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Predicting music enjoyment in cochlear implant users

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PREDICTING MUSIC ENJOYMENT IN COCHLEAR IMPLANT USERS

by

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Abstract: Most cochlear implant (CI) users perceive music poorly. Little is known, however, about the musical enjoyment received by CI users. The author examined possible relationships between musical enjoyment and music perception tasks through the use of 1) multiple musical tests, and 2) two groups of listeners: normal-hearing (NH) listeners with a CI-simulation and actual CI users. The two groups' performances are compared to determine whether NH participants listening to music via CI-simulation software are a good model for actual CI users for perceiving music.

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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 (Nimmons et al., 2008). Like language, music is universal and is considered the most important non-speech sound processed by humans (Boucher & Brydon, 1997). The importance of music, however, goes beyond perception or enjoyment. Consider a post-lingually deafened CI user for whom music is "lost." Hearing loss of any magnitude may give rise to poorer quality of life, including negative emotional reactions and socio-situational limitations (Monzani, Galeazzi, Genovese, Marrara & Martini, 2008). The "loss" of music for post-lingually deafened CI users may be yet another hardship contributing to decreased quality of life. For pre-lingually deafened CI users, good music perception may be important to develop rhythm and prosody in speech production and in the perception of speech of others. Musicality seems to be related to prosody, which can be important to semantics in tonal languages and to emotion in non-tonal languages (Patel, 2008; Zatorre & Gandour, 2008; Wong, Skoe, Russo, Dees & Kraus, 2007). Hence, good perception and enjoyment of music by all CI users is greatly desired.

The ultimate goal of research pertaining to music and cochlear implants is to improve CI users' enjoyment of music. An intermediate goal is to identify predictors of musical enjoyment in CI users so researchers and clinicians can try to improve CI devices and processing strategies. One step toward achieving this goal is to determine whether normal hearing (NH) subjects, listening with a CI-simulation, can be used as a model for real CI users – for music perception and appraisal tasks. This step is one aim of this Capstone Project. A second aim of this study is to examine the relations, if any, between music perception skills and musical enjoyment – for

both groups of listeners. That is, can music appraisal ratings be predicted from performance on any of the individual music perception skills.

In the context of success or benefit with a CI, it is important to distinguish between the accuracy of music perception and the appraisal of musical stimuli. In this context, accuracy of music perception refers to the ability to discriminate between complex pitch changes, identify familiar melodies, identify timbre of musical instruments, and perform other similar musical tasks. These will henceforth be called music perception skills. On the other hand, music appraisal simply refers to the enjoyment of music. Good music perception skills might be necessary, but not sufficient or required for good music appraisal. While it seems likely that a CI user who has poor music perception skills would also rate (appraise) music poorly, it is 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 unenjoyable and unpleasant (i.e., have a low appraisal of music). Thus, these two types of assessments, music perception skills and music appraisal, are not necessarily coincident.

Music perception skills have been studied in CI users (Looi, McDermott, McKay, & Hickson, 2008; Galvin, Fu, & Nogaki, 2007; Gfeller, Turner, Woodworth, Mehr, Fearn, Witt, & Stordahl, 2002) and generally, CI users' skills are poor. For example, compared to normal-hearing listeners, CI users are significantly less accurate in pitch perception, specifically in detecting pitch changes, identifying the direction of pitch change, and discriminating brief pitch patterns (McDermott, 2004). When asked to recognize "real-world" musical excerpts (in an open-set task), 79 CI subjects obtained a mean score of 16% (Gfeller, Olszewski, Rychener, Sena, Knutson, Witt & Macpherson, 2005). While the overall mean score was low, there were a few CI subjects who achieved a score of 94% on the same test. This suggests highly variable

music perception abilities are found among CI users. Only one study examined musical appraisal by CI users (Gfeller, Oleson, Knutson, Breheny, Driscoll, and Olszewski, 2008). For 209 CI users, Gfeller et al (2008) examined individual listener characteristics including cognitive measures, technical characteristics of the CI devices, environmental musical background, and experiences that might predict performance in the recognition and appraisal of musical excerpts. Their primary question concerned the predictability of music appraisal from these measures. To appraise music, listeners used a scale of 0 to 100 to rate the pleasantness or likability of 24 musical excerpts. In their results, the best predictors had only very weak relationships with music appraisal. At best, 7% of the variance in the appraisal ratings of music, without including singing, could be predicted from the best combination of the independent variables (which in this study was music listening experience after implantation and performance on a visual monitoring task). Interestingly, across these 209 CI users, there was substantial variation in music appraisals, with the mean, minimum and maximum ratings for instrumental excerpts reported as 49, 7, and 95 respectively; and for lyrical excerpts, the scores were 61, 28, and 96, respectively. In sum, for CI users music perception is generally poor and little is known about CI users musical enjoyment, especially how enjoyment may be related to other abilities.

The present study employed two adult listener groups. The first group consisted of listeners with normal hearing (NH), who heard music stimuli that had been processed through CI simulation software (http://www.tigerspeech.com/index.html). The second group consisted of post-lingually deafened CI users. All listeners performed several music perception tests, appraised musical excerpts and completed a musical background questionnaire. Results from the two listener groups were then: 1) compared to test whether the NH participants listening to music via CI simulation software are a good model for CI users, and 2) examined for relations, if any,

between music perception skills and music appraisal. This study differs from Gfeller et al. (2008), in the breadth of music perception tests employed and in the absence of any explicit cognitive measures.

Methods and Materials:

Design: This was a cross-sectional observational study.

Subjects: Twenty-seven normal-hearing (NH) adults were recruited, of these, two did not complete testing (Subjects CI_sim 13 and 15). Twenty-five normal-hearing adults (17 females, 8 males) participated. The age of these subjects ranged from 22 to 56 years (mean, 31 years; SD, 10), and had bilateral, soundfield hearing thresholds of 25 dB HL or better at all frequencies at octave intervals from 250 to 8000 Hz. Further details of the NH subject group are reported in Table 1. The CI subject group consisted of 10 post-lingually deafened adult users of the Nucleus CI system, ranging from 46 to 80 years (mean, 60 years; SD = 13), with a minimum of one year of implant experience. All CI users, except CI_orig 04 and 05, wear a CI in one ear and no device in the other. Subjects CI_orig 04 and 05 wear bilateral CIs. Demographic characteristic details of the CI subject group (CI_orig) are reported in Table 2. All listeners satisfied two requirements: 1) English is their primary language, and 2) had experience predominantly with American music culture. Participants were recruited through collaborators' patient populations (i.e., Adult Cochlear Implant Program), posted advertisements on campus kiosks, Washington University's Volunteers for Health (VFH) database, and word of mouth. Subjects were paid $10 an hour for participating.

All testing was conducted in a single-walled booth. Stimuli were presented via a loudspeaker in the soundfield, with the listener positioned approximately 41 inches from the loudspeaker straight ahead. The presentation level was 67 dB SPL at the position of the listener's head. Test stimuli was computer-controlled (a Dell Latitude XT or a Dell Inspriron 5150) and audio output from the PC was connected to a GSI 61 audiometer and directed to the loudspeaker.

Tests: The outcome variable was musical enjoyment, as measured by musical appraisal ratings. The predictor variables consisted of the scores obtained on various subtests of four publically-available music perception tests, a) Appreciation of Music in Cochlear Implantees (AMICI) (Spitzer, Mancuso, & Cheng, 2008), b) Montreal Battery for Evaluation of Amusia (MBEA) (Peretz, Champod, & Hyde, 2003), c) Melodic Contour Identification test (MCI) (Galvin, Fu, & Nogaki, 2007), and d) University of Washington Clinical Assessment of Music Perception (UW-CAMP) (Nimmons et al., 2008), as well as the results of a musical background questionnaire. Both outcome and predictor variables are described below.

Outcome (or Dependent) Variable

Musical Appraisal: Similar to the appraisals reported in Gfeller et al (2008) and Gfeller et al (2003), participants rated twenty-four musical selections, twelve with lyrical components and twelve without (instrumental), using a seven-point likert-scale. The musical selections equally represented three musical styles (classical, popular, and country western). A detailed list of the musical excerpts used in the appraisal can be found in Appendix A.

Predictor (or Independent) Variables

Appreciation of Music in Cochlear Implantees (AMICI): Developed by Spitzer, Mancuso, and Cheng (2008), the AMICI 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.

In the noise versus music discrimination test, twenty-five trials were presented in which the listener's task was to respond whether the selection was music or noise (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, and female vocal and male vocal) which instrument was used in the selection played (1I, 10AFC task). 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 was asked to identify the musical category or style (classical, Latin, country and western, jazz, rock and roll/popular) for each selection played (1I, 5AFC task). For the first three subtests, listeners responded on paper by marking an 'x' in the appropriate box-alternative 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.

Montreal Battery for Evaluation of Amusia (MBEA): Developed by Peretz, Champod, and Hyde (2003), the MBEA consists of six musical tasks (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 use in assessing amusia, but has been recently employed with CI users and NH subjects listening via CI-simulation (Cooper, Tobey & Loizou; 2008). The scale, contour, and interval tests measure pitch-based aspects of music. The rhythm and meter tests measure the perception of temporal aspects of music. In the first four tests (scale, contour, interval and rhythm), there are thirty experimental trials in which two melodies are presented to the listener, and the listener's task is to respond whether the two melodies sounded the "same" or "different", by marking an 'x' in the corresponding column on the response sheet. In each test, a catch trial, in which the comparison melody has pitch set at random, is presented to ensure participants are attentive. (These four tests are two-interval, two-alternative forced choice tasks, abbreviated as 2I, 2AFC.) For the fifth test, the meter test, there are thirty trials in which a melodic pattern is presented and listeners are asked whether the pattern is in 'duple' (sounds like a 'march') or 'triple' (sounds like a waltz) meter. 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. (These last two tests are one-interval, two-alternative forced choice tasks, abbreviated as 1I, 2AFC.) All music stimuli were created with a MIDI sequencing program delivered with a piano sound.

Melodic Contour Identification (MCI): Developed by Galvin, Fu, and Nogaki (2007) for CI users, the MCI consists of 135 trials of synthesized stimuli (3-tone complexes) with nine

different types of five-note melodic contours. There are nine contours: rising, rising-flat, rising-falling, flat-rising, flat, flat-falling, falling-rising, falling-flat, and falling pitch. The melodic contours vary 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). Also, 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 x 3 base-notes x 5 interval sizes = 135 trials). After each melody was presented, the listener was asked to identify which of the nine melodic contours was heard and to select one of the nine contours displayed on a computer screen. (This is a one-interval, nine-alternative forced choice task; 1I, 9AFC.)

