more enjoyable by CI users than by the NH listeners hearing music through a simulation (CIsim), and the difference is statistically significant. For roughly half of the music perception tests, there are no statistically significant differences between the performance of the CI users and of the CIsim listeners. Generally, correlations between appraisal ratings and music perception scores are weak or non-existent.

Conclusions—NH adults listening to music that has been processed through a CI-simulation program are a reasonable model for actual CI users for many music perception skills, but not for rating musical enjoyment. For CI users, the apparent independence of music perception skills and music enjoyment (as assessed by appraisals), indicates that music enjoyment should not be assumed and should be examined explicitly.

Keywords

music; cochlear implant; cochlear implant simulation; timbre; melody; appraisal

INTRODUCTION

Cochlear implants (CIs) restore substantial hearing in profoundly deafened adults and for these listeners, CI signal processing strategies enable good speech recognition in quiet. Music perception, however, for CI listeners is still relatively poor (Limb, 2006; Nimmons et al., 2008). Yet music is considered the most important non-speech sound processed by humans (Boucher & Bryden, 1997) and, like language, is universal. For post-lingually deafened CI users, the loss of music may contribute to a decreased quality of life, including negative emotional reactions and socio-situational limitations (Lassaletta et al., 2007; Zhao et al., 2008). Due to the strong links between musicality and speech prosody, music perception may have a role in perceiving semantics in tonal languages and in perceiving many paralinguistic properties, such as emotion, for non-tonal languages (Wong et al., 2007; Patel, 2008; Zatorre & Gandour, 2008). In addition, there is evidence that good music perception, specifically complex-pitch perception, is associated with good speech perception in noise (Won et al., 2010). Hence, good perception and enjoyment of music by CI users is greatly desired for increasing quality of life and improving speech communication (Drennan & Rubinstein, 2008).

Music perception skills in CI users have been studied for many years (Gfeller & Lansing, 1992; Pijl & Schwarz, 1995; Gfeller et al., 2002; Galvin et al., 2007; Looi et al., 2008; Nimmons et al., 2008), and generally CI users' skills for several key structures of music are poor. Compared to normal-hearing listeners, CI users are significantly less accurate in identifying direction of pitch change, musical timbre and familiar melodies (for a review, see McDermott, 2004). For example, when asked to recognize "real-world" musical excerpts in an open-set task, a group of 79 CI subjects yielded a mean score of 16% while NH listeners achieved 55% correct (Gfeller et al., 2005). The exception is perception of rhythm and tempo: CI users and NH listeners often perform comparably in perceiving these musical features (McDermott, 2004).

Musical enjoyment by CI users has also been studied (e.g., Gfeller et al., 2000), and in this literature, other terms have been used synonymously, e.g., 'music appreciation,' 'musical appraisal,' and 'musical pleasantness.' Typically, such 'musical enjoyment' has been evaluated in two ways: 1) through questionnaires in which CI recipients provide general attitudinal data based upon recollections of how music sounds, or how particular types of musical experiences sound (used commonly), and 2) through direct sound quality ratings by

CI recipients of actual musical stimuli (used rarely). Enjoyment of music is one of the most common hearing difficulties self-reported by CI users, even four years post-implantation (Zhao et al., 2008). Despite this, many CI users do enjoy and listen to music, though they listen less often than before deafness (Lassaletta et al., 2007; Migirov et al., 2009). Several studies have examined CI users' pre- and post-implantation listening habits and enjoyment of music (Zhao et al., 2008; Migirov et al., 2009). In other studies, the association between musical listening habits and quality of life has been explored (Lassaletta et al., 2007; Lassaletta et al., 2008a, 2008b; Zhao et al., 2008). Lassaletta et al. (2007) found a positive relation between quality of life (assessed with the Glasgow Benefit Inventory, GBI) and the reported quality of music heard through the implant, in their study of 65 CI users. Notably, there was no association between these CI users' GBI scores and their musical training or background.

Music appreciation or enjoyment, however, does not necessarily reflect highly-accurate music perception skills. This should not be surprising due to the subjective complexity of real-world musical enjoyment, which involves individual preferences, situational variables, cultural experiences, etc. (Gfeller et al., 2003). Music perception skills, by contrast, are often tested in laboratory settings using sounds that have restricted physical variation (e.g., a timbre identification experiment with each instrument playing exactly the same melody). For CI users, good music perception skills might be necessary, but not sufficient for high music appraisals. While it seems likely that a CI user with poor music perception skills would rate (appraise) music poorly, it is certainly conceivable for a CI user to perform well on various music perception tasks (e.g., could identify familiar melodies very accurately) and yet find listening to music unpleasant. Thus, these two types of assessments, music perception skills and musical appraisals, are not necessarily coincident and should be distinguished when examining CI benefit (Gfeller et al., 2008).

Only a few research studies have explored the relation between music perception skills and musical enjoyment in CI users. Gfeller et al. (2008), examined whether demographic, cognitive, life experience, and CI technology variables could predict either music perception skills or musical enjoyment for 209 CI users. In this study, musical enjoyment is determined by musical appraisal: CI users rated the pleasantness or likability of 24 musical excerpts using a scale of 0 to 100. At best, 7% of the variance in the subjects' appraisal ratings of instrumental music (i.e., without singing) could be predicted from any combination of independent variables. The two most predictive variables were music listening experience after implantation and performance on a visual monitoring task (VMT). Other combinations of variables accounted for somewhat higher percentages of the variance in these CI users' music perception skills. For example, hearing aid use, extensive musical training beyond basic lessons, and VMT performance accounted for 31% of the variation in Familiar Melody Recognition Performance. In general, though, these demographic, cognitive, life experience and CI technology variables were very poor predictors of music appraisals¹ and relatively poor predictors of music perception skills (recognizing familiar melodies, ranking pitch, recognizing timbre, etc.). In addition, the variables that predicted music perception skills were, for the most part, distinct from those that predicted (very weakly) music appraisals. This result may indicate that music perception skills and music appraisal are unrelated. Lassaletta et al. (2008b) assessed music perception skills (using the Primary Measures of Music Audiation, PMMA, test), and administered the GBI and a music questionnaire to 88 adult CI users. The music questionnaire included items on music listening habits, the quality of music heard through the patients' implants, and enjoyment of music. For these patients, the results of the PMMA music test were not associated with their reported enjoyment of

¹Speech perception scores are also not good predictors of music appraisals (Gfeller et al., 2008). Speech scores have no relation with appraisals of instrumental excerpts, and have a small contribution to appraisals of musical excerpts with lyrics.

music (Lassaletta et al., 2008b), consistent with the results of Gfeller et al. (2008) in that music perception skills and music appraisal (or enjoyment) seem to be unrelated.

Research efforts to improve music perception by CI users could be enhanced through a better understanding of the possible relations between music perception skills and music appraisal (or enjoyment). For example, if there was a strong correlation between performance in a certain task (e.g., timbre identification) and music appraisal ratings, then researchers could direct their efforts to improving performance in that particular task, with the knowledge that any improvement gained would also be associated with an improvement in musical enjoyment. Alternatively, if there are weak relations between music perception skills and musical enjoyment, then this is also an important result – as it would suggest the need for separate assessment of musical skills and musical enjoyment, as well as different clinical interventions, depending upon the desired ultimate benefit for individual CI users. In addition, knowledge of whether NH participants listening with a CI simulation perform similarly to actual CI users, for either music perception skills or music appraisal, would improve research efforts since NH participants are easier to recruit than CI users.

Thus, the goals of this study are 1) to further explore and clarify the nature and relation between CI users' music perception skills and their music appraisals, through use of a battery of music perception tests, and 2) to determine whether NH listeners perform similar to CI users, for either music perception skills or music appraisals, when listening to music processed through a CI simulation.

METHOD

Design

This was a prospective, cross-sectional observational study. All listeners appraised musical excerpts, performed several music perception tests, and completed a musical background questionnaire.

Subjects

Two groups of adult participants were recruited through collaborators' patient populations (e.g., an Adult Cochlear Implant Program), posted advertisements on campus kiosks, Washington University's Volunteers for Health (VFH) database, and word of mouth. All listeners use English as their primary language and have had experience predominantly with American music culture. The first group consisted of twenty-seven normal-hearing adults. All but two of the NH participants assigned to the simulation condition (CIsim12 and CIsim15) completed testing. The twenty-five NH adults (17 females, 8 males) who fully participated ranged in age from 22 to 56 years (mean = 31 yrs; SD = 10 yrs), and had bilateral, sound-field hearing thresholds of 25 dB HL or better at all octave frequencies from 250 to 8000 Hz. These listeners were divided into a sub-group that served as a control ("NH", N=5) for listening to unprocessed (original) music, and a sub-group who heard music that had been processed through a CI simulation program ("CIsim", N=20). Demographic details about the NH participants are given in Table 1. The second group of participants, the CI subjects, consisted of 10 post-lingually deafened adult users of the Cochlear Corporation CI system, who ranged in age from 46 to 80 years (mean = 60 yrs; SD = 13 yrs), had at least one year of implant experience, and did not use a hearing aid at the time of testing. Eight CI participants were unilateral CI users and wore no device in their other ear, while two CI participants (CI04, CI05) were bilateral CI users. Demographic details about the CI participants are shown in Table 2. All subjects received a token amount of remuneration for participating.

