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Clinical evaluation of music perception, appraisal and experience in cochlear implant users

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Abstract

Objectives—The objectives were to evaluate the relationships among music perception, appraisal, and experience in cochlear implant users in multiple clinical settings and to examine the viability of two assessments designed for clinical use.

Design—Background questionnaires (IMBQ) were administered by audiologists in 14 clinics in the United States and Canada. The CAMP included tests of pitch-direction discrimination, and melody and timbre recognition. The IMBQ queried users on prior musical involvement, music listening habits pre and post implant, and music appraisals.

Study sample—One-hundred forty-five users of Advanced Bionics and Cochlear Ltd cochlear implants.

Results—Performance on pitch direction discrimination, melody recognition, and timbre recognition tests were consistent with previous studies with smaller cohorts, as well as with more extensive protocols conducted in other centers. Relationships between perceptual accuracy and music enjoyment were weak, suggesting that perception and appraisal are relatively independent for CI users.

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Conclusions—Perceptual abilities as measured by the CAMP had little to no relationship with music appraisals and little relationship with musical experience. The CAMP and IMBQ are feasible for routine clinical use, providing results consistent with previous thorough laboratory-based investigations.

Keywords

Music; music perception; cochlear implant; music appraisal; hearing impairment

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Music is a pervasive acoustical form associated with emotional expression, quality of life, and social and cultural connection (Gfeller et al, 2000). There has been increasing interest on the part of clinicians and engineers to seek technical and rehabilitative approaches to improve the music perception and music enjoyment of cochlear implant (CI) users. Despite these considerations, music is rarely considered in clinical evaluations of CI benefit. This might be due in part to the extensive time commitment required for laboratory-based testing.

A growing body of laboratory-based studies has evaluated specific aspects of music perception (See reviews by McDermott (2004), Limb (2006), Drennan & Rubinstein (2008), and Limb & Rubinstein (2012)) and music appraisal in CI listeners (Gfeller et al, 2002b, 2003, 2008, 2010; Looi et al, 2007). The perceptual testing has generally utilized a thorough scientific approach, requiring more time than is feasible for clinical evaluations. Other batteries of music perception tests that have been used for CI listeners include the MuSIC test (Brockmeier et al, 2011) and the Montreal battery of the evaluation of amusia (MBEA) (Peretz et al, 2003; Wright & Uchanski, 2012). Both of these tests require 2–3 times the testing time of the Clinical Assessment of Music Perception (CAMP), so are not viable for routine clinical use. The appreciation of music in cochlear implantees (AMICI) test (Cheng et al, 2013; Spitzer et al, 2008) offers a comparable test time to the CAMP but provides substantially less control over the stimuli.

The present study employs a clinical assessment test, the CAMP, initially described by Nimmons et al (2008) and validated by Kang et al (2009) at the University of Washington with post-lingually deafened speakers of American English. Validation of the CAMP involved establishing content and construct validity. It demonstrated that the CAMP successfully measured what it intended to and behaved as expected based on previously established relationships with other clinical measures. Kang et al also verified excellent test-retest reliability. The CAMP, which can be administered in 30–40 minutes, includes three basic perception tests designed to evaluate three specific music perception abilities in cochlear implant users: pitch direction discrimination, familiar melody recognition, and timbre recognition. These tests assess several aspects of music that are relevant to real-life music listening.

Previous CAMP results were consistent with more extensive laboratory studies of music perception tests. Kang et al's (2009) CAMP timbre discrimination results of 45.3 percent correct, were, in particular, highly consistent with Gfeller et al (2002b) and McDermott (2004) who reported timbre perception tests score means of 47 and 51 percent correct, respectively. Rhythmless melody perception scores of 29% reported by Galvin et al (2007) were similar to Kang et al's (2009) result of 25% and similar to Kong et al's (2005) mean result of 28%. In an earlier study, Gfeller et al (2002a) reported a 12 percent correct score for CI users. For pitch, Gfeller et al (2002a) found worse thresholds (7.6 semitones) than Kang et al (2009) (3.0 semitones). The differences in scores between the Gfeller and Kang studies are likely due to population differences and the different methodology.