University of Washington Clinical Assessment of Music Perception (UW-CAMP):
Developed by Nimmons, Kang, Drennan, Longnion, Ruffin, Worman, Yueh, and Rubinstein (2008) for CI users, the UW-CAMP consists of three subtests: pitch-direction discrimination, melody identification, and timbre identification. The stimuli for all three subtests consist of synthesized sounds.

In the pitch-direction discrimination task, a two-alternative forced-choice adaptive procedure is used. Two synthesized complex tones are presented, and listeners are asked to identify the sound with the higher pitch (2I, 2AFC task). The adaptive procedure used in this subtest finds the size of the difference in fundamental frequency (JND information) for which listeners correctly identify the pitch direction 79% of the time. This is found for three different base frequencies (262, 330, and 391 Hz). The melody identification test employs twelve familiar, synthesized, melodies that were created without rhythm cues. The twelve melodies are: "Frere Jacques", "Happy Birthday", "Here Comes the Bride", "Jingle Bells", "London Bridge",

"Mary Had a Little Lamb", "Old MacDonald", "Rock-a-Bye Baby", "Row Row Row Your Boat", "Silent Night", "Three Blind Mice", and "Twinkle Twinkle Little Star". Each melody was presented three times in random order for identification from a closed set, for a total of 36 trials (1I, 12AFC task). The timbre task consisted of a single melody played by eight different synthesized 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 task). For all subtests, listeners responded by selecting items on a computer screen.

Musical Background Questionnaire: Peretz's online questionnaire (http://www.brams.umontreal.ca/amusia-demo/) and Cuddy, Balkwill, Peretz, & Holden's (2005) questionnaire were designed for testing amusia. These questionnaires were revised in this study for use 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 that 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.' Full questionnaires (NH and CI versions) and scoring information can be found in Appendices B and C.

Stimuli: For the ten cochlear implant users (CI_orig), the stimuli are the original sounds provided with each test. For 20 of the 25 the normal hearing listeners, the stimuli were processed by a cochlear-implant simulation program (CI_sim in Table 1). This group of listeners are henceforth called CI_sim. The remaining five listeners (NH_orig in Table 1) with normal hearing performed all tests with the original (unprocessed) musical stimuli, the same as the

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CI_orig listener group. This group of five listeners are henceforth called NH_orig. In the Cooper et al (2008) study, the CI users' perceptual results for the MBEA tests were most similar to those of NH subjects listening via a six-channel CI-simulation vocoder. Thus, a six-channel vocoder was employed here. Other CI-simulation processing parameters are also similar to those used by Cooper et al (2008) and Loizou et al (1999). For the six-channel vocoder, the six bandpass regions are 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). White noise was the carrier, the signals were pre-emphasized (filter cutoff of 1200 Hz), and the envelope signals were low-pass filtered at 200 Hz. The processing was accomplished using publicly-available CI-simulation software from TigerSpeech and House Ear Institute (TigerCIS MFC Application).

Results:

Testing with unprocessed stimuli with NH listeners was completed before testing the other two groups (CI_sim and CI_orig) to confirm that NH listeners perform at 100% correct, or nearly so, when listening to the original stimuli. Appraisal ratings and perception scores for this group (NH_orig) are reported in Tables 3 and 4. The CI_sim and CI_orig group scores for the musical appraisal, all perception tasks, and the questionnaire are reported in Tables 5 through 9. Appraisal data are shown in Figure 1, results from music perception tests in Figures 2 and 3, and plots of questionnaire values are shown in Figure 4. Chance performance was calculated for each perception task, when applicable. The upper and lower 95% confidence intervals for chance performance on twelve tasks are provided in Table 10.

Musical Appraisal: Data in Tables 5 and 7 indicate that music is generally rated as more enjoyable by CI users (CI_orig) than by listeners hearing music through a simulation (CI_sim). This may be due, in part, to the limited experience with the CI simulation for the CI_sim listeners. For the NH_orig group (see Table 3), the overall, lyrical, and instrumental mean appraisal ratings were 0.88 (SD = 0.42), 0.89 (SD= 0.59), and 0.87 (SD = 0.49). For the CI_sim group, the corresponding mean appraisal rating were -0.51 (SD = 0.79), -0.86 (SD = 0.83), and -0.16 (SD = 0.81), respectively. For the CI_orig group, the corresponding mean appraisal ratings were 0.25 (SD = 0.43), 0.26 (SD = 0.48), and 0.23 (SD = 0.5). Differences on appraisal ratings between the CI_orig and CI_sim groups are statistically significant at the .001 level for overall and lyrical appraisal averages based on two-tailed, unequal variance t-tests. Figure 1 displays boxplots of appraisal ratings for individual listeners, in the listener groups NH_orig, CI_sim and CI_orig, for the 24 musical excerpts.

Nonparametric Spearman ρ correlation coefficients were obtained for each pair of appraisal ratings. The overall and lyrical, overall and instrumental, and lyrical and instrumental, correlations had r values of 0.95, 0.92 and 0.77 respectively. Scatterplots of the appraisal rating pairs can be found in Appendix D.

Appreciation of Music in Cochlear Implantees (AMICI): The mean NH_orig group performance was 100% (SD = 0), 99% (SD = 1%), 96% (SD = 5%), and 84% (SD = 14%) for the noise versus music, timbre identification, genre identification and open-set melody recognition subtests. For the CI_sim group, the mean scores were 77% (SD = 13%), 40% (SD = 14%), 50% (SD = 18%), and 44% (SD = 16%) correct, respectively. For the CI_orig group, the corresponding mean scores were 93% (SD = 5%), 58% (SD = 12%), 55% (SD = 13%), and 28% (SD = 14%) correct. For the CI_sim group, the number of individuals whose performance was

above chance for the subtests noise versus music, timbre and genre were fourteen, eighteen, and twelve individuals. For the CI_orig group, the corresponding number of individuals were ten, ten, and eight individuals, respectively.

Montreal Battery for Evaluation of Amusia (MBEA): As a baseline, the mean NH_orig group performances were 91% (SD = 3%), 84% (SD = 2%), 91% (SD = 4%), 88% (SD = 4%), 95% (SD = 6%) and 92% correct (SD = 6%) on the scale, contour, interval, rhythm, meter, and short-term memory subtests. For the CI_sim group, the corresponding mean scores were 63% (SD = 9%), 70% (SD = 8%), 63% (SD = 8%), 84% (SD = 10%), 91% (SD = 7%), and 64% (SD = 13%) correct, respectively. For the CI_orig group, the corresponding mean scores were 60% (SD = 8%), 61% (SD = 9%), 50% (SD = 11%), 81% (SD = 6%), 68% (SD = 17%), and 55% (SD = 9%) correct. Both listener groups' average performances are not different from what would be expected by chance alone for four of the six subtests – scale, contour, interval, and short-term memory. For the CI_sim group, the number of individuals whose performance was above chance for each of the subtests were five, nine, seven, nineteen, twenty, and seven individuals, respectively. For the CI_orig group, the corresponding number of individuals were two, three, zero, ten, six, and one.

Melodic Contour Identification (MCI): The mean NH_orig group performance was 95% (SD = 7%) on the MCI task. For the CI_sim group, the mean score was 64% (SD = 22%) and for the CI_orig group, the mean score was 30% (SD = 13%). Both listener groups' average performances were above what would be expected by chance alone. For the CI_sim group, all twenty individuals performed above chance. For the CI_orig group, 8 individuals performed above chance.

University of Washington Clinical Assessment of Music Perception (UW-CAMP): The mean NH_orig group performance was .58 semitones (SD = .1), 90% (SD = 11%), and 82% (SD = 10%) for the pitch, melody and timbre subtests. For the CI_sim group, the mean scores for the pitch, melody, and timbre subtests were 6 semitones (SD = 1 semitones), 12% correct (SD = 6%), and 38% (SD = 17%) correct, respectively. For the CI_orig group, the corresponding mean scores are 4 semitones (SD = 2 semitones), 14% correct (SD = 7%), and 37% (SD = 16%) correct. It should be noted that a smaller semitone difference corresponds to better pitch discrimination. Both CI_sim and CI_orig groups performed within 95% confidence interval for chance for the melody task, with the exception of two individuals from each group whose performances were above chance. Concerning the timbre task, eleven of the CI_sim group and seven of the CI_orig group performed above chance.

Musical Background Questionnaire: The mean NH_orig value for each of the music questionnaire subtests were 22.8 (SD = 7), 50.7 (SD = 27.6), and 78.6 (SD = 14). For the CI_sim group, the mean values were 16.6 (SD = 7.3), 63.3 (SD = 87.2), and 67.6 (SD = 11.2), respectively. For the CI_orig group, the corresponding mean scores were 15.2 (SD = 5.2), 30.9 (SD = 23.9), 60.4 (SD = 16.1), and 46.3 (SD = 12.7). Of these subscales, one subtest was significantly different between the CI_sim and CI_orig groups, "Current Listening Habits/Possible Musical Difficulties", p = .003. Figure 4 displays boxplots of musical background questionnaire totals for the listener groups NH_orig, CI_sim and CI_orig, for 'Early Experience', 'Musical Training', and 'Current Listening Habits/Possible Musical Difficulties', and 'Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss'.

CI_sim Perception Performance Compared with CI_Orig Perception Performance:

Performance on the musical perception tests are fairly similar for CI_orig and CI_sim listeners. The CI_sim and CI_orig subject group's mean scores across the perception tests are shown in Figure 2 and 3. Two-tailed, unequal variance t-tests with Bonferroni correction were applied to compare the two subject groups' performances. Of these 14 subtests, four yielded a significant difference, AMICI Subtest 1 (Music vs. Noise), AMICI Subtest 2 (Timbre Identification), MBEA Subtest 5 (Meter – Waltz vs. March), and MCI, $p < 0.003$ for all comparisons. Figure 2 displays boxplots for 13 of the 14 music perception tests, for the NH_orig, CI_sim and CI_orig listener groups. Figure 3 displays boxplots of the data from the pitch subtest of the UW-CAMP test.

Correlations amongst the Music Perception Tests:

Nonparametric Spearman ρ correlation coefficients were obtained for each pair of music perception tests to assess redundancy. Correlation tables for both CI_sim and CI_orig groups are reported in Tables 11 and 12. For both groups, most correlations amongst perception tasks are weak indicating either unreliability or little to no redundancy in these tests. The CI_sim music perception correlations ranged from r values of -0.45 to 0.63, with the three strongest correlations between AMICI subtest 3 (Genre) and MBEA subtest 5 (Meter), $r = 0.63$; AMICI subtest 3 (Genre) and MCI, $r = 0.61$; and AMICI subtest 3 (Genre) and MBEA subtest 2 (Contour), $r = 0.58$. The CI_orig music perception correlations ranged from r values of -0.83 to 0.71, with the three strongest correlations between AMICI subtest 1 (Music vs Noise) and Questionnaire C (Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss), $r = -0.83$;

MBEA subtest 2 (Contour) and UW-CAMP Pitch, $r = -0.73$; and AMICI subtest 2 (Timbre) and UW-CAMP Timbre, $r = 0.71$.