Music Appraisals

Appraisal ratings were elicited in a manner similar to that used in Gfeller (2003) and Gfeller (2008). Participants rated twenty-four musical selections, twelve musical excerpts with lyrics and twelve without lyrics (i.e., instrumental), using a Likert-like-scale. The musical selections represented equally three musical styles, namely classical, popular, and country western, and excerpts ranged in duration from 10 to 16 s. Excerpts were from songs written or released in the span of years from 1725 to 2004 AD. Participants were instructed to rate the musical pleasantness of each excerpt by making a vertical mark along a horizontal line with the descriptors “Extremely Unpleasant,” “Unpleasant,” “Somewhat Unpleasant,” “Indifferent,” “Somewhat Pleasant,” “Pleasant,” and “Extremely Pleasant.” The participants’ marks were converted to values ranging from -3 to +3.

Music Perception Tests

Four music perception tests were employed. These tests represent, at the time of planning this study, all the known and publicly-available music tests that were either designed for, or applied to CI recipients. The tests are: 1) Appreciation of Music in Cochlear Implantees (AMICI) (Spitzer et al., 2008), 2) Montreal Battery for Evaluation of Amusia (MBEA) (Peretz et al., 2003), 3) Melodic Contour Identification test (MCI) (Galvin et al., 2007), and 4) University of Washington Clinical Assessment of Music Perception (UW-CAMP) (Nimmons et al., 2008). Each is described briefly below.

AMICI

Developed by Spitzer, Mancuso, and Cheng (2008), the AMICI test consists of four subtests that assess discrimination of music versus noise, identification of musical instruments, identification of musical style, and open-set recognition of individual musical excerpts. The stimuli for the four subtests are recordings of real instruments and voices of varying style. In the noise versus music discrimination test, twenty-five trials were presented for which the listener responds whether the selection was music or noise (a one-interval, two-alternative forced choice, or 1I, 2AFC, task). The second subtest, identification of instruments, consisted of thirty trials in which the listener identified from a closed-set (trumpet, saxophone, piano, flute, drums/tympani, tuba, guitar, violin/strings, female vocal, male vocal) which instrument was used in the selection played (1I, 10AFC). Different musical instruments were represented by different musical pieces, and each instrument was represented by three different musical pieces. The third subtest, identification of musical style, consisted of twenty-five trials for which the listener identifies the musical category or style (classical, Latin, country and western, jazz, rock and roll/popular) for each selection played (1I, 5AFC). For the first three subtests, listeners responded on paper score-sheets by marking an ‘x’ in the appropriate box to indicate the answer. The last subtest, open-set identification of musical excerpts, consisted of twenty trials in which the listener was asked to verbally identify each selection by responding with the name of the song, its composer, a context in which it was used (such as a movie or advertisement), or by singing or humming the melody.

MBEA

Developed by Peretz, Champod, and Hyde (2003), the MBEA consists of six musical subtests (scale, contour, interval, rhythm, meter and memory) that evaluate music perception and memory skills along both melodic and temporal dimensions. As reflected in the title, this test was developed for assessing amusia, but has been employed recently with CI users and NH subjects listening via CI-simulation (Cooper et al., 2008). In each of the first four subtests (scale, contour, interval and rhythm), there are thirty trials in which two melodies are presented to the listener (2I, 2AFC). The listener responds, by marking an ‘x’ on a

response sheet, whether the two melodies sound the “same” or “different.” The fifth test, the meter test, has thirty trials in which a melodic pattern is presented and listeners are asked whether the pattern is in ‘duple’ or ‘triple’ meter (i.e., sounds like a ‘march’ or a ‘waltz,’ respectively). Always administered last, the sixth test - the melodic memory test - consists of 15 previously tested melodies and 15 unheard melodies, for a total of 30 trials. Participants are asked to identify whether the pattern just presented was heard previously during these MBEA tests. The fifth and sixth subtests are one-interval, two-alternative forced choice tasks (1I, 2AFC). All MBEA music stimuli were created with a MIDI sequencing program using a synthetic piano sound.

MCI

Developed by Galvin, Fu, and Nogaki (2007) for CI users, the MCI stimuli are synthetic sounds (3-tone complexes) with nine different five-note melodic contours. The nine melodic contours are: rising, rising-flat, rising-falling, flat-rising, flat, flat-falling, falling-rising, falling-flat, and falling pitch. In addition, the synthetic stimuli varied in two ways: by the lowest note (base-note) in the melody and by the size of the musical interval (number of semitones) between successive notes. Three different base-notes are used, A3 (220 Hz), A4 (440 Hz), and A5 (880 Hz). And, five different sizes of musical intervals are used, 1, 2, 3, 4 and 5 semitones. All variations (base-note and size of musical interval) are presented together in random order (9 contours $\times$ 3 base-notes $\times$ 5 interval sizes = 135 trials total). After each melody was presented, the listener responded, which of the melodic contours was heard, by selecting one of the nine contours displayed on a computer screen (1I, 9AFC).

UW-CAMP

Developed by Nimmons et al. (2008) for CI users, the UW-CAMP consists of three subtests: pitch-direction discrimination, melody identification, and timbre identification. The stimuli for all subtests consist of synthesized sounds. In the pitch-direction discrimination task, two synthetic notes (harmonic complexes) are presented in sequence, and listeners identify whether the first sound, or the second sound, had the higher pitch (2I, 2AFC). This task employs an adaptive procedure to estimate the just-noticeable-difference in fundamental frequency (corresponding to the 79%-correct level) for three different base frequencies (262, 330, and 391 Hz). The melody identification test employs twelve familiar melodies (e.g., “Jingle Bells,” “Three Blind Mice,” etc.) created without rhythm cues. Each melody was presented three times in random order for identification from a closed set, for a total of 36 trials (1I, 12AFC). For the timbre identification task stimuli, one melody is synthesized using eight different instruments: cello, piano, clarinet, saxophone, flute, trumpet, guitar, and violin. Each instrument sample was presented three times in random order for identification from a closed-set, for a total of 24 trials (1I, 8AFC). For all subtests, listeners responded by selecting items on a computer screen.

Musical Background Questionnaire

The musical background questionnaires developed by Cuddy et al. (2005) and Peretz (2011), designed for examining amusia, were revised slightly for use in this study with CI listeners. Participants answered an assortment of likert-scale, yes/no, multiple choice, and open-ended questions. NH listeners received a three-part questionnaire which contained sections entitled, ‘Early Experience,’ ‘Musical Training,’ and ‘Current Listening Habits/Possible Musical Difficulties’; CI listeners received these same parts along with an additional section, ‘Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss.’

Stimuli

Depending on the listener group, music stimuli for all the music tests and appraisals were either unprocessed or processed through a CI-simulation. All the CI listeners (CI01 – CI10) and 5 of the NH listeners (NH01 – NH05) were presented with the original (unprocessed) music stimuli. The remaining twenty NH listeners (CIsim01 – CIsim22) heard music stimuli that had been processed through publicly-available CI-simulation software (Fu, 2011). Parameter values for the CI-simulation were based on the results of Cooper et al. (2008) and Loizou et al. (1999). In Cooper et al. (2008), NH subjects' perceptual results on the MBEA music test were most similar to CI users' results when the NH subjects were listening via a six-channel CI-simulation vocoder (4-, 8-, 12- and 16-channel vocoders were also tested). Thus, a six-channel vocoder was employed here, with bandpass regions of 300–487 Hz, 487–791 Hz, 791–1284 Hz, 1284–2086 Hz, 2086–3387 Hz, and 3387–5500 Hz (6th-order Butterworth filters; slopes of 36 dB/oct) similar to those used by Loizou et al. (1999). Music stimuli were pre-emphasized (filter cutoff of 1200 Hz), envelope signals were low-pass filtered at 200 Hz, and white noise was used as the carrier signal.