Predicting Appraisals from Music Perception Scores:

The CI_sim and CI_orig music perception scores and music appraisal scores were assessed. Nonparametric, Spearman ρ correlation coefficients were obtained; all correlations between performance on music perception tests and musical appraisals are weak (see last column of Tables 11 and 12). All scatterplots can be found in Appendix D.

Discussion

When speech recognition is the task of interest, then accuracy of speech recognition is the most obvious objective measure to use. But, when music is the signal of interest, it is not obvious what objective measure or tests should be used. The ability to recognize a musical excerpt can reflect an important outcome of cochlear implantation. In addition, whether the implant user finds a musical signal "pleasant" or "unpleasant" will determine whether he/she chooses to listen to music. Thus it is important to make the distinction between music perception and music appreciation, or enjoyment.

This study addressed whether a) music perception ability can predict music enjoyment and b) whether a CI-simulation is an appropriate model for actual CI users for music listening tasks. The results of this study show all correlations between performance on music perception tests and musical appraisals are weak (see Tables 11 and 12 and Figures in Appendix D). This

result is consistent with Gfeller et al (2008), in that good predictors of musical enjoyment are still unidentified.

With regard to whether a CI-simulation is an appropriate model for actual CI users, music is generally rated as more enjoyable by CI users (CI_orig) than by listeners hearing music through a simulation (CI_sim) for all music – lyrical and instrumental. This may be due, in part, to the limited experience with the CI simulation for the CI_sim listeners. Ratings may also reflect personal musical tastes and preferences, as is evidenced by some negative (unpleasant) appraisals, by NH_orig listeners, of high-fidelity music excerpts. Thus all listeners' musical ratings seem to reflect more than sound quality. Since performances on the musical perception tests are fairly similar for CI_orig and CI_sim listeners, it would seem that CI_sim listeners can be used as models for CI users for music listening tasks. For the music perception tests, ten of fourteen tests revealed no statistically significant difference between CI_orig and CI_sim listeners. The four perception tests that have a statistically significant difference are the AMICI music versus noise, AMICI timbre identification, MBEA meter, and MCI tests.

CI_orig performance on the AMICI test can be compared to those reported in Spitzer et al (2008). Scores seem to be similar with the exception of the open-set melody task. CI_orig group mean percentage scores were 93%, 58%, 55%, and 28% correct for the music versus noise, timbre, genre and melody tasks, respectively. Spitzer et al (2008) corresponding group mean percentage scores were 92%, 63%, 62% and 44% correct.

Parameters for the CI-simulator were adopted from Cooper et al (2008). Cooper's NH subjects listening through a CI-simulator with 6-channels, and the current CI_sim subjects show similar performance on the MBEA perception test, with a difference noted for the meter subtest.

Cooper et al (2008) mean percentage scores were 55%, 65%, 55%, 81%, 77% and 57% correct for the scale, contour, interval, rhythm, meter and short-term memory subtests, respectively. The current study's CI_sim subjects had corresponding scores at 63%, 70%, 63%, 84%, 91% and 64% correct. In addition, Cooper et al (2008) assessed CI users' performance on the MBEA test, with corresponding scores of 52%, 55%, 52%, 81%, 83% and 63% correct. The current study's CI_orig subjects had corresponding scores of 60%, 61%, 50%, 81%, 68%, and 55% correct. Likewise, with the exception of the meter task, performance was similar.

Concerning Melodic Contour Identification test, Galvin et al (2007) found very different results from the current study. The CI_orig group mean percentage for the MCI test was 30% correct, compared to Galvin et al (2007) 53% correct. In addition, only one CI_orig individual subject scored equivalent to the Galvin et al (2007) reported group average.

In Nimmons et al (2008), CI users' pitch threshold ranged from 1 to 11.5 semitones for the UW-CAMP pitch subtest, and their mean scores were 23% and 49% correct for the melody and timbre subtests. The current study's CI_orig subjects had pitch thresholds that ranged from 2 to 5 semitones and mean scores of 14% and 37% correct, respectively for the melody and timbre subtests.

In any study of cochlear implant users, a host of other factors should be considered that may affect an individual implantee's perceptual abilities, whether for music or other stimuli. These factors include a range of environmental, physiological, and pathological factors, such as memory for melodic pitches, music knowledge or training; the location, number, and density of surviving neurons in the cochlea; the electrode's placement or insertion depth; the impedance surrounding the electrodes; pathological processes; central processing factors; and the

stimulation mode used or electrical current path within the cochlea (Looi, McDermott, McKay & Hickson, 2008; McDermott, 2004).

While implants continue to show increased benefit of speech recognition in everyday listening situations, this is not the case with music perception and enjoyment as a result of incidental exposure to music in everyday life (Gfeller et al., 2008). Accordingly, researchers have been designing and evaluating a number of different sound-processing strategies or techniques that might improve the perception of music by providing more temporal information. Examples of these attempts include providing additional fine-structure information, enhancing the F0 modulation depths, representing the F0 by changing the stimulation rate, eliminating the phase shifts that occur when information is combined across electrode positions, or using higher carrier, and/or sampling rates (Looi et al., 2008, McDermott, 2004). However, until improvements in music perception are achieved in CI users, these generally poor music skills and low enjoyment ratings have implications for counseling with regard to device benefit and making cautious choices for listening experiences, as well as training to help patients optimize CI benefit for music (Gfeller et al., 2008). This study did not include any form of music rehabilitation or structured training program and none have been reported so far. Possible future studies could investigate whether specialized training improves music perception.

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Table 1: Demographic information and music questionnaire values for normal-hearing subjects in the NH_orig and CI_sim listener groups.

Subject ID	Gender	Age at time of testing (yrs)	A: Early Experience	B: Musical Training	C: Current Listening Habits/Possible Musical Difficulties
					Questionnaire Values
NH_Orig_01	F	26	14	33	91
NH_Orig_02	F	24	19	27	57
NH_Orig_03	M	29	32	45.75	76
NH_Orig_04	F	56	22	50.75	78
NH_Orig_05	M	26	27	97	91
Mean		**32.2**	**22.8**	**50.7**	**78.6**
St Dev		**13.42**	**6.98**	**27.58**	**13.97**
Median		**26**	**22**	**45.75**	**78**
CI_Sim_01	F	24	20	43.75	67
CI_Sim_02	M	27	13	1	63
CI_Sim_03	F	23	15	60.5	81
CI_Sim_04	F	28	22	64	82
CI_Sim_05	F	50	25	21.5	62
CI_Sim_06	F	32	34	431.5	75
CI_Sim_07	F	22	20	44.5	85
CI_Sim_08	M	28	11	52.25	54
CI_Sim_09	M	23	17	32	74
CI_Sim_10	F	23	18	27.5	74
CI_Sim_11	F	27	13	30.5	48
CI_Sim_12	F	23	30	130	72
CI_Sim_14	M	24	8	54	48
CI_Sim_16	F	28	10	31.5	59
CI_Sim_17	F	45	19	43.5	80
CI_Sim_18	M	52	17	35	60
CI_Sim_19	F	25	22	60.5	83
CI_Sim_20	M	26	7	45	56
CI_Sim_21	F	49	3	1	59
CI_Sim_22	F	29	13	27.5	75
Mean		**30.4**	**16.55**	**63.27**	**67.59**
St Dev		**9.93**	**7.33**	**87.17**	**11.24**
Median		**27**	**16**	**44.13**	**66.5**

Table 2: Demographic and implant information for the subjects who use cochlear implants (CI_orig).

Subject ID	Gender	Age at time of testing (yrs)	Etiology	Years of Hearing Loss	Duration profound hearing loss (yrs)	Device experience (yrs)	Ear implanted	Processor	Strategy	Stimulation Rate
CI_Orig_01	F	46	Unknown	18	14	3	R	Nucleus Freedom	ACE	900
CI_Orig_02	F	57	Unknown	35	10	5	L	ESPrit 3G	ACE	900
CI_Orig_03	F	49	Unknown	33	16	6	L	ESPrit 3G	ACE	900
CI_Orig_04	M	59	Noise exposure	25	15	3	B**	Nucleus Freedom	ACE	1800
CI_Orig_05	M	50	Unknown	47	43	3	B	Nucleus Freedom	ACE	1800
CI_Orig_06	F	60	Otosclerosis	45	10	6	L	Nucleus Freedom	ACE	900
CI_Orig_07	F	80	Unknown	20	15	6	L	Nucleus Freedom	ACE	1200
CI_Orig_08	M	74	Unknown	15	13	11	L	Sprint	ACE	1800
CI_Orig_09	F	48	Unknown	43	30	10	R	Nucleus Freedom	SPEAK	250
CI_Orig_10	F	79	Unknown	1	1	8	R	Nucleus Freedom	ACE	1800
Mean		**60.2**		**28.2**	**16.7**	**6.1**				
St Dev		**13.03**		**14.98**	**11.7**	**2.85**				
Median		**58**		**29**	**14.5**	**6**				

** = Subject wears bilateral CIs, but was tested with the left implant only due to the lack of experience with the right implant (one month).

Table 3: Music appraisal ratings from the NH_orig listener group.

Subject ID	Music Appr (Avg of 24 excerpts)	Lyrics (Avg of 12)	Without Lyrics (Avg of 12)	Min (of 24)	Max (of 24)
NH_Orig_01	1.42	1.83	1	-2.0	3.0
NH_Orig_02	1.10	1.04	1.16	-1.0	2.5
NH_Orig_03	0.66	0.25	1.07	-3.0	3.0
NH_Orig_04	0.33	0.67	0	-3.0	3.0
NH_Orig_05	0.91	0.68	1.14	-1.1	2.5
Mean	**0.88**	**0.89**	**0.87**	**-2.02**	**2.80**
St Dev	**0.42**	**0.59**	**0.49**	**0.98**	**0.27**
Median	**0.91**	**0.68**	**1.07**	**-2.00**	**3.00**

Table 4: Percent-correct scores (except UW-CAMP Pitch) for the music perception tests for NH_orig listener group. UW-CAMP Pitch values are the JND in semitones

Subject ID	AMICI				MBEA						MCI	UW-CAMP		
	Music vs Noise	Timbre	Genre	Melody	Scale	Contour	Interval	Rhythm	Meter	Memory	Overall	Pitch	Melody	Timbre
NH_Orig_01	100	97	96	85	90	81	87	87	87	87	84	.50	81	71
NH_Orig_02	100	100	96	90	90	84	94	84	90	87	96	.69	75	83
NH_Orig_03	100	100	100	90	94	84	87	90	97	97	100	.52	97	75
NH_Orig_04	100	100	88	60	87	84	94	87	100	90	94	.69	97	83
NH_Orig_05	100	100	100	95	94	87	94	94	100	100	100	.50	100	96
Mean	**100**	**99**	**96**	**84**	**91**	**84**	**91**	**88**	**95**	**92**	**95**	**.58**	**90**	**82**
St Dev	**0**	**1**	**5**	**14**	**3**	**2**	**4**	**4**	**6**	**6**	**7**	**.10**	**11**	**10**
Median	**100**	**100**	**96**	**90**	**90**	**84**	**94**	**87**	**97**	**90**	**96**	**.52**	**97**	**83**

Table 5: Music appraisal ratings from the CI_sim listener group.

Subject ID	Music Appr (Avg of 24 excerpts)	Lyrics (Avg of 12)	Without Lyrics (Avg of 12)	Min (of 24)	Max (of 24)
CI_Sim_01	-1.00	-1.50	-0.50	-2.00	2.00
CI_Sim_02	-0.17	-0.06	-0.28	-3.00	2.60
CI_Sim_03	-1.38	-1.56	-1.20	-3.00	0.80
CI_Sim_04	-0.92	-1.43	-0.42	-3.00	2.90
CI_Sim_05	0.88	0.38	1.38	-1.00	3.00
CI_Sim_06	0.59	0.18	0.99	-1.10	2.50
CI_Sim_07	0.48	-0.24	1.19	-2.00	2.00
CI_Sim_08	-0.67	-1.43	0.09	-3.00	2.10
CI_Sim_09	-0.19	-0.49	0.11	-2.00	2.00
CI_Sim_10	-0.13	-0.41	0.16	-2.00	2.60
CI_Sim_11	0.10	-0.11	0.30	-2.00	1.80
CI_Sim_12	-0.35	-0.74	0.05	-2.50	2.90
CI_Sim_14	-0.78	-1.27	-0.28	-3.00	2.20
CI_Sim_16	-0.40	-0.70	-0.10	-2.00	2.00
CI_Sim_17	-1.38	-2.00	-0.76	-2.80	2.60
CI_Sim_18	0.25	0.30	0.19	-0.80	1.60
CI_Sim_19	-0.58	-0.83	-0.32	-3.00	1.50
CI_Sim_20	-0.86	-0.81	-0.91	-3.00	2.90
CI_Sim_21	-1.25	-1.73	-0.78	-2.70	1.50
CI_Sim_22	-2.40	-2.72	-2.08	-3.00	0.00
Mean	**-0.51**	**-0.86**	**-0.16**	**-2.35**	**2.08**
St Dev	**0.79**	**0.83**	**0.81**	**0.73**	**0.76**
Median	**-0.49**	**-0.78**	**-0.19**	**-2.60**	**2.05**

Table 6: Percent-correct scores (except UW-CAMP Pitch) for the music perception tests for CI_sim listener group. UW-CAMP Pitch values are the JND in semitones.

Subject ID	AMICI				MBEA						MCI	UW-CAMP		
	Noise vs	Timbre	Genre	Melody	Scale	Contour	Interval	Rhythm	Meter	Melody	Overall	Pitch	Melody	Timbre
CI_Sim_01	60	30	44	55	65	65	58	74	97	77	74.07	7.69	11	67
CI_Sim_02	92	70	60	45	68	77	74	87	90	73	57.78	6.02	8	46
CI_Sim_03	88	37	64	45	48	77	71	97	100	83	88.89	6.32	6	46
CI_Sim_04	60	37	36	40	61	68	71	84	87	83	71.11	5.05	0	58
CI_Sim_05	56	27	32	35	58	68	58	84	83	53	39.26	6.19	14	13
CI_Sim_06	88	50	76	75	52	74	61	100	93	63	85.19	5.48	17	54
CI_Sim_07	84	60	84	50	52	74	58	94	100	80	88.89	5.33	25	25
CI_Sim_08	76	27	68	70	71	71	52	87	100	63	91.11	5.28	14	42
CI_Sim_09	68	33	40	15	65	68	61	81	93	60	78.52	5.53	25	21
CI_Sim_10	72	27	68	55	68	68	61	71	90	67	68.15	5.33	8	38
CI_Sim_11	80	33	44	45	68	65	55	90	93	77	51.11	5.68	6	54
CI_Sim_12	88	23	40	30	74	61	48	77	87	43	61.48	5.85	11	29
CI_Sim_14	64	40	40	40	58	77	74	94	90	67	74.07	5.87	17	29
CI_Sim_16	60	53	48	20	58	77	74	71	90	73	23.7	5.89	14	21
CI_Sim_17	72	27	40	40	61	68	61	97	97	50	24.44	5.52	11	25
CI_Sim_18	76	67	28	35	71	65	74	74	87	60	31.85	7.61	8	4
CI_Sim_19	96	23	72	70	74	90	74	90	97	67	88.89	5.22	19	50
CI_Sim_20	84	47	48	30	52	55	58	65	83	53	45.19	4.26	6	42
CI_Sim_21	96	40	16	45	52	58	61	84	80	37	54.07	6.29	11	29
CI_Sim_22	76	47	44	35	77	71	55	77	77	53	69.63	5.80	11	67
Mean	76.80	39.90	49.60	43.75	62.65	69.85	62.95	83.90	90.70	64.10	63.37	58.11	12.12	37.99
St Dev	12.62	14.26	17.67	15.72	8.70	7.86	8.36	9.97	6.72	13.11	21.82	7.89	6.32	17.47
Median	76.00	37.00	44.00	42.50	63.00	68.00	61.00	84.00	90.00	65.00	68.89	5.74	11.11	39.84

Table 7: Music appraisal ratings from the CI_orig listener group.

Subject ID	Music Appr (Avg of 24 excerpts)	Lyrics (Avg of 12)	Without Lyrics (Avg of 12)	Min (of 24)	Max (of 24)
CI_Orig_01	0.54	0.58	0.50	-3.00	3.00
CI_Orig_02	0.66	0.75	0.57	-1.80	2.50
CI_Orig_03	0.77	0.68	0.86	-2.50	2.70
CI_Orig_04	0.24	0.30	0.18	-1.90	2.40
CI_Orig_05	0.33	0.41	0.24	-3.00	3.00
CI_Orig_06	-0.34	-0.07	-0.62	-2.10	2.90
CI_Orig_07	0.42	0.14	0.69	-2.50	3.00
CI_Orig_08	0.39	0.19	0.58	-2.00	2.50
CI_Orig_09	0.11	0.55	-0.33	-1.50	2.00
CI_Orig_10	-0.61	-0.89	-0.33	-2.50	2.50
Mean	**0.25**	**0.26**	**0.23**	**-2.28**	**2.65**
St Dev	**0.43**	**0.48**	**0.50**	**0.50**	**0.33**
Median	**0.36**	**0.35**	**0.37**	**-2.30**	**2.60**

Table 8: Percent-correct scores (except UW-CAMP Pitch) for the music perception tests for CI_orig listener group. UW-CAMP Pitch values are the JND in semitones.

Subject ID	AMICI				MBEA						MCI	UW-CAMP		
	Music vs Noise	Timbre	Genre	Melody	Scale	Contour	Interval	Rhythm	Meter	Memory	Overall	Pitch	Melody	Timbre
CI_Orig_01	96	40	48	35	55	71	58	74	53	40	16.30	0.69	22	33
CI_Orig_02	92	70	72	20	55	74	61	81	83	60	24.44	2.24	3	33
CI_Orig_03	96	73	64	40	71	58	26	81	57	57	22.96	4.85	17	67
CI_Orig_04	88	53	56	15	52	58	48	81	40	47	43.70	2.26	6	29
CI_Orig_05	96	53	32	20	58	55	42	77	70	57	33.33	2.92	11	42
CI_Orig_06	92	63	40	55	52	55	58	90	87	63	20.00	4.67	17	42
CI_Orig_07	84	70	68	35	65	74	61	81	77	43	54.07	2.17	25	54
CI_Orig_08	100	47	60	30	58	52	55	77	50	50	40.00	5.04	8	8
CI_Orig_09	96	67	60	20	55	55	39	90	80	70	34.07	4.78	17	38
CI_Orig_10	88	47	52	5	77	55	48	74	87	60	11.85	6.93	11	21
Mean	**92.80**	**58.30**	**55.20**	**27.50**	**59.80**	**60.70**	**49.60**	**80.60**	**68.40**	**54.70**	**30.07**	**36.55**	**13.70**	**36.70**
St Dev	**4.91**	**11.71**	**12.47**	**14.38**	**8.460**	**8.69**	**11.36**	**5.68**	**17.08**	**9.45**	**13.30**	**18.83**	**7.07**	**16.43**
Median	**94.00**	**58.00**	**58.00**	**25.00**	**56.50**	**56.50**	**51.50**	**81.00**	**73.50**	**57.00**	**28.88**	**3.79**	**14.00**	**35.50**

Table 9: Music questionnaire values for CI_orig listener group.

Subject ID	Questionnaire Values			
	A: Early Experience	B: Musical Training	C1: Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss	C2: Current Listening Habits/Possible Musical Difficulties
CI_Orig_01	7	33	47	46
CI_Orig_02	12	30	49	40
CI_Orig_03	13	32	44	51
CI_Orig_04	25	90	83	39
CI_Orig_05	15	17	44	44
CI_Orig_06	16	6	62	50
CI_Orig_07	21	39	82	77
CI_Orig_08	11	25	55	46
CI_Orig_09	19	34	56	27
CI_Orig_10	13	4	82	43
Mean	**15.20**	**30.90**	**60.40**	**46.30**
St Dev	**5.26**	**23.90**	**16.13**	**12.73**
Median	**14.00**	**30.75**	**55.50**	**45.00**

Table 10: Lower and upper limits on chance performance. Based on binomial distributions chance performance will yield values within these limits 95% of the time. The "number correct" values are rounded to the nearest integer.