Test Protocol

All testing was conducted in a single-walled booth. Delivery of the test stimuli was computer-controlled (a Dell Latitude XT or a Dell Inspiron 5150), and audio output was routed from the PC to a loudspeaker in the soundfield via a GSI 61 audiometer. The listener was positioned 41 inches from the loudspeaker straight ahead, and the presentation level was roughly 67 dB SPL at the position of the listener's head. Music perception tests were presented in a random order to each participant, with the music appraisals always occurring last. Participants were given the option of completing the tests in either one 3-hr session or in two 1½-hr sessions.

Statistical analyses include descriptive statistics for all data; appraisal ratings, music perception test scores, and questionnaire results. Additionally, appraisal ratings, music test scores, and questionnaire results from the three listener groups were subjected to non-parametric one-way ANOVAs (Kruskal-Wallis test), and post hoc analyses were completed using Mann-Whitney U tests with p-values adjusted with Bonferroni's correction. Finally, Spearman's rank correlations were computed between appraisals and each of the music test scores for the CI users and CIsim listeners, separately. Spearman's rank correlations were also computed amongst all the music test scores, again, for the CI users and CIsim listeners separately.

RESULTS

Music appraisals

Box-plots of individual listener's music appraisals are shown in Figure 1. Each box-plot, one per subject, represents graphically the distribution of appraisal ratings from that listener for all 24 musical excerpts. In addition, the average appraisal ratings for each participant are given in Tables 3, 4, and 5 for the NH, CIsim and CI listeners, respectively. An inspection of Figure 1 reveals that most listeners used a wide range of ratings across the excerpts. Exceptions are listeners CIsim18 and CIsim21 whose boxplots are rather short reflecting these listeners' use of a rather limited range of rating values. Generally, across the listener groups, music was rated more 'pleasant' by NH listeners (mean = 0.88, standard deviation = 1.48) and CI users (mean = 0.25, standard deviation = 1.53) than by CIsim listeners (mean = -0.51, standard deviation = 1.55). Overall, from the ANOVA analysis, there is a significant difference in appraisal ratings for the three groups ($\chi^2 = 14.92$, $df = 2$, $p = 0.001$). And, from post hoc analyses, significant differences were found for both contrasts with the CIsim listeners; CIsim listeners' ratings are lower than those of the CI users ($Z = -2.64$, $p = 0.007$).

and NH listeners ($Z = -3.13$, $p < 0.001$). CI users' appraisals, though lower on average, are not significantly different from those of the NH listener group ($Z = -2.27$, $p = 0.019$).

Music Perception Tests

Individual scores from all the music perception tests are given in Tables 3, 4 and 5, respectively, for the NH, CIsim and CI listeners. In addition, Figure 2 displays boxplots for 13 of the 14 music perception tests, for all three groups of listeners. Data from the pitch subtest of the UW-CAMP test are plotted separately in Figure 3. Similarly, boxplots are shown for all three listener groups. Table 6 contains results from the ANOVAs and post hoc analyses for all the music perception test scores. The results were significantly different across the three listener groups for all music tests except one; there are no differences in performance across the listener groups for the MBEA rhythm subtest. Not surprisingly, NH listeners performed very well overall. Post hoc analyses indicate NH listeners performed significantly better than CI users in all tests except the MBEA rhythm, and performed better than CIsim listeners in all tests except the MBEA rhythm and meter subtests.

The CI users and CIsim listeners performed similarly in six of the music perception tests, and differently in the other eight tests. Specifically, these two listener groups did not perform significantly different from each other for the AMICI genre, MBEA scale, MBEA rhythm, MBEA melody, UW-CAMP melody and UW-CAMP timbre subtests. For two subtests the CI users performed significantly better than the CIsim listeners (AMICI music vs. noise and AMICI timbre) while for the remaining six subtests these CI users performed more poorly than the CIsim listeners (AMICI melody, MBEA contour, MBEA interval, MBEA meter, MCI, and UW-CAMP pitch). For some subtests, many of the CI users and CIsim listeners could not perform the task, i.e., their performance was not significantly different from chance-level performance. For example, 15 (75%) of the 20 CIsim listeners performed at levels indistinguishable from chance on the MBEA scale subtest. On the other MBEA subtests - contour, interval, rhythm, meter, and melodic memory - 11 (55%), 13 (65%), 1 (5%), 0, and 13 (65%) of the CIsim listeners performed at levels indistinguishable from chance. Similarly, of the 10 CI users, 8 (80%), 7 (70%), 10 (100%), 0, 4 (40%), and 9 (90%), respectively, did not perform significantly above chance for those same six subtests.

Musical Background Questionnaires

The results of the questionnaires for the NH and CIsim listeners are reported in Table 1, and for the CI users in Table 7. Figure 4 displays boxplots of the musical background questionnaire scores, for all three listener groups, for the sections 'Early Experience', 'Musical Training', and 'Current Listening Habits/Possible Musical Difficulties.' There are no statistically significant differences amongst the three groups of listeners for the subsections 'Early Experience' and 'Musical Training' (Early Experience: $\chi^2 = 3.97$, $df = 2$, $p = .137$; Musical Training: $\chi^2 = 3.59$, $df = 2$, $p = .166$). When 'Listening Habits' refers to "Current" for the NH and CIsim listeners, and to "Pre-Hearing Loss" listening for the CI users, there are again no statistically significant differences amongst the three listener groups (Listening Habits: $\chi^2 = 4.90$, $df = 2$, $p = .086$). However, when 'Listening Habits' refers to "Post-Hearing Loss" (truly 'Current') for the CI users, then there are significant differences amongst the listener groups (Listen Habits: $\chi^2 = 16.07$, $df = 2$, $p < .001$); post hoc comparisons revealed significant differences between CI users' and both the NH and CIsim listeners' scores ($Z = -2.82$, $p = 0.003$ and $Z = -3.57$, $p < 0.001$). Finally, for the CI users only, a comparison of their pre- vs. post-Hearing Loss Listening Habits' questionnaire scores also yields a significant difference ($Z = -2.31$, $p = 0.021$).

General

For each of the music perception tests, a Spearman's rank correlation was computed between performance on that test and overall musical appraisal ratings. For the CI users' results ($N = 10$), all correlations are not significant: across the 14 music tests, correlations (ρ) range from -0.48 (MBEA melody vs. appraisal) to 0.62 (MBEA contour vs. appraisal). Similarly, for the CIsim listeners' data ($N = 20$), all 14 correlations are not significant, with the correlations ranging from -0.37 (UW-CAMP timbre vs. appraisal) to 0.28 (UW-CAMP melody vs. appraisal). Finally, Spearman's rank correlations were computed between the CI users' overall appraisal ratings and results from each of the four parts of the questionnaire (i.e., early experience, musical training, pre-HL music listening and current post-HL music listening). All four correlations were not significant.

To examine the possible relations amongst these music tests that have been administered to CI users, Spearman's rank correlations amongst all 14 music tests were examined for the CI users and CIsim listeners separately. For the CI users' results, a handful of correlations were found to be significant (see Table 8): AMICI Timbre vs. AMICI Genre ($\rho = .65$, $p < .05$), AMICI Timbre vs. MBEA Rhythm ($\rho = .71$, $p < .05$), AMICI Timbre vs. UW-CAMP Timbre ($\rho = .72$, $p < .05$), MBEA Meter vs. MBEA Melodic Memory ($\rho = .73$, $p < .05$), and MBEA Contour vs. UW-CAMP Pitch ($\rho = -0.80$, $p < .01$). For the CIsim listeners' results, 16 of the 84 possible correlations were found to be significant (see Table 9): four were significant at the .001 level, namely AMICI Genre vs. AMICI Melody ($\rho = .60$), AMICI Genre vs. MBEA Meter ($\rho = .62$), AMICI Melody vs. MCI ($\rho = .58$), and MBEA Meter vs. MCI ($\rho = .59$). Only one correlation was significant, in common, for both groups of listeners, MBEA Meter vs. MBEA Melodic Memory (CI users: $\rho = .75$, $p < .05$; CIsim: $\rho = .53$, $p < .05$).