Test	# Trials	# Choices	Lower Limit		Upper Limit	
			% correct	Number correct	% correct	Number correct
AMICI Task 1 (Music vs Noise)	25	2	29.1	7	17.7	71
AMICI Task 2 (Timbre)	30	10	2.1	1	8.0	27
AMICI Task 3 (Genre)	25	5	6.8	2	10.2	41
AMICI Task 4 (Melody)	20	Open set	N/A	N/A	N/A	N/A
MBEA Task 1 (Scale)	31	2	31.3	10	21.3	69
MBEA Task 2 (Contour)	31	2	31.3	10	21.3	69
MBEA Task 3 (Interval)	31	2	31.3	10	21.3	69
MBEA Task 4 (Rhythm)	31	2	31.3	10	21.3	69
MBEA Task 5 (Meter)	30	2	31.3	9	20.6	69
MBEA Task 6 (Memory)	30	2	31.3	9	20.6	69
MCI	135	9	6.4	9	23.8	18
UW-CAMP Pitch	Variable	2	N/A	N/A	N/A	N/A
UW-CAMP Melody	36	12	1.8	1	8.1	22
UW-CAMP Timbre	24	8	2.7	1	7.8	32

Figure 1: Boxplots of music appraisal ratings (across the 24 musical excerpts) for individual subjects in each of the three listener groups. Median, 25th- and 75th- percentiles are represented by the central mark, bottom-edge and top-edge of the box, respectively. Vertical lines extend to the extreme data points that are not considered outliers.
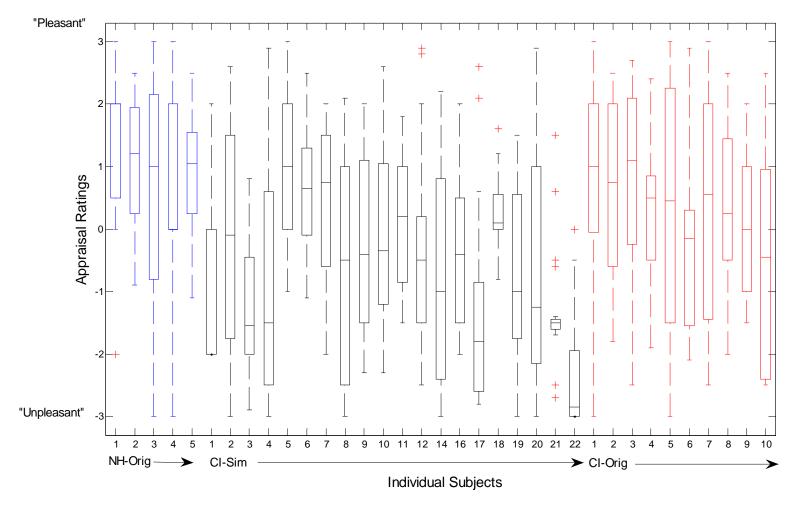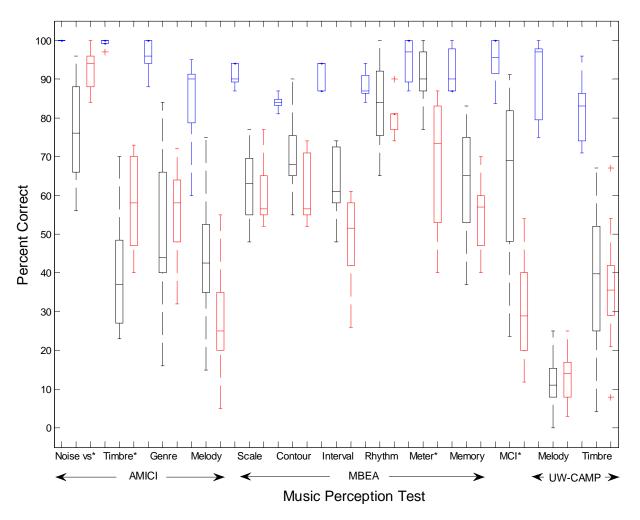
Figure 2: Music perception graph. Median, 25th- and 75th- percentiles are represented by the central mark, bottom-edge and top-edge of the box, respectively. "Whiskers" extend to the extreme data points, that are not considered outliers.

* Denote statistically significant differences in performance between the CI_sim and CI-orig listener groups.

Figure 3: UW-CAMP Pitch boxplot. Median, 25th- and 75th- percentiles are represented by the central mark, bottom-edge and top-edge of the box, respectively. Vertical lines extend to the extreme data points that are not considered outliers.
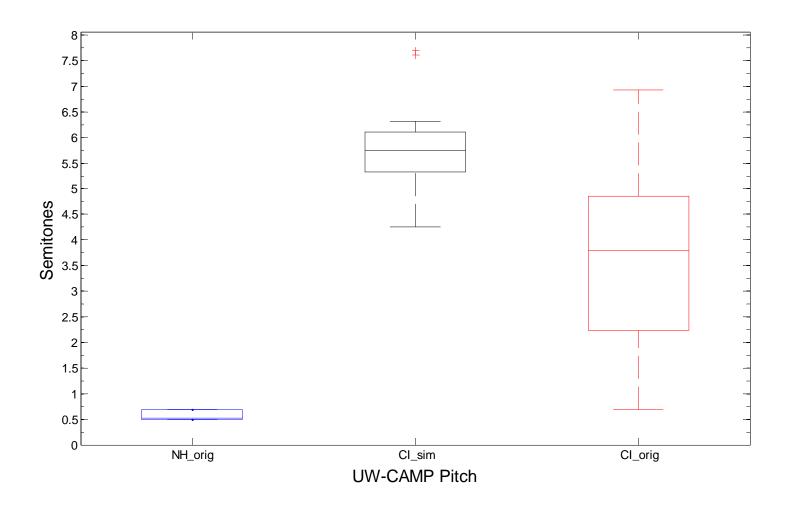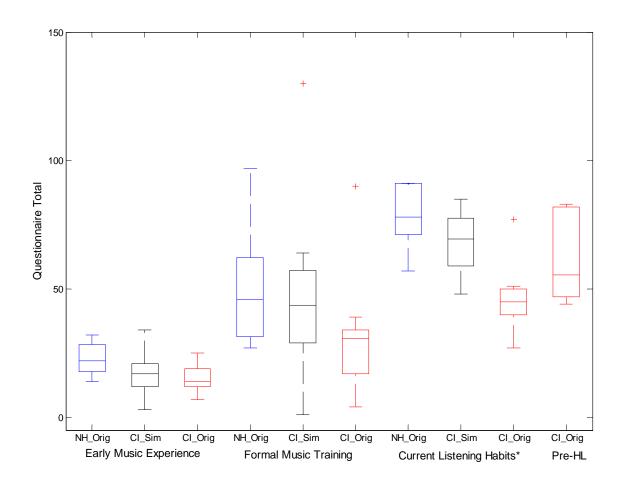
Figure 4: Boxplots of scores from Parts A, B, C of the Questionnaire, for the three listener groups (NH_orig, CI_sim and CI_orig). Listener group, CI_orig, also has scores for Questionnaire Part C1: Listening Habits/Possible Musical Difficulties: Pre-Hearing Loss. Median, 25th- and 75th- percentiles are represented by the central mark, bottom-edge and top-edge of the box, respectively. "Whiskers" extend to the extreme data points, that are not considered outliers.

* Denote statistically significant differences in performance between the CI_sim and CI-orig listener groups.

Table 11: CI_sim correlations

	AMICI 1	AMICI 2	AMICI 3	AMICI 4	MBEA 1	MBEA 2	MBEA 3	MBEA 4	MBEA 5	MBEA 6	MCI	UW-CAMP Pitch	UW-CAMP Melody	UW-CAMP Timbre	Questionnaire A	Questionnaire B	Questionnaire C	Music Appraisal
AMICI 1		0.18	0.33	0.38	-0.02	0.09	-0.04	0.27	0.07	-0.22	0.29	-0.19	0.05	0.15	-0.03	0.22	0.17	-0.06
AMICI 2			0.09	-0.16	-0.20	0.07	0.42	-0.06	-0.18	0.21	-0.19	0.18	-0.01	-0.16	-0.22	0.03	-0.12	0.18
AMICI 3				0.61	-0.06	0.58	0.00	0.34	0.64	0.50	0.61	-0.38	0.34	0.30	0.30	0.37	0.40	0.24
AMICI 4					0.04	0.38	-0.05	0.46	0.46	0.22	0.57	-0.06	0.08	0.47	0.28	0.45	0.16	0.11
MBEA 1						0.11	-0.17	-0.30	-0.11	-0.14	0.01	0.14	-0.04	0.17	0.13	-0.22	-0.03	-0.12
MBEA 2							0.57	0.49	0.48	0.50	0.40	-0.06	0.39	0.14	0.17	0.12	0.33	0.06
MBEA 3								0.13	0.09	0.43	-0.11	0.18	-0.09	-0.15	-0.20	-0.12	0.04	0.01
MBEA 4									0.52	0.22	0.39	-0.09	0.28	0.09	0.25	0.37	0.26	0.10
MBEA 5										0.57	0.44	0.00	0.33	0.07	0.22	0.15	0.28	0.19
MBEA 6											0.36	0.04	-0.10	0.35	0.06	-0.02	0.18	0.15
MCI												-0.19	0.34	0.49	0.21	0.30	0.37	-0.06
UW-CAMP Pitch													-0.07	-0.15	0.03	-0.14	-0.16	0.03
UW-CAMP Melody														-0.32	0.18	0.17	0.18	0.32
UW-CAMP Timbre															0.07	0.22	0.18	-0.45
Questionnaire A																0.63	0.57	0.45
Questionnaire B																	0.21	0.30
Questionnaire C																		-0.13
Music Appraisal																		

Table 12: CI_orig correlations

	AMICI 1	AMICI 2	AMICI 3	AMICI 4	MBEA 1	MBEA 2	MBEA 3	MBEA 4	MBEA 5	MBEA 6	MCI	UW-CAMP Pitch	UW-CAMP Melody	UW-CAMP Timbre	Questionnaire A	Questionnaire B	Questionnaire C	Questionnaire C2	Music Appraisal
AMICI 1		-0.23	-0.22	0.19	-0.25	-0.41	-0.34	-0.04	-0.31	0.21	-0.25	0.12	-0.15	-0.19	-0.59	-0.26	-0.83	-0.49	0.33
AMICI 2			0.52	0.29	0.06	0.23	-0.23	0.66	0.40	0.42	0.25	0.06	0.13	0.71	0.37	0.04	-0.07	0.22	0.28
AMICI 3				-0.11	0.20	0.47	0.08	0.08	-0.04	-0.08	0.31	-0.04	-0.08	0.09	0.11	0.34	0.16	0.17	0.44
AMICI 4					-0.26	0.10	0.14	0.41	0.00	-0.12	-0.02	-0.15	0.54	0.46	-0.16	-0.21	-0.31	0.46	0.20
MBEA 1						-0.08	-0.38	-0.43	0.22	0.04	-0.24	0.55	0.18	0.20	-0.18	-0.36	0.24	0.32	-0.20
MBEA 2							0.54	-0.17	0.10	-0.49	0.11	-0.73	0.27	0.27	-0.11	0.19	0.01	0.45	0.49
MBEA 3								-0.10	0.20	-0.40	0.13	-0.41	0.00	-0.43	-0.10	-0.06	0.29	0.33	-0.12
MBEA 4									0.36	0.60	0.17	0.15	0.15	0.34	0.49	0.05	0.01	-0.16	-0.16
MBEA 5										0.63	-0.31	0.36	0.13	0.15	-0.04	-0.68	0.09	0.06	-0.51
MBEA 6											-0.34	0.64	-0.27	0.06	0.06	-0.43	-0.20	-0.56	-0.40
MCI												-0.30	0.06	0.07	0.67	0.57	0.34	0.38	0.32
UW-CAMP Pitch													-0.16	-0.18	-0.04	-0.51	0.16	-0.22	-0.61
UW-CAMP Melody														0.55	-0.02	-0.18	0.03	0.55	0.02
UW-CAMP Timbre															0.21	0.03	-0.20	0.42	0.36
Questionnaire A																0.61	0.64	0.10	-0.18
Questionnaire B																	0.32	-0.07	0.39
Questionnaire C																		0.30	-0.55
Questionnaire C2																			0.17
Music Appraisal																			