DISCUSSION

Appraisals

CI users, despite listening with their implants, rated music as significantly more pleasant sounding than did listeners who heard music that had been processed through a CI simulation. To the best of our knowledge, there have been no other reports of musical appraisals with music stimuli that had been processed through a CI simulation. The lower ratings by CIsim listeners may be due, in part, to the limited experience these CIsim listeners had in hearing music (or any other kinds of sounds) that had been processed with the CI simulation. Overall, most NH listeners and CI users gave positive ratings to most musical excerpts (see Figure 1). Appraisals of musical excerpts are lower for CI users than for NH listeners, though the difference was not statistically different. A comparison of these CI users' appraisals to those of other studies are difficult because of differences in the musical excerpts² presented (not specified explicitly in Gfeller et al., 2003) and in the rating scale employed (Gfeller et al., 2008). The relative appraisal ratings of CI users and NH listeners in this study cannot be compared to those of others because most studies of music enjoyment and appraisal by CI users have not included results from NH listeners (e.g., Gfeller et al., 2008; Lassaletta et al., 2008b; Migirov et al., 2009). One possible exception is the very recent study by Brockmeier et al. (2011) in which both CI users and NH listeners performed all subtests of their newly-developed MuSIC test. Although explicit ratings of musical excerpts are not part of the MuSIC test, one MuSIC subtest requires listeners to rate the dissonance of chords using a scale of 1–10. Brockmeier et al. (2011) report that these ratings

²Due to the tremendous variety of musical genres across ages and cultures, and because of the predilections of individual listeners, the creation of a standard set of musical excerpts for appraisal ratings might be unachievable.

were not significantly different for CI users and NH listeners. They attributed this result to the CI users having adjusted and adapted their perceptions of pleasantness and dissonance.

Music Perception Tests

Across the subtests of the various music perception tests, CI users' performance ranges from very good (i.e., does not differ from NH listeners) to very poor (i.e., does not differ from chance-level performance). Consistent with well-known results from others, these CI users' ability to perceive musical rhythm is excellent (Gfeller & Lansing, 1991; Leal et al., 2003; Cooper et al., 2008). At the other extreme, some musical tests were so difficult that many CI users simply could not perform the task. For example, for our group of 10 CI users, 8, 7, and 10 had chance-level scores on the MBEA scale, contour, and interval subtests. This result is consistent and similar to the results of Cooper et al. (2008), in which 9, 11, and 11 of their group of 12 CI users also had chance-level scores on these same three MBEA subtests, respectively. For all six MBEA subtests (scale, contour, interval, rhythm, meter, melodic memory), average scores were 60, 61, 50, 81, 68, and 55 percent correct for the 10 CI users in this study, and 56, 61, 60, 81, 81, and 67 percent correct for the 12 CI users in Cooper's study. Across the two studies, CI users' performances are very similar (< 4 percentage points difference) for the scale, contour, and rhythm tests, and somewhat similar (10–13 percentage point differences) for the interval, meter and melodic memory subtests.

CI users' performance on the other musical tests, AMICI, MCI, UW-CAMP, are also fairly similar to those reported previously. For their 11 CI users, Spitzer et al. (2008) reported mean percent-correct scores of 92, 63, 62, and 44, respectively for the 4 subtests of the AMICI. Percent-correct scores from our 10 CI users are similar: 93, 58, 55, and 28, respectively. (NH listeners in Spitzer et al. and in this study also performed very similarly; percent-correct scores of 99.8, 94, 88, 87 and 100, 99, 96, 84 for the 4 subtests, respectively.) For the MCI task, Galvin et al. (2007) reported higher Melodic Contour Identification performance (mean = 53% correct, S.D. = 26.2; range: 14–91) for their group of 11 CI users than for our 10 CI users (mean = 30% correct, S.D. = 13.3; range: 12–54). This difference may be due to the relatively small numbers of participants in each study, and to the notably larger range in performance amongst the 11 CI users in the Galvin et al. study. And, for the UW-CAMP tests, the 8 CI users of Nimmons et al. (2008) performed, on average, somewhat better than the 10 CI users here. Mean percent-correct scores on the Melody and Timbre identification tests were 23 and 49 in Nimmons et al., and 14 and 37 in this study. The mean UW-CAMP pitch discrimination JNDs are about 3 semitones for Nimmons' CI users and about 4 semitones for the CI users here. Again, some of this difference may be attributable to the relatively small numbers of participants in each study, and consequent population-sampling differences. In addition, the extremely good performance of one particular listener skewed the mean scores reported by Nimmons et al. With the data from this one listener (L4) omitted, the means for the Melody and Timbre identification tests become 16 and 39% correct, which are nearly the same as those of the 10 CI users here.

Music perception for the CIsim listeners in the present study can also be compared to those of others, in particular to those in the Cooper et al. (2008) study for the 6-channel vocoder simulation condition. For the six MBEA subtests, our 20 CIsim listeners scored 63, 70, 63, 84, 91 and 64 percent correct while the 30 CIsim listeners of Cooper et al. had mean scores of 60, 67, 62, 85, 78 and 63, respectively. The only discrepancy between the two groups is for the Meter subtest; all other subtest scores are nearly the same. As expected, CIsim listeners' ability to perceive musical rhythm is excellent. Unlike the results for CI users, though, our CIsim listeners' ability to perceive musical meter (waltz vs. march, in this case) is also excellent, and is not significantly different from that of NH listeners. For the subtests scale, contour and interval, many of the CIsim listeners perform at chance levels, as was also

found for our 10 CI users. Specifically, 15, 11, and 13 of our 20 CIsim listeners did not perform significantly above chance for these three MBEA subtests. It is not possible to determine how many of the CIsim listeners in the Cooper et al. study performed at chance levels because individual scores are not reported. However, since group mean scores for CIsim listeners are very similar in both studies, one would expect that many of the 6-channel CI-simulation listeners in the Cooper et al. study performed at chance levels.

Questionnaire

Despite the significantly older mean age of the group of CI users in comparison to both the NH and CIsim listeners, these groups do not differ significantly from each other in any questionnaire category when the CI users' listening-habits responses are from their pre-HL period. Hence, our three listener groups are similar with respect to their early music experience, musical training, and music listening habits (pre-HL). Unsurprisingly, when the CI users' responses reflect their current post-HL listening habits the three groups of listeners do differ significantly; CI users (post-HL) report more difficulty listening to music than do either NH or CIsim listeners³. For the CI users alone, their current (post-HL) listening habits are significantly different from their pre-HL listening habits. This result is consistent with reports by others. For example, of the 53 participants in the study by Migirov et al. (2009), 2 listeners rated their pre-HL musical enjoyment with a '0' (did not enjoy music) and 26 listeners with a '10' (enjoyed music very much and often). After their HL and cochlear implant surgery, 6 listeners rated music with a '0' and only 14 listeners rated music with a '10'. Similarly, Lassaletta et al. (2008b) report that for 74 CI patients, on average, the number of hours spent listening to music and the number of patients who enjoy listening to music both decrease significantly in comparison to their pre-HL listening habits.

General

The primary goals of this study were to determine 1) whether music enjoyment of CI users, as assessed by appraisal ratings, are related to their music perception abilities, and 2) whether a CI simulation is an appropriate representation for actual CI users for music listening tasks. Here, we found no statistically significant correlations between appraisal ratings and music perception scores for either the CI users, or for the CIsim listeners. Thus, for these listeners and this set of music perception tests, no objective music test yields performance that is predictive of music appraisal ratings. However, it is difficult to achieve statistically significant correlations with relatively small numbers of participants, such as those here (i.e., 10 CI users and 20 CIsim listeners). This inability to predict appraisals is consistent, though, in a very general way with the results of Gfeller et al.'s study of music appraisals for a very large number (>100) of adult CI users. Gfeller et al., found that, at best, musical background, cognitive factors, speech perception scores and demographic variables could account for only about 7% of the variance in instrumental music appraisal ratings. Despite some major differences between these two studies, such as the number of subjects and the types of independent variables employed, both studies' results indicate that music appraisals are independent of other objective assessments, including those that employ music stimuli. As stated succinctly in Gfeller et al. (Gfeller et al., 2008), the assessment of music perception is quite unlike that of speech. To evaluate speech perception for CI users, accuracy of perception is the well-accepted criterion. Though there may be some debate about the exact type of speech materials that should be employed (e.g., isolated words vs.

³An important point about the body of data from the CIsim listeners: the appraisals and music perception tests were performed while listening to music that had been processed through a 6-channel vocoder simulation. However, these CIsim listeners' current-listening-habits questionnaire results reflect their listening with normal hearing, not their listening with a CI-simulation. In essence, the current listening habits' data of the 20 CIsim listeners should be considered simply as data from an additional 20 NH listeners. The other questionnaire sections, early musical experience and musical training, are independent of listening with or without a CI simulation.

words in sentences), few would argue about ‘percent words understood’ as the primary assessment measure. By contrast, for listening to music, there is no well-accepted assessment measure. Accuracy in identifying or discriminating particular musical characteristics (e.g., timbre, scale, etc.) represents one type of music listening criterion. But, another, equally important, music listening criterion is the likeability of music. And, for CI users, the latter seems to be unrelated to the former. The results in this study show no relation between a CI user’s performance on a specific music task, such as timbre identification or contour discrimination, and his/her rating of the pleasantness or likeability of music. In addition, the results show no relation between CI users’ ratings of the pleasantness of music and their reported musical ‘Listening Habits’ (post-HL). Thus, for CI users, assessments of music enjoyment or likeability should be done explicitly and directly.

The second goal of this study was to determine whether a CI-simulation is an appropriate representation for actual CI users. With regard to appraisals of musical excerpts, CIsim listeners rated music as sounding significantly less pleasant than did CI users, for both instrumental music and music with lyrics. This may be partly, or primarily, due to the chronic vs. acute listening experience of these two listener groups with sounds heard through a CI processor or simulation. CI users and CIsim listeners also differ in their assignments of frequency-to-electrode and frequency-to-place, respectively. Similar to most studies with a CI simulation, the analysis filters and noise bands in this CI simulation have identical frequencies. This represents the ideal (and rare) case for CI users, namely having an exact correspondence between the frequency range of the CI-front-end analysis filter and the characteristic frequencies of the neural population stimulated by the electrode assigned to that analysis filter. While there are reports of CI users adapting somewhat to various frequency-to-electrode allocation tables for speech perception (Fu, Shannon, & Galvin, 2002), there are no such reports for music perception. Appraisal ratings undoubtedly also reflect individual musical preferences (note the presence of some negative or unpleasant appraisals by NH listeners of high-fidelity music excerpts) and do not simply reflect sound quality. These results do indicate, however, that appraisals from NH adults listening to music that has been processed through a CI simulation program may not be representative of appraisals by actual CI users. Hence, for music appraisals, CIsim listeners are probably not a good representation for actual CI users.

With regard to objective music perception tests, the 6-channel CI-simulation program seems to provide an adequate model for CI users for roughly half of the music subtests examined here. There was not a statistically significant difference in performance between these 10 adult CI users and the 20 adult CIsim listeners for 6 of the 14 music tests, namely AMICI genre, MBEA scale, MBEA rhythm, MBEA melody, UW-CAMP melody and UW-CAMP timbre. For other music tests, performance was significantly different, but not always better for one group than the other. It is possible that CI-simulations with 4- or 8-channel processing would yield results in NH listeners similar to those of CI users for these other music tests. Overall, though, these results are consistent with those of Cooper et al. (2008): for many tests, listening to music that has been processed through a CI-simulation yields performance in NH listeners similar to that of CI users. This result holds not only for some subtests in the MBEA battery, as found by Cooper et al., but also for some subtests in the AMICI and UW-CAMP batteries. Thus, for some, but not necessarily all, music perception tests CIsim listeners can be used as a representation of CI users.

Within the last 4 years three different music tests have been developed explicitly for CI users, namely the AMICI (2008), MCI (2007) and UW-CAMP (2008) tests (by contrast, the MBEA battery was designed for amusia patients). Except for the MCI test, these newly-developed tests are batteries of music perception tests, and some subtests, at least in name, would appear to be similar across batteries. For example, both the AMICI and UW-CAMP

batteries contain a timbre identification test, and the AMICI, MBEA, and UW-CAMP batteries all include a test that requires melody identification or memory. Remarkably, though, there is very little correlation in performance across these 14 musical subtests for the CI users in this study (see Table 8). Only four correlations are significant at the .05 level, and one at the .01 level⁴. The UW-CAMP timbre and AMICI timbre tests are significantly correlated (Spearman's correlation = 0.72, $p < .05$) for these CI users. But other similarly-named subtests are not significantly correlated, such as AMICI melody and UW-CAMP melody. One might have also expected listeners with good pitch discrimination JNDs (UW-CAMP pitch) to perform well on the melodic contour identification (MCI) or the MBEA interval tasks, but this was not found for these 10 CI users.

Correlations amongst the music tests scores for the 20 CIsim listeners are similarly provided in Table 9. For these CIsim listeners, more correlations are statistically significant; 12 of the possible 91 correlations are significant at the .05 level and 4 at the .01 level. In contrast to the results for the CI users, for these CIsim listeners there is no significant correlation between their scores on the AMICI timbre and UW-CAMP timbre tests. In fact, there is only one significant correlation 'in common' for the CI users and CIsim listeners, namely the correlation between the MBEA meter vs. MBEA melodic memory tests. All other significant correlations are different for the two sets of listeners. This finding of different correlations amongst tests for different groups of listeners is consistent with a recent report by Brockmeier et al. (2011). They reported that for NH listeners, significant correlations are found amongst the scores of all the subtests in their newly-developed MuSIC battery, but that no significant correlations are found for scores from their group of CI users ($n = 31$). Certainly one possible reason for the mere handful of significant correlations amongst the music tests in this study is the relatively small number of participants, only 10 CI users and 20 CIsim listeners. It is also possible that these music tests are inherently unreliable. However, results for groups of CI users in this study and in other studies, for each test battery, are fairly consistent. Thus, it seems unlikely that the tests are inherently unreliable.

Another possible reason for the small number of significant correlations across music tests is that despite some similar-sounding names these 14 music tests really do reflect different abilities. Music listening requires a myriad of abilities, perhaps even more than speech perception, such as the abilities to hear simultaneously melody, timbre, lyrics, rhythm and other musical dynamics. Not only can these various aspects of music be combined in possibly infinite ways, but their perception may depend on the specific stimuli, response tasks, contextual cues, listener-dependent cultural traditions, etc. In the music tests examined here, similarly-named tests differed in their choice of melodies, use of synthetic vs. actual instruments, number of possible responses, etc. And, even when examining the same aspect of music perception, different tests may tax the listener in different ways. For example, two of the tests in this study seem to examine the same ability, namely distinguishing musical intervals. Yet, in detail they are very different. In the MBEA interval test the differences between melodies, for a seemingly-easy same-different task, are quite small and represent only one- or two-semitone intervals in a single restricted frequency range. By contrast, the MCI test also examines musical interval perception implicitly with contours, using a task with more choices (nine instead of two), but presents intervals with much larger semitone differences than those in the MBEA interval task, and examines several frequency ranges. Thus, researchers designing future studies of music perception by CI users should consider carefully which aspects of music perception their tests actually represent, and should consider which aspects are most appropriate for their research questions.

⁴Since there are 91 possible correlations, finding four significant correlations at the .05 level and one significant correlation at the .01 level are almost exactly the numbers that would be expected by chance (5% of 91 is 4.6 and 1% of 91 is 0.9).

While implants continue to show increased benefit of speech recognition in everyday listening situations, this is not the case with music perception and enjoyment (Gfeller et al., 2008). Accordingly, researchers seek new sound-processing strategies or techniques that might improve the perception of music by providing more melodic information. Examples include providing additional fine-structure information, enhancing fundamental frequency modulation depths, representing fundamental frequency by changing the stimulation rate, and using higher carrier and/or sampling rates (e.g., Zakis et al., 2007; Milcynski et al., 2009). However, until improvements in music perception are achieved in CI users, these generally poor music skills have implications for counseling with regard to device benefit for music (Gfeller et al., 2008). In addition, these results indicate that for CI users, performance on music perception tests may be unrelated to ratings of music pleasantness. And, that use of a CI-simulation program may not be a reasonable model for actual CI users for such musical appraisal ratings.

Acknowledgments

This research was supported by TL1 Predoctoral Training Grant, NIH/NCRR: TL1RR024995, NIDCD R21 DC008124, Valente Student Research Scholarship, and funds donated to the Hearing Rehabilitation and Cochlear Implant Program, Washington University in St. Louis. We are grateful to all the listeners who participated in this study, to Laura Holden for help recruiting participants, and to Dorina Kallogjeri for her statistical analyses and advice. This research was approved by the Human Research Protection Office of Washington University in St. Louis.