Appendix A: Music appraisal excerpts

Number	Label	Lyrical/ Instrumental	Source (Artist, Musical piece/song)
1	V_Popular_01_mono_appr	Lyrical	Beatles, "Sergeant Pepper's Lonely Heart Club Band"
2	NV_Country Western_04_mono_appr	Instrumental	Yonder Mountain String Band, "Half Moon Rising"
3	NV_Classical_03_mono_appr	Instrumental	Mozart (performed by Westminster Boys Choir), "Amen" from Requiem in D Minor
4	NV_Popular_02_mono_appr	Instrumental	Kiss, "I love it loud"
5	NV_Popular_01_mono_appr	Instrumental	Beastie Boys, "Brass Monkey"
6	V_Country Western_01_mono_appr	Lyrical	Patsy Cline, "I fall to pieces"
7	NV_Country Western_03_mono_appr	Instrumental	Johnny Cash & Willie Nelson, "Folsom Prison Blues"
8	V_Country Western_03_mono_appr	Lyrical	Brooks and Dunn, "Boot Scootin' Boogy"
9	NV_Country Western_02_mono_appr	Instrumental	Allison Kraus, "Fast Fiddle & Banjo Tuen"
10	NV_Popular_04_mono_appr	Instrumental	Queen, "We will rock you"
11	V_Classical_02_mono_appr	Lyrical	Handel, "Hallelujah Chorus"
12	V_Country Western_04_mono_appr	Lyrical	Garth Brooks, "The Dance"
13	NV_Classical_02_mono_appr	Instrumental	Vivaldi, "Concerto for Mandolin in C Major"
14	NV_Country Western_01_mono_appr	Lyrical	Toby Keith, "How do you like me now?"
15	V_Classical_01_mono_appr	Lyrical	Josh Groban, "To Where You Are"
16	NV_Popular_03_mono_appr	Instrumental	Chick Correa, Charlie Chaplin, "Smile"
17	V_Popular_03_mono_appr	Lyrical	The Eagles, "Take It Easy"
18	V_Country Western_02_mono_appr	Lyrical	Rascal Flats, "God bless the broken road"
19	V_Classical_04_mono_appr	Lyrical	Gershwin, "Summertime" from Porgy & Bess
20	V_Popular_02_mono_appr	Lyrical	Elvis, "Hound Dog"
21	V_Classical_03_mono_appr	Lyrical	Mozart (performed by Westminster Boys Choir), "Amen" from Requiem in D Minor
22	NV_Classical_01_mono_appr	Instrumental	Tchaikovsky, "Serenade in C for Strings"
23	V_Popular_04_mono_appr	Lyrical	Michael Jackson, "Thriller"
24	NV_Classical_04_mono_appr	Instrumental	F. Mendelssohn-Bartholdy (performed by Andres Segovia & the Rias Orchestra), "Romantic Affairs: Symphony No. 4, 2nd Movement"

Appendix B: Normal-hearing music history questionnaire

MUSICAL BACKGROUND QUESTIONNAIRE

Part A: Early Experience

Date: _____

Age (years): _____

....

INSTRUCTIONS

For each of the multiple-choice questions, please circle the response(s) that you feel best applies to each statement. If you circle an "other" response, please elaborate.

NOTE: For the purposes of this questionnaire, a "child" is someone ranging in age from newborn to 11 years old and the "childhood environment" refers to the circumstances of this time period (e.g., family configuration; home, school, & church environments; learning locations, etc.).

....

1. Did any members of your family sing when you were a child (e.g. lullabies)?

   Please circle all that apply:

   a)   mother   c)   sibling   e)   aunt/uncle
   b)   father   d)   grandparent   f)   other: _____

2. Was choral or individual singing encouraged in your childhood environment?

                        Yes   No

                        ☐   ☐

If yes, how was it encouraged? Please circle all that apply.

   a)   family sing-a-long
   b)   joining choirs
   c)   attending singing performances with family (e.g., musicals, vocal concerts, recitals)
   d)   singing lessons
   e)   other: _____

3. How often did singing occur in your childhood environment?

Never	On special occasions	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

4. Was recorded music (CDs, tapes, music videos, etc.) available in your childhood environment?

Yes	No
□	□

5. How often did you hear music in your childhood environment?

Never	On special occasions	Sometimes	Often	Very frequently
□	□	□	□	□

6. Were musical instruments played in your childhood environment?

Yes	No
□	□

If yes, which musical instruments? Please circle all that apply and indicate who played them.

a) piano _____   h) trumpet _____   o) other _____
b) guitar _____   i) trombone _____
c) flute _____   j) tuba _____
d) recorder _____   k) violin _____
e) saxophone _____   l) cello _____
f) clarinet _____   m) base _____
g) oboe _____   n) drums _____

7. Were/Are any of your family members professional or semi-professional musicians and/or vocalists? Please circle all that apply.

a) mother   c) sibling   e) aunt/uncle
b) father   d) grandparent   f) other: _____

8. Was listening to music an important part of your environment?

Never	Rarely	Sometimes	Often	Very often
□	□	□	□	□

Part B: Musical Training

....

INSTRUCTIONS

For each of the multiple-choice questions, please circle the response(s) that you feel best applies to each statement. If you circle an "other" response, please elaborate.

NOTE: In this section, VOICE is considered an instrument.

....

1. Please indicate what type of musical education you have had. (circle all that apply and indicate type of instrument, **including VOICE**)

   a) group, class at school (e.g., choir, band) _____
   b) parental instruction _____
   c) private lessons _____
   d) self-taught _____
   e) other: _____
   f) none   *(If 'none' skip to Question #12.)*

2. At what age (in years) did you begin your earliest music training? (Circle one)

Never	1 yr	2 yrs	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	21	22	23	24+

3. What instruments have you played? (Fill out the table below)

Instrument	Age Began (years)	Age Stopped (years)	Total Years and Months (approx.)
a) voice			
b) piano			
c) violin			
d) recorder			
e) saxophone			
f) clarinet			
g) guitar			
h) trumpet			
i) trombone			
j) flute			
k) cello			
l) base			
m) drums			
n) Other: _____			

4. To what degree was this experience...

Frustrating:

Not at all   Somewhat   Moderately   Very much   Extremely

☐   ☐   ☐   ☐   ☐

Tedious:

Not at all   Somewhat   Moderately   Very much   Extremely

☐   ☐   ☐   ☐   ☐

Important:

Not at all   Somewhat   Moderately   Very much   Extremely

☐   ☐   ☐   ☐   ☐

Enjoyable:

Not at all   Somewhat   Moderately   Very much   Extremely

☐   ☐   ☐   ☐   ☐

5. What do you consider your main instrument (including voice)? _____

6. How many years of training have you received on this instrument? _____

7. At the peak of your interest, how many hours per week did you play/practice this instrument? (Circle one)

Hrs/wk	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	More

8. How long did you maintain this peak?

Months: _____   OR   Years _____

9. Do you still play this instrument?

Yes   No

☐   ☐

If 'No', how old (in years) were you when you last played this instrument? _____

10. Do you still play any other instrument (including voice)?

            Yes   No

            ☐   ☐

   If 'No', how old were you when you last played your other instrument?

   Instrument: _____   age (years): _____
   Instrument: _____   age (years): _____
   Instrument: _____   age (years): _____

11. How old (in years) were you when you last received musical training?

   Vocal music instruction? _____

   Instrumental instruction? _____   Which instrument? _____

12. How often have you performed in other arts (e.g., drama, poetry reading, radio broadcasting, etc.)?

   Never   Rarely   Sometimes   Often   Very often

   ☐   ☐   ☐   ☐   ☐

13. Given the opportunity, my interest in participating in future musical instruction is:

   Non-existent   Minimal   Moderate   Often   Very high

   ☐   ☐   ☐   ☐   ☐

Part C: Current Listening Habits & Possible Musical Difficulties

---

INSTRUCTIONS

For each of the multiple-choice questions, please circle the response(s) which you feel best applies to each statement. If you circle an "other" response, please elaborate.

---

1. Do you listen to music?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

2. Do you dance?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

If you answered "Never", skip to Question #4.

3. If so, would you consider yourself to be a good dancer?

Terrible	Not very good	Moderate	Good	Excellent
☐	☐	☐	☐	☐

4. Can you recognize a very familiar melody (such as the national anthem) without the help of lyrics?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

5. Do you sing in private (in my car, in the shower, in my environment, etc.)?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

6. Do you sing in public (as part of a group or solo: e.g., a choir, carols, a sing-a-long, hanging out with friends)?

Never	On special occasions	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

7. How often do you purposely listen to music (as opposed to hearing music in your environment that you had no part in choosing, e.g., hearing music in stores, elevators, restaurants, etc.)?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

8. Which of these statements do you agree with? (circle all that apply)

   a)   Music is very important to me.
   b)   I have to have music on most of the time.
   c)   I like music but it's not that important to me.
   d)   I can't stand having music on while I work or study.
   e)   I find most music very irritating.
   f)   I don't much care one way or the other about music.
   g)   I spend a lot of time choosing the music I listen to.
   h)   I find most music boring.
   i)   My friends and I talk about music a lot and exchange our favorite tunes.
   j)   Music is not really a part of my life.
   k)   I find music to be relaxing.
   l)   I love music, listening to music is a real pleasure.
   m)   Music is like noise to me.
   n)   Music is like a foreign language to me.
   o)   I never listen to music when I am alone.
   p)   I am indifferent towards music.
   q)   Music is a very unpleasant experience for me.