Abbreviations

AMICI	Appreciation of Music in Cochlear Implantees
CI	cochlear implant
MBEA	Montreal Battery for Evaluation of Amusia
MCI	Melodic Contour Identification
NH	normal hearing
CIsim	normal hearing listeners presented with music stimuli processed through a CI simulation
UW-CAMP	University of Washington Clinical Assessment of Music Perception

References

- Boucher R, Bryden MP. Laterality effects in the processing of melody and timbre. *Neuropsychologia*. 1997; 35(11):1467–1473. [PubMed: 9352524]
- Brockmeier SJ, Fitzgerald D, Searle O, Fitzgerald H, Grasmeder M, Hilbig S, et al. The MuSIC perception test: A novel battery for testing music perception of cochlear implant users. *Cochlear Implants International*. 2011; 12(1):10–20. [PubMed: 21756454]
- Cooper WB, Tobey E, Loizou PC. Music Perception by Cochlear Implant and Normal Hearing Listeners as Measured by the Montreal Battery for Evaluation of Amusia. *Ear Hear*. 2008
- Cuddy LL, Balkwill LL, Peretz I, Holden RR. Musical difficulties are rare: a study of “tone deafness” among university students. *Ann N Y Acad Sci*. 2005; 1060:311–324. [PubMed: 16597781]
- Drennan WR, Rubinstein JT. Music perception in cochlear implant users and its relationship with psychophysical capabilities. *Journal of Rehabilitation Research and Development*. 2008; 45(5):779–790. [PubMed: 18816426]
- Fu, QJ. Cochlear Implant and Hearing Loss Simulator. 2011. Retrieved April 25, 2011, from <http://www.tigerspeech.com/index.html>

- Fu QJ, Shannon RV, Galvin JJ. Perceptual learning following changes in the frequency-to-electrode assignment with the Nucleus-22 cochlear implant. *J Acoust Soc Am*. 2002; 112(4):1664–1674. [PubMed: 12398471]
- Galvin JJ, Fu QJ, Nogaki G. Melodic Contour Identification by Cochlear Implant Listeners. *Ear & Hearing*. 2007; 28(3):302–319. [PubMed: 17485980]
- Gfeller K, Christ A, Knutson J, Witt S, Mehr M. The effects of familiarity and complexity on appraisal of complex songs by cochlear implant recipients and normal hearing adults. *J Music Ther*. 2003; 40(2):78–112. [PubMed: 14505444]
- Gfeller K, Christ A, Knutson JF, Witt S, Murray KT, Tyler RS. Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. *J Am Acad Audiol*. 2000; 11(7):390–406. [PubMed: 10976500]
- Gfeller K, Lansing CR. Melodic, Rhythmic, and Timbral Perception of Adult Cochlear Implant Users. *Journal of Speech and Hearing Research*. 1991; 34:916–920. [PubMed: 1956198]
- Gfeller K, Oleson J, Knutson JF, Breheny P, Driscoll V, Olszewski C. Multivariate predictors of music perception and appraisal by adult cochlear implant users. *J Am Acad Audiol*. 2008; 19(2):120–134. [PubMed: 18669126]
- Gfeller K, Olszewski C, Rychener M, Sena K, Knutson JF, Witt S, et al. Recognition of “real-world” musical excerpts by cochlear implant recipients and normal-hearing adults. *Ear Hear*. 2005; 26(3):237–250. [PubMed: 15937406]
- Gfeller K, Turner C, Mehr M, Woodworth G, Fearn R, Knutson J, et al. Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults. *Cochlear Implants International*. 2002; 3(1):29–53. [PubMed: 18792110]
- Gfeller KE, Lansing CR. Musical perception of cochlear implant users as measured by the *Primary measures of music audiation*: an item analysis. *The Journal of Music Therapy*. 1992; 29:18–39.
- Lassaletta L, Castro A, Bastarrica M, Pérez-Mora R, Herrán B, Sanz L, et al. Changes in listening habits and quality of musical sound after cochlear implantation. *Otolaryngol Head Neck Surg*. 2008a; 138:363–367. [PubMed: 18312886]
- Lassaletta L, Castro A, Bastarrica M, Pérez-Mora R, Herrán B, Sanz L, et al. Musical Perception and Enjoyment in Post-Lingual Patients with Cochlear Implants. *Acta Otorrinolaringol Esp*. 2008b; 59(5):228–234. [PubMed: 18501158]
- Lassaletta L, Castro A, Bastarrica M, Pérez-Mora R, Madero R, de Sarriá J, et al. Does music perception have an impact on quality of life following cochlear implantation? *Acta Otolaryngologica*. 2007; 127:682–686.
- Leal MC, Shin YJ, Laborde ML, Calmels MN, Verges S, Lugardon S, et al. Music perception in adult cochlear implant recipients. *Acta Otolaryngol*. 2003; 123(7):826–835. [PubMed: 14575398]
- Limb CJ. Cochlear implant-mediated perception of music. *Curr Opin Otolaryngol Head Neck Surg*. 2006; 14(5):337–340. [PubMed: 16974148]
- Loizou PC, Dorman M, Tu Z. On the number of channels needed to understand speech. *J Acoust Soc Am*. 1999; 106(4):2097–2103. [PubMed: 10530032]
- Looi V, McDermott H, McKay C, Hickson L. Music perception of cochlear implant users compared with that of hearing aid users. *Ear Hear*. 2008; 29(3):421–434. [PubMed: 18344870]
- McDermott HJ. Music Perception with Cochlear Implants: A Review. *Trends in Amplification*. 2004; 8(2):49–82. [PubMed: 15497033]
- Migirov L, Kronenberg J, Henkin Y. Self-Reported Listening Habits and Enjoyment of Music Among Adult Cochlear Implant Recipients. *Annals of Otolaryngology, Rhinology & Laryngology*. 2009; 118(5):350–355.
- Milcynski M, Wouters J, Wieringen Av. Improved fundamental frequency coding in cochlear implant signal processing. *J Acoust Soc Am*. 2009; 125(4):2260–2271. [PubMed: 19354401]
- Nimmons GL, Kang RS, Drennan WR, Longnion J, Ruffin C, Worman T, et al. Clinical assessment of music perception in cochlear implant listeners. *Otol Neurotol*. 2008; 29(2):149–155. [PubMed: 18309572]
- Patel AD. Science & music: talk of the tone. *Nature*. 2008; 453(7196):726–727. [PubMed: 18528382]
- Peretz, I. Amusia Demo. 2011. Retrieved April 25, 2011, from <http://www.brams.umontreal.ca/amusia-demo/>

- Peretz I, Champod AS, Hyde K. Varieties of musical disorders. The Montreal Battery of Evaluation of Amusia. *Annals of the New York Academy of Science*. 2003; 999:58–75.
- Pijl S, Schwarz DWF. Intonation of musical intervals by deaf subjects stimulated with single bipolar cochlear implant electrodes. *Hear Res*. 1995; 89(1–2):203–211. [PubMed: 8600127]
- Spitzer JB, Mancuso D, Cheng MY. Development of a Clinical Test of Musical Perception: Appreciation of Music in Cochlear Implantees (AMICI). *Journal of the American Academy of Audiology*. 2008; 19(1):56–81. [PubMed: 18637410]
- Won JH, Drennan WR, Kang RS, Rubinstein JT. Psychoacoustic Abilities Associated With Music Perception in Cochlear Implant Users. *Ear & Hearing*. 2010; 31(6):796–805. [PubMed: 20595901]
- Wong PCM, Skoe E, Russo NM, Dees T, Kraus N. Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience*. 2007; 10(4):420–422.
- Zakis JA, McDermott HJ, Vandali AE. A fundamental frequency estimator for the real-time processing of musical sounds for cochlear implants. *Speech Communication*. 2007; 49:113–122.
- Zatorre RJ, Gandour JT. Neural specializations for speech and pitch: moving beyond the dichotomies. *Philos Trans R Soc Lond B Biol Sci*. 2008; 363(1493):1087–1104. [PubMed: 17890188]
- Zhao F, Bai Z, Stephens D. The relationship between changes in self-rated quality of life after cochlear implantation and changes in individual complaints. *Clinical Otolaryngology*. 2008; 33:427–434. [PubMed: 18983375]

Figure 1.

Boxplots of music appraisal ratings (across the 24 musical excerpts) for individual subjects in each of the three listener group. Each boxplot represents the distribution of appraisal ratings for all 24 musical excerpts from an individual listener. NH listeners' data are shown with dark-gray-filled boxes, CIsim listeners with unfilled boxes, and CI users with light-gray-filled boxes. For each box-plot, the median, 25th- and 75th- percentiles are represented by the central mark, bottom-edge and top-edge of the box, respectively. Vertical dashed lines extend to extreme data points ("whiskers") that are not considered outliers. Outliers are represented by bold '+' signs, and are data points that lay outside $\pm 2.7\sigma$.

Figure 2. Boxplots of percent-correct scores for 13 of the music perception tests for the three listener groups. Each boxplot represents the distribution of test scores across a group of listeners. NH listeners' data are shown with dark-gray-filled boxes, CIsim listeners with unfilled boxes, and CI users with light-gray-filled boxes. See Figure 1 caption for a description of boxplot features. *Denotes a music perception test for which the scores are significantly different between the CIsim listeners and CI users.

Figure 3.

Boxplots of the UW-CAMP Pitch test (discrimination results) for the three listener groups. NH listeners' data are shown with the dark-gray-filled box, Clsim listeners with the unfilled box, and CI users with the light-gray-filled box. See Figure 1 caption for a description of boxplot features. *Indicates that the pitch discrimination results are significantly different between the Clsim listeners and CI users.

Figure 4.

Boxplots of scores from Parts A, B, and C of the Musical Background Questionnaire, for the three listener groups. NH listeners' data are shown with the dark-gray-filled boxes, CIsim listeners with the unfilled boxes, and CI users with the light-gray-filled boxes. CI users have two scores for Part C, "Listening Habits/Possible Musical Difficulties." They have "Current Listening Habits/Possible Musical Difficulties" and "Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss." See Figure 1 caption for a description of boxplot features.

*Indicates that the questionnaire scores for "Current Listening Habits" are significantly different between the CIsim listeners and CI users.

Table 1

Demographic information and music questionnaire values for normal-hearing subjects in the NH (control) and CIsim listener groups.

Subject ID	Gender	Age at test (yrs)	Music Questionnaire Values		
			A: Early Experience	B: Musical Training	C: Current Listening Habits/Possible Musical Difficulties
NH01	F	26	14	33	91
NH02	F	24	19	27	57
NH03	M	29	32	46	76
NH04	F	56	22	51	78
NH05	M	26	27	97	91
Mean		32.2	22.8	50.7	78.6
St Dev		13.4	7.0	27.6	14.0
CIsim01	F	24	20	44	67
CIsim02	M	27	13	1	63
CIsim03	F	23	15	61	81
CIsim04	F	28	22	64	82
CIsim05	F	50	25	22	62
CIsim06	F	32	34	432	75
CIsim07	F	22	20	45	85
CIsim08	M	28	11	52	54
CIsim09	M	23	17	32	74
CIsim10	F	23	18	28	74
CIsim11	F	27	13	31	48
CIsim12	F	23	30	130	72
CIsim14	M	24	8	54	48
CIsim16	F	28	10	32	59
CIsim17	F	45	19	44	80
CIsim18	M	52	17	35	60
CIsim19	F	25	22	61	83
CIsim20	M	26	7	45	56
CIsim21	F	49	3	1	59
CIsim22	F	29	13	28	75
Mean		30.4	16.6	63.3	67.6

Subject ID	Gender	Age at test (yrs)	Music Questionnaire Values		
			A: Early Experience	B: Musical Training	C: Current Listening Habits/Possible Musical Difficulties
St Dev		9.9	7.3	87.2	11.2

Table 2

Demographic information and implant characteristics for the CI participants.

Subject ID	Gender	Age test (yrs)	Etiology	Duration of HL (yrs)	Duration of PHL (yrs)	CI experience (yrs)	CI Ear	Processor	Strategy	Stim Rate (Hz)	CNC Word Score
CI01	F	46	Unknown	18	14	3	R	Nucleus Freedom	ACE	900	48
CI02	F	57	Unknown	35	10	5	L	ESPril 3G	ACE	900	54
CI03	F	49	Unknown	33	16	6	L	ESPril 3G	ACE	900	78
CI04	M	59	Noise exposure	25	15	3	B*	Nucleus Freedom	ACE	1800	41
CI05	M	50	Unknown	47	43	3	B	Nucleus Freedom	ACE	1800	52
CI06	F	60	Otosclerosis	45	10	6	L	Nucleus Freedom	ACE	900	75
CI07	F	80	Unknown	20	15	6	L	Nucleus Freedom	ACE	1200	62
CI08	M	74	Unknown	15	13	11	L	Sprint	ACE	1800	82
CI09	F	48	Unknown	43	30	10	R	Nucleus Freedom	SPEAK	250	96
CI10	F	79	Unknown	9	9	8	R	Nucleus Freedom	ACE	1800	50
Mean		60.2		28.2	16.7	6.1					63.8
St Dev		13.0		15.0	11.7	2.9					17.9

Duration of HL: Duration of Hearing Loss; Duration of PHL: Duration of Profound Hearing Loss; B: Bilateral; R: Right; L: Left; Stim Rate: Stimulation Rate; CNC Word Score: in quiet, near time of music testing (percent correct). B*: CI04 is a bilateral user, but was tested with only the Left implant because this participant's experience with the Right implant was one month.

Table 3

Average appraisal ratings (Avg Appr) for the NH listeners. Perceptual scores for the NH listeners for each subtest of the four music perception tests. AMICI subtests are Music v Noise, Timbre, Genre, and Melody. MBEA subtests are Scale, Contour, Interval, Rhythm, Meter, and Melodic Memory. UW-CAMP subtests are Pitch Melody, and Timbre. All scores are percent-correct, except for the UW-CAMP Pitch subtest.

Subj ID	Avg Appr	AMICI				MBEA				MCI				UW-CAMP			
		Music v Noise	Timbr	Genre	Mldy	Scale	Contour	Interv	Rhym	Meter	Mem	Pitch	Mldy	Pitch	Mldy	Timbr	Timbr
NH01	1.4	100	97	96	85	90	81	87	87	87	87	84	81	50	81	71	71
NH02	1.1	100	100	96	90	90	84	94	84	90	87	96	75	69	75	83	83
NH03	0.7	100	100	100	90	94	84	87	90	97	97	100	97	52	97	75	75
NH04	0.3	100	100	88	60	87	84	94	87	100	90	94	97	69	97	83	83
NH05	0.9	100	100	100	95	94	87	94	94	100	100	100	100	50	100	96	96
Mean	0.88	100	99	96	84	91	84	91	88	95	92	95	90	58	90	82	82
StDev	0.42	0.0	1.3	4.9	13.9	3.0	2.1	3.8	3.8	6.0	6.0	6.7	11.2	1.0	11.2	9.6	9.6

Values for the UW-CAMP Pitch subtest are the just-noticeable-difference, in semitones, for a pitch direction discrimination task. Timbr: Timbre; Mldy: Melody; Interv: Interval; Rhym: Rhythm; Mem: Melodic Memory.

Table 4

Average appraisal ratings (Avg Appr) for the Clsim listeners. Perceptual scores for the Clsim listeners for each subtest of the four music perception tests. Music subtests names and labels are the same as those in Table 3.

Subj ID	Avg Appr	AMICI				MBEA				MCI			UW-CAMP		
		Music v Noise	Tmbr	Genre	Mldy	Scale	Contour	Interv	Rhym	Meter	Men	Pitch	Mldy	Tmbr	
Clsim01	-1.0	60	30	44	55	65	65	58	74	97	77	74	7.7	11	67
Clsim02	-0.2	92	70	60	45	68	77	74	87	90	73	58	6.0	8	46
Clsim03	-1.4	88	37	64	45	48	77	71	97	100	83	89	6.3	6	46
Clsim04	-0.9	60	37	36	40	61	68	71	84	87	83	71	5.1	0	58
Clsim05	0.9	56	27	32	35	58	68	58	84	83	53	39	6.2	14	13
Clsim06	0.6	88	50	76	75	52	74	61	100	93	63	85	5.5	17	54
Clsim07	0.5	84	60	84	50	52	74	58	94	100	80	89	5.3	25	25
Clsim08	-0.7	76	27	68	70	71	71	52	87	100	63	91	5.3	14	42
Clsim09	-0.2	68	33	40	15	65	68	61	81	93	60	79	5.5	25	21
Clsim10	-0.1	72	27	68	55	68	68	61	71	90	67	68	5.3	8	38
Clsim11	0.1	80	33	44	45	68	65	55	90	93	77	51	5.7	6	54
Clsim12	-0.4	88	23	40	30	74	61	48	77	87	43	61	5.9	11	29
Clsim14	-0.8	64	40	40	40	58	77	74	94	90	67	74	5.9	17	29
Clsim16	-0.4	60	53	48	20	58	77	74	71	90	73	24	5.9	14	21
Clsim17	-1.4	72	27	40	40	61	68	61	97	97	50	24	5.5	11	25
Clsim18	0.3	76	67	28	35	71	65	74	74	87	60	32	7.6	8	4
Clsim19	-0.6	96	23	72	70	74	90	74	90	97	67	89	5.2	19	50
Clsim20	-0.9	84	47	48	30	52	55	58	65	83	53	45	4.3	6	42
Clsim21	-1.3	96	40	16	45	52	58	61	84	80	37	54	6.3	11	29
Clsim22	-2.4	76	47	44	35	77	71	55	77	77	53	70	5.8	11	67
Mean	-0.51	76.8	39.9	49.6	43.8	62.7	69.9	63.0	83.9	90.7	64.1	63.4	5.8	12.1	38.0
St Dev	0.79	12.6	14.3	17.7	15.7	8.7	7.9	8.4	10.0	6.7	13.1	21.8	0.8	6.3	17.5

Table 5

Average appraisal ratings (Avg Appr) for the CI listeners. Perceptual scores for the CI listeners for each subtest of the four music perception tests. AMICI subtests are Music v Noise, Timbre, Genre, and Melody. MBEA subtests are Scale, Contour, Interval, Rhythm, Meter, and Melodic Memory. UW-CAMP subtests are Pitch Melody, and Timbre. All scores are percent-correct, except for the UW-CAMP Pitch subtest.