9. Please check your favorite genres of music and rank them in order of most favorite to least favorite.

   a)   Pop _____   g)   Jazz _____   m)   Gospel _____
   b)   Rap/Hip-hop _____ h)   Classical _____   n)   Trance _____
   c)   Soft Rock _____   i)   Folk _____   o)   Other: _____
   d)   Rock _____   j)   World Beat _____
   e)   Heavy Metal _____ k)   Country _____
   f)   Blues _____   l)   Bluegrass _____

10. Do you prefer to listen to solo instruments or to an orchestra / a band?

Solo instruments	Orchestra/band	No preference
☐	☐	☐

11. When you listen to music, how difficult is it to hear the difference between the notes?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
☐	☐	☐	☐	☐

12. How difficult do you find singing in general?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
☐	☐	☐	☐	☐

13. Do any of the following statements apply to you? (circle all that apply)

a) I cannot sing very well.
b) I cannot sing tones to match piano notes.
c) I sing off key.
d) I do not like to listen to music.
e) Someone once told me that I was tone-deaf.
f) I cannot dance.

g) I don't enjoy singing.
h) I cannot remember songs very well.
i) I cannot identify notes by ear.
j) I cannot keep the beat of music.
k) I cannot sing in harmony.
l) I have difficulty learning to play instruments.

14. Rate your ability to memorize a short song. (circle one)

Non-existent	Poor	Fair	Good	Excellent
☐	☐	☐	☐	☐

15. If I am asked to repeat a tune someone else has recently sung to me...

a) I can reproduce the tune perfectly.
b) I can remember the lyrics, but have problems with singing the tune.
c) I have problems with both the lyrics and tune.
d) I cannot do this at all.

16. If I imagine the tune 'Happy Birthday', I can hear the melody in my head with...

No accuracy	Poor accuracy	Some accuracy	Moderate accuracy	Perfect accuracy
☐	☐	☐	☐	☐

17. Do you know your favorite songs by heart?

Yes	Sometimes	No
☐	☐	☐

18. When music is being played in my environment (e.g., on the radio, in the store, on TV), I can recognize familiar songs by the first two or three notes...

Never	Rarely	Sometimes	Often	Very frequently
□	□	□	□	□

19. When I sing or hum along to my favorite recorded music...

   a) I can match the song note for note.
   b) I have difficulty landing on the same notes as the singer some of the time.
   c) I have difficulty landing on the same notes as the singer most of the time.
   d) I do not sing along to recorded music.

20. Singing a note to match one played on the piano is a task I find...

Impossible	Very difficult	A little difficult	Somewhat easy	Very easy
□	□	□	□	□

21. If someone played two notes on the piano separately and asked me which was higher in pitch, I would find this task...

Very difficult	Difficult	Neither easy nor difficult	Somewhat easy	Very easy
□	□	□	□	□

22. When I sing...

   a) I can tell when I am out of tune and can correct it.
   b) I can tell when I am out of tune, but I cannot correct it.
   c) I cannot tell when I am out of tune unless someone tells me.
   d) I do not sing.

23. When I sing, I perform best... (circle one)

   a) individually.
   b) in a small group.
   c) in a large group.
   d) I do not sing.

24. How often do you get a tune "stuck" in your head?

Never	Rarely	Sometimes	Often	Very frequently
□	□	□	□	□

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25. In my opinion, someone has musical difficulties when they... (circle all that apply)

a) cannot sing with a pleasant sound.   f) cannot recognize tunes.
b) occasionally sing out of tune.   g) cannot identify notes in a scale.
c) have a clinical hearing deficit.   h) cannot dance.
d) always sing out of tune.   i) cannot match notes played on a piano.
e) have little or no musical training.   j) dislike music.

THE END:

If there are any parts of your musical background that have not been asked, then please provide that information here. Thank you.

_____
_____
_____

Your time and input is greatly appreciated.

Scoring: For likert-scale and multiple choice questions, answers were assigned a number ranging from zero to four. Zero indicated no musical experience and four indicated much experience. For yes/no questions, answers were assigned a zero for "no" answers and a one for "yes" answers. When applicable, open-ended questions were scored according to years of experience; otherwise judgment was used to evaluate answers given.

Appendix C: Cochlear implant user music history questionnaire

MUSICAL BACKGROUND QUESTIONNAIRE

Part A: Early Experience

Date: _____

Age (years): _____

···

INSTRUCTIONS
For each of the multiple-choice questions, please circle the response(s) that you feel best applies
to each statement. If you circle an "other" response, please elaborate.
NOTE: For the purposes of this questionnaire, a "child" is someone ranging in age from
newborn to 11 years old and the "childhood environment" refers to the circumstances of this
time period (e.g., family configuration; home, school, & church environments; learning
locations, etc.).

···

1. Did any members of your family sing when you were a child (e.g. lullabies)?

   Please circle all that apply:

   a)   mother   c)   sibling   e)   aunt/uncle
   b)   father   d)   grandparent   f)   other: _____

2. Was choral or individual singing encouraged in your childhood environment?

                         Yes   No

                         ☐   ☐

If yes, how was it encouraged? Please circle all that apply.

   a)   family sing-a-long
   b)   joining choirs
   c)   attending singing performances with family (e.g., musicals, vocal concerts,
        recitals)
   d)   singing lessons
   e)   other: _____

3. How often did singing occur in your childhood environment?

Never	On special occasions	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

4. Was recorded music (CDs, tapes, music videos, etc.) available in your childhood environment?

	Yes	No
	☐	☐

5. How often did you hear music in your childhood environment?

Never	On special occasions	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

6. Were musical instruments played in your childhood environment?

	Yes	No
	☐	☐

If yes, which musical instruments? Please circle all that apply and indicate who played them.

a) piano _____   h) trumpet _____   o) other _____
b) guitar _____   i) trombone _____
c) flute _____   j) tuba _____
d) recorder _____   k) violin _____
e) saxophone _____   l) cello _____
f) clarinet _____   m) base _____
g) oboe _____   n) drums _____

7. Were/Are any of your family members professional or semi-professional musicians and/or vocalists? Please circle all that apply.

a) mother   c) sibling   e) aunt/uncle
b) father   d) grandparent   f) other: _____

8. Was listening to music an important part of your environment?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

Part B: Musical Training

....

INSTRUCTIONS

For each of the multiple-choice questions, please circle the response(s) that you feel best applies to each statement. If you circle an "other" response, please elaborate.

NOTE: In this section, VOICE is considered an instrument.

....

1. Please indicate what type of musical education you have had. (circle all that apply and indicate type of instrument, **including VOICE**)

    a)   group, class at school (e.g., choir, band) _____
    b)   parental instruction _____
    c)   private lessons _____
    d)   self-taught _____
    e)   other: _____
    f)   none   *(If 'none' skip to Question #12.)*

2. At what age (in years) did you begin your earliest music training? (Circle one)

Never	1 yr	2 yrs	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	21	22	23	24+

3. What instruments have you played? (Fill out the table below)

Instrument	Age Began (years)	Age Stopped (years)	Total Years and Months (approx.)
a) voice			
b) piano			
c) violin			
d) recorder			
e) saxophone			
f) clarinet			
g) guitar			
h) trumpet			
i) trombone			
j) flute			
k) cello			
l) base			
m) drums			
n) Other: _____			

4. To what degree was this experience...

Frustrating:

Not at all	Somewhat	Moderately	Very much	Extremely
□	□	□	□	□

Tedious:

Not at all	Somewhat	Moderately	Very much	Extremely
□	□	□	□	□

Important:

Not at all	Somewhat	Moderately	Very much	Extremely
□	□	□	□	□

Enjoyable:

Not at all	Somewhat	Moderately	Very much	Extremely
□	□	□	□	□

5. What do you consider your main instrument (including voice)? _____

6. How many years of training have you received on this instrument? _____

7. At the peak of your interest, how many hours per week did you play/practice this instrument? (Circle one)

Hrs/wk	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	More

8. How long did you maintain this peak?

Months: _____   OR   Years _____

9. Do you still play this instrument?

Yes	No
□	□

If 'No', how old were you (in years) when you last played this instrument? _____

10. Do you still play any other instrument (including voice)?

	Yes	No
	☐	☐

If 'No', how old were you when you last played your other instrument?

Instrument: _____   age (years): _____
Instrument: _____   age (years): _____
Instrument: _____   age (years): _____

11. How old (in years) were you when you last received musical training?

Vocal music instruction? _____

Instrumental instruction? _____   Which instrument? _____

12. How often have you performed in other arts (e.g., drama, poetry reading, radio broadcasting, etc.)?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

13. Given the opportunity, my interest in participating in future musical instruction is:

Non-existent	Minimal	Moderate	Often	Very high
☐	☐	☐	☐	☐

14. Have you practiced listening to music with your implant?

	Yes	No
	☐	☐

If you have not practiced listening to music with you implant, please skip to Part C1.

15. How have you practiced listening to music with your implant? Please check all

applicable answers.

a) I have listened to familiar music repeatedly.
b) I have listened to unfamiliar music repeatedly.
c) I have listened to and read music.
d) I took music lessons.
e) I have read and played music.
f) I have played familiar music repeatedly without reading the music.
g) I have worked on music listening in my rehabilitation.

Part C1: Listening Habits & Possible Musical Difficulties: Pre-Hearing Loss

....

INSTRUCTIONS

As best as you can, remember a period of time when you had normal, or close-to-normal, hearing in at least one ear. For each of the multiple-choice questions, please circle the response(s) which you feel best applies to each statement <u>for that period of time</u>. If you circle an "other" response, please elaborate.

....

1. Did you listen to music?

Never	Rarely	Sometimes	Often	Very often
□	□	□	□	□

2. Did you dance?

Never	Rarely	Sometimes	Often	Very often
□	□	□	□	□

If you answered "Never", skip to Question #4.

3. If so, did you consider yourself to be a good dancer?

Terrible	Not very good	Moderate	Good	Excellent
□	□	□	□	□

4. Could you recognize a very familiar melody (such as the national anthem) without the help of lyrics?

Never	Rarely	Sometimes	Often	Very often
□	□	□	□	□

5. Did you sing in private (in my car, in the shower, in my environment, etc.)?

Never	Rarely	Sometimes	Often	Very often
□	□	□	□	□

6. Did you sing in public (as part of a group or solo: e.g., a choir, carols, a sing-a-long, hanging out with friends)?

Never	On special occasions	Sometimes	Often	Very frequently
□	□	□	□	□

7. How often did you purposely listen to music (as opposed to hearing music in your environment that you had no part in choosing, e.g., hearing music in stores, elevators, restaurants, etc.)?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

8. Which of these statements did you agree with, with that time period? (circle all that apply)

a) Music was very important to me.
b) I had to have music on most of the time.
c) I liked music but it was not that important to me.
d) I couldn't stand having music on while I worked or studied.
e) I found most music very irritating.
f) I didn't much care one way or the other about music.
g) I spent a lot of time choosing the music I listened to.
h) I found most music boring.
i) My friends and I talked about music a lot and exchanged our favorite tunes.
j) Music was not really a part of my life.
k) I found music to be relaxing.
l) I loved music, listening to music was a real pleasure.
m) Music was like noise to me.
n) Music was like a foreign language to me.
o) I never listened to music when I was alone.
p) I was indifferent towards music.
q) Music was a very unpleasant experience for me.