Subj ID	Avg Appr	AMICI				MBEA				MCI				UW-CAMP		
		Music vs Noise	Timbr	Genre	Mldy	Scale	Contour	Interv	Rhym	Meter	Mem	Pitch	Mldy	Pitch	Mldy	Timbr
CI01	0.5	96	40	48	35	55	71	58	74	53	40	16	22	2.8	22	33
CI02	0.7	92	70	72	20	55	74	61	81	83	60	24	3	2.2	3	33
CI03	0.8	96	73	64	40	71	58	26	81	57	57	23	17	4.9	17	67
CI04	0.2	88	53	56	15	52	58	48	81	40	47	44	6	2.3	6	29
CI05	0.3	96	53	32	20	58	55	42	77	70	57	33	11	2.9	11	42
CI06	-0.3	92	63	40	55	52	55	58	90	87	63	20	17	4.7	17	42
CI07	0.4	84	70	68	35	65	74	61	81	77	43	54	25	2.2	25	54
CI08	0.4	100	47	60	30	58	52	55	77	50	50	40	8	5.0	8	8
CI09	0.1	96	67	60	20	55	55	39	90	80	70	34	17	4.8	17	38
CI10	-0.6	88	47	52	5	77	55	48	74	87	60	12	11	6.9	11	21
Mean	0.25	92.8	58.3	55.2	27.5	59.8	60.7	49.6	80.6	68.4	54.7	30	13.7	3.9	13.7	36.7
St Dev	0.43	4.9	11.7	12.5	14.4	8.5	8.7	11.4	5.7	17.1	9.5	13.3	7.1	1.6	7.1	16.4

Values for the UW-CAMP Pitch subtest are the just-noticeable-difference, in semitones, for a pitch direction discrimination task. Timbr: Timbre; Mldy: Melody; Interv: Interval; Rhym: Rhythm; Mem: Melodic Memory.

Table 6

Result of statistical tests on the music perception scores. For the non-parametric ANOVA (Kruskal-Wallis) results, the number shown is χ^2 , followed by the p-value; the number of degrees of freedom is 2 for all tests.

		ANOVA (Kruskal-Wallis)		Post hoc (Mann-Whitney)	
Music Test		CI vs. CIsim	CI vs. NH	CI vs. NH	CI vs. NH
AMICI	Music v Noise	20.38* p < .001	-3.32* p < .001	-2.88* p = .003	-3.42* p < .001
	Timbre	19.33* p < .001	-3.03* p = .002	-3.10* p = .001	-3.41* p < .001
	Genre	13.24* p = .001	-0.95 p = .350	-3.07* p = .001	-3.41* p < .001
	Melody	16.38* p < .001	-2.50* p = .011	-3.08* p = .001	-3.21* p < .001
MBEA	Scale	13.18* p = .001	-0.87 p = .397	-3.08* p = .001	-3.41* p < .001
	Contour	15.64* p < .001	-2.44* p = .015	-3.11* p = .001	-3.08* p = .001
	Interval	18.49* p < .001	-2.81* p = .005	-3.08* p = .001	-3.44* p < .001
	Rhythm	3.49 p = .175	-0.97 p = .350	-2.24 p = .028	-0.92 p = .371
	Meter	16.67* p < .001	-3.72* p < .001	-2.95* p = .001	-1.17 p = .272
	Melodic Memory	15.46* p < .001	-1.99 p = .049	-3.07* p = .001	-3.41* p < .001
MCI	-	19.98*	-3.43*	-3.07*	-3.06*

Music Test	ANOVA (Kruskal-Wallis)		Post hoc (Mann-Whitney)	
	CI vs. NH	CI vs. NH	CI vs. NH	CI vs. NH
UW-CAMP	p < .001	p < .001	p = .001	p = .001
	21.25*	-3.43*	-3.12*	-3.41*
	p < .001	p < .001	p = .001	p < .001
Melody	12.93*	-0.58	-3.08*	-3.42*
	p = .002	p = .588	p = .001	p < .001
Timbre	12.59*	-0.18	-3.07*	-3.40*
	p = .002	p = .88	p = .001	p < .001

An asterisk indicates a statistically significant result ($p < .05$). For the non-parametric Mann-Whitney U post hoc comparisons, the number shown is “Z” followed by the p-value. An asterisk indicates a statistically significant result ($p < .017 = .05/3$, the Bonferroni correction).

Table 7

Music questionnaire values for CI users. The higher the value, the more experience/training and less difficulty with music a person has.

Subject ID	Music Questionnaire Values			
	A: Early Experience	B: Musical Training	C1: Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss	C2: Current Listening Habits/Possible Musical Difficulties
CI01	7	33	47	46
CI02	12	30	49	40
CI03	13	32	44	51
CI04	25	90	83	39
CI05	15	17	44	44
CI06	16	6	62	50
CI07	21	39	82	77
CI08	11	25	55	46
CI09	19	34	56	27
CI10	13	4	82	43
Mean	15.2	30.9	60.4	46.3
St Dev	5.3	23.9	16.1	12.7

Table 8

Spearman’s rank correlations amongst the 14 music perception tests, for scores from 10 CI users.

	AMICI Timb	AMICI Genre	AMICI Mel	MBEA Scale	MBEA Cont	MBEA Interv	MBEA Rhym	MBEA Meter	MBEA MelM	MCI	UW Pitch	UW Mel	UW Timb
AMICI vs. Noise	−0.22	−0.17	0.25	0.003	−0.5	−0.42	−0.15	−0.37	0.06	−0.11	0.47	−0.05	−0.09
AMICI Timbre	1	0.65*	0.31	0.10	0.43	−0.06	0.71*	0.26	0.31	0.30	−0.30	0.11	0.72*
AMICI Genre		1	0.03	0.23	0.51	0.23	0.29	−0.02	−0.04	0.41	−0.26	−0.10	0.10
AMICI Melody			1	−0.08	0.14	0.21	0.31	−0.01	−0.14	−0.09	−0.09	0.62	0.62
MBEA Scale				1	−0.06	−0.25	0.48	0.12	−0.10	−0.14	0.42	0.20	0.13
MBEA Contour					1	0.50	0.07	−0.03	−0.42	0.10	−0.80**	0.21	0.35
MBEA Interval						1	−0.05	0.20	−0.30	0.08	−0.61	0.05	−0.14
MBEA Rhythm							1	0.27	0.52	0.35	−0.23	0.09	0.48
MBEA Meter								1	0.73*	−0.47	0.13	0.11	0.19
MBEA Mel Mem									1	−0.30	0.42	−0.22	0.07
MCI										1	−0.44	−0.10	0.07
UW Pitch											1	−0.09	−0.30
UW Mel												1	0.60

* indicates significance at the .05 level, and

** indicates significance at the .01 level.

Table 9

Spearman’s rank correlations amongst the 14 music perception tests, for scores from 20 CIsim listeners.

	AMICI Timb	AMICI Genre	AMICI Mel	MBEA Scale	MBEA Cont	MBEA Interv	MBEA Rhym	MBEA Meter	MBEA MelM	MCI	UW Pitch	UW Mel	UW Timb
AMICI v. Noise	0.13	0.36	0.36	0.01	0.07	0.01	0.32	0.09	−0.14	0.26	−0.09	−0.05	0.22
AMICI Timbre	1	0.07	−0.15	−0.35	0.18	0.37	−0.03	−0.21	0.21	−0.17	0.21	−0.08	−0.06
AMICI Genre		1	0.60**	−0.06	0.56*	−0.04	0.27	0.61**	0.45*	0.56*	−0.44	0.24	0.35
AMICI Melody			1	−0.02	0.30	−0.01	0.49*	0.56*	0.37	0.58**	−0.18	0.11	0.50*
MBEA Scale				1	−0.05	−0.19	−0.39	−0.10	−0.18	−0.01	−0.07	−0.03	0.18
MBEA Contour					1	0.52*	0.50*	0.45*	0.48*	0.44	−0.07	0.42	0.10
MBEA Interval						1	0.12	0.03	0.31	−0.10	0.18	0.02	−0.19
MBEA Rhythm							1	0.56*	0.23	0.44	−0.09	0.27	0.14
MBEA Meter								1	0.53*	0.59**	−0.14	0.31	0.10
MBEA Mel Mem									1	0.40	−0.04	−0.17	0.38
MCI										1	−0.29	0.38	0.41
UW Pitch											1	−0.09	−0.21
UW Mel												1	−0.34

* indicates significance at the .05 level, and
** indicates significance at the .01 level.