9. For that time period, please check which were your favorite genres of music and rank them in order of most favorite to least favorite.

a) Pop _____
b) Rap/Hip-hop _____
c) Soft Rock _____
d) Rock _____
e) Heavy Metal _____
f) Blues _____

g) Jazz _____
h) Classical _____
i) Folk _____
j) World Beat _____
k) Country _____
l) Bluegrass

m) Gospel _____
n) Trance _____
o) Other: _____

10. For that time period, did you prefer to listen to solo instruments or to an orchestra / a band?

Solo instruments	Orchestra/band	No preference
☐	☐	☐

11. When you listened to music, how difficult was it to hear the difference between the notes?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
□	□	□	□	□

12. How difficult did you find singing in general?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
□	□	□	□	□

13. Did any of the following statements apply to you? (circle all that apply)

a) I could not sing very well.
b) I could not sing tones to match piano notes.
c) I sang off key.
d) I did not like to listen to music.
e) Someone once told me that I was tone-deaf.
f) I could not dance.

g) I did not enjoy singing.
h) I could not remember songs very well.
i) I could not identify notes by ear.
j) I could not keep the beat of music.
k) I could not sing in harmony.
l) I had difficulty learning to play musical instruments.

14. Rate your ability to memorize a short song, for that time period. (circle one)

Non-existent	Poor	Fair	Good	Excellent
□	□	□	□	□

15. If I was asked to repeat a tune someone else had recently sung to me...

    a) I could reproduce the tune perfectly.
    b) I could remember the lyrics, but had problems singing the tune.
    c) I had problems with both the lyrics and tune.
    d) I could not do this at all.

16. If I imagined the tune 'Happy Birthday', I could hear the melody in my head with...

No accuracy	Poor accuracy	Some accuracy	Moderate accuracy	Perfect accuracy
□	□	□	□	□

17. Did you know your favorite songs by heart?

Yes	Sometimes	No
□	□	□

18. When music was being played in my environment (e.g., on the radio, in the store, on TV, I could recognize familiar songs by the first two or three notes...

Never	Rarely	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

19. When I sang or hummed along to my favorite recorded music...

   a) I could match the song note for note.
   b) I had difficulty landing on the same notes as the singer some of the time.
   c) I had difficulty landing on the same notes as the singer most of the time.
   d) I did not sing along to recorded music.

20. Singing a note to match one played on the piano is a task I found...

Impossible	Very difficult	A little difficult	Somewhat easy	Very easy
☐	☐	☐	☐	☐

21. If someone played two notes on the piano separately and asked me which was higher in pitch, I would have found this task...

Very difficult	Difficult	Neither easy nor difficult	Somewhat easy	Very easy
☐	☐	☐	☐	☐

22. When I sang...

   a) I could tell when I was out of tune and could correct it.
   b) I could tell when I was out of tune, but I could correct it.
   c) I could not tell when I was out of tune unless someone told me.
   d) I did not sing.

23. When I sang, I performed best... (circle one)

   a) individually.
   b) in a small group.
   c) in a large group.
   d) I did not sing.

24. How often did you get a tune "stuck" in your head?

Never	Rarely	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

25. My opinion, during that period of time in my life, was that someone has musical difficulties when they... (circle all that apply)

a) cannot sing with a pleasant sound.
b) occasionally sing out of tune.
c) have a clinical hearing deficit.
d) always sing out of tune.
e) have little or no musical training.

f) cannot recognize tunes.
g) cannot identify notes in a scale.
h) cannot dance.
i) cannot match notes played on a piano.
j) dislike music.

Part C2: Current Listening Habits & Possible Musical Difficulties: Post-Implantation

....

INSTRUCTIONS

Now, for the current period of time with your cochlear implant, please respond with the choice that best applies to you. If you circle an "other" response, please elaborate.

....

1. Do you listen to music?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

2. Do you dance?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

If you answered "Never", skip to Question #4.

3. If so, would you consider yourself to be a good dancer?

Terrible	Not very good	Moderate	Good	Excellent
☐	☐	☐	☐	☐

4. Can you recognize a very familiar melody (such as the national anthem) without the help of lyrics?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

5. Do you sing in private (in my car, in the shower, in my environment, etc.).

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

6. Do you sing in public (as part of a group or solo: e.g., a choir, carols, a sing-a-long, hanging out with friends).

Never	On special occasions	Sometimes	Often	Very frequently
☐	☐	☐	☐	☐

7. How often do you purposely listen to music (as opposed to hearing music in your environment that you had no part in choosing, e.g., hearing music in stores, elevators, restaurants, etc.)?

Never	Rarely	Sometimes	Often	Very often
☐	☐	☐	☐	☐

8. Which of these statements do you agree with? (circle all that apply)

    a)   Music is very important to me.
    b)   I have to have music on most of the time.
    c)   I like music but it's not that important to me.
    d)   I can't stand having music on while I work or study.
    e)   I find most music very irritating.
    f)   I don't much care one way or the other about music.
    g)   I spend a lot of time choosing the music I listen to.
    h)   I find most music boring.
    i)   My friends and I talk about music a lot and exchange our favorite tunes.
    j)   Music is not really a part of my life.
    k)   I find music to be relaxing.
    l)   I love music, listening to music is a real pleasure.
    m)   Music is like noise to me.
    n)   Music is like a foreign language to me.
    o)   I never listen to music when I am alone.
    p)   I am indifferent towards music.
    q)   Music is a very unpleasant experience for me.

9. Please check your favorite genres of music and rank them in order of most favorite to least favorite.

a) Pop _____	g) Jazz _____	m) Gospel _____
b) Rap/Hip-hop _____	h) Classical _____	n) Trance _____
c) Soft Rock _____	i) Folk _____	o) Other: _____
d) Rock _____	j) World Beat _____	
e) Heavy Metal _____	k) Country _____	
f) Blues _____	l) Bluegrass _____	

10. Do you prefer to listen to solo instruments or to an orchestra / a band?

Solo instruments	Orchestra/band	No preference
☐	☐	☐

11. When you listen to music, how difficult is it to hear the difference between the notes?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
□	□	□	□	□

12. How difficult do you find singing in general?

Very difficult	A little difficult	Neither difficult nor easy	Somewhat easy	Very easy
□	□	□	□	□

13. Do any of the following statements apply to you? (circle all that apply)

a) I cannot sing very well.
b) I cannot sing tones to match piano notes.
c) I sing off key.
d) I do not like to listen to music.
e) Someone once told me that I was tone-deaf.
f) I cannot dance.

g) I don't enjoy singing.
h) I cannot remember songs very well.
i) I cannot identify notes by ear.
j) I cannot keep the beat of music.
k) I cannot sing in harmony.
l) I have difficulty learning to play instruments.

14. Rate your ability to memorize a short song. (circle one)

Non-existent	Poor	Fair	Good	Excellent
□	□	□	□	□

15. If I am asked to repeat a tune someone else has recently sung to me...

a) I can reproduce the tune perfectly.
b) I can remember the lyrics, but have problems with singing the tune.
c) I have problems with both the lyrics and tune.
d) I cannot do this at all.

16. If I imagine the tune 'Happy Birthday', I can hear the melody in my head with...

No accuracy	Poor accuracy	Some accuracy	Moderate accuracy	Perfect accuracy
□	□	□	□	□

17. Do you know your favorite songs by heart?

Yes	Sometimes	No
□	□	□

18. When music is being played in my environment (e.g., on the radio, in the store, on TV) I can recognize familiar songs by the first two or three notes...

Never   Rarely   Sometimes   Often   Very frequently

□   □   □   □   □

19. When I sing or hum along to my favorite recorded music...

     a) I can match the song note for note.
     b) I have difficulty landing on the same notes as the singer some of the time.
     c) I have difficulty landing on the same notes as the singer most of the time.
     d) I do not sing along to recorded music.

20. Singing a note to match one played on the piano is a task I find...

Impossible   Very difficult   A little difficult   Somewhat easy   Very easy

□   □   □   □   □

21. If someone played two notes on the piano separately and asked me which was higher in pitch, I would find this task...

Very difficult   Difficult   Neither easy nor difficult   Somewhat easy   Very easy

□   □   □   □   □

22. When I sing...

     a) I can tell when I am out of tune and can correct it.
     b) I can tell when I am out of tune, but I cannot correct it.
     c) I cannot tell when I am out of tune unless someone tells me.
     d) I do not sing.

23. When I sing, I perform best... (circle one)

     a) individually.
     b) in a small group.
     c) in a large group.
     d) I do not sing.

24. How often do you get a tune "stuck" in your head?

Never   Rarely   Sometimes   Often   Very frequently

□   □   □   □   □

25. In my opinion, someone has musical difficulties when they... (circle all that apply)

   a) cannot sing with a pleasant sound.   f) cannot recognize tunes.
   b) occasionally sing out of tune.   g) cannot identify notes in a scale.
   c) have a clinical hearing deficit.   h) cannot dance.
   d) always sing out of tune.   i) cannot match notes played on a piano.
   e) have little or no musical training.   j) dislike music.

THE END:

If there are any parts of your musical background that have not been asked, then please provide that information here. Thank you.

_____
_____
_____
_____

Your time and input is greatly appreciated.

Scoring: For likert-scale and multiple choice questions, answers were assigned a number ranging from zero to four. Zero indicated no musical experience and four indicated much experience. For yes/no questions, answers were assigned a zero for "no" answers and a one for "yes" answers. When applicable, open-ended questions were scored according to years of experience; otherwise judgment was used to evaluate answers given.

Appendix D: Scatterplots

Legend:
- CI_Sim_02
- CI_Sim_03
- CI_Sim_04
- CI_Sim_05
- CI_Sim_06
- CI_Sim_07
- CI_Sim_08
- CI_Sim_09
- CI_Sim_10
- CI_Sim_11
- CI_Sim_12
- CI_Sim_14
- CI_Sim_16
- CI_Sim_17
- CI_Sim_18
- CI_Sim_19
- CI_Sim_20
- CI_Sim_21
- CI_Sim_22
- NH_Orig_01
- NH_Orig_02
- NH_Orig_03
- NH_Orig_04
- NH_Orig_05
- CI_Orig_01
- CI_Orig_02
- CI_Orig_03
- CI_Orig_04
- CI_Orig_05
- CI_Orig_06
- CI_Orig_08
- CI_Orig_07
- CI_Orig_09
- CI_Orig_10

Overall Musical Appraisal (Avg) vs. AMICI Subtest 2 (Timbre)

Overall Musical Appraisal (Avg) vs. AMICI Subtest 3 (Genre)

Overall Music Appraisal (Avg) vs. UW-CAMP Timbre

Overall Musical Appraisal (Avg) vs. Questionnaire Part A (Early Experience)