Perceptual accuracy, however, is not the only important aspect of music listening. The extent to which a listener enjoys music is of considerable interest, given that most people listen to music for purposes of entertainment, aesthetic appreciation, or for positive mood enhancement (Looi et al, 2012; Gfeller et al; 2008, 2010; Laukka, 2007; Wright & Uchanski, 2012). Such rating of musical sound quality is of clinical relevance, being directly related to the CI patients' satisfaction for everyday music listening. Gfeller et al (2008), found little to no relationship between pitch ranking, timbre and familiar melody recognition and appraisal ratings. Some weak effects of training and experience were found on these music perception factors. Wright and Uchanski (2012), using 10 CI listeners, evaluated different musical appraisal factors using a 7-point rating scale, correlating to results from a number of different perception tests (AMICI, the CAMP, and the MBEA). They found no significant correlations between appraisals and perception test scores; however, the generalizability of these findings are limited by the small number of listeners. Given that these previous results were obtained in a controlled laboratory environment, and often with more time-consuming tests, translation of the science into the clinic, in order to adequately assess clinical outcome, requires evaluating music perception, appraisal, and experience in a clinical setting.

The present study was executed by clinicians in clinical settings at 14 cochlear implant clinics in the United States and Canada, using a cohort of 145 cochlear implant users. The study utilized two assessment tools, the CAMP (Kang et al, 2009, Nimmons et al, 2008), and the Iowa musical background questionnaire (IMBQ) (Gfeller et al, 2000, 2003). The IMBQ is a self-report questionnaire in which CI users respond to survey questions to describe the quality of music through the CI. The IMBQ also examines other factors that prior experiments suggest might influence music listening, such as musical training and music listening habits, before and after treatment with a cochlear implant (Gfeller et al, 2008, 2010). The aim of the present study is to translate previous research on the CAMP and IMBQ into a clinical setting to determine the extent to which they yield meaningful results in such an environment.

Methods

Listeners

One hundred and forty-five adult, post-lingually deafened CI listeners were recruited by their audiologists in the United States and Canada. The participants used either Advanced Bionics (N = 48) or Cochlear devices (N = 97). The CAMP was intended to measure hearing ability with a CI; therefore, listeners who used contralateral hearing aids were plugged in the aided ear. Bilateral CI users were tested with both devices. The number of bilateral users and contralateral hearing-aid users could not be determined, because this information was not established a priori as an item of interest for this study and that data could not be recovered from all the centers. Listeners ages ranged from 22 to 85 years old, (M = 57.7 years; SD =

14.0 years) at the time of testing. Implant experience ranged from 0.5 to 22 years, (*M* = 4.0 years; SD = 3.7 years). Duration of profound deafness ranged from 0.25 to 63 years (*M* = *14*.7 years; SD = 14.4 years). The work was approved by the Institutional Review Boards at each of the 14 sites.

Clinical assessment of music perception (CAMP)

The CAMP, initially developed by Nimmons et al (2008) and validated by Kang et al (2009), was designed to be a clinically meaningful assessment of music perception capabilities for CI users. The CAMP was administered in sound-attenuating booths, presenting sounds at 65 dBA over a loudspeaker meeting ANSI standards for speech audiometry. A tone was used for calibration with the rms matched to the music stimuli. The audiometer was used to calibrate the level measured with a sound level meter one metre from the speaker. Administered in 30–35 minutes, the CAMP consists of a pitch direction discrimination test, a melody recognition test and a timbre recognition test.

Pitch direction discrimination test—The pitch direction discrimination test is a two-alternative forced-choice (2AFC) task in which the listeners were asked to identify one of two complex tones that was higher in pitch. Listeners responded using a computer mouse, choosing one of two response options. The test used harmonic complexes with multiple sinusoids and a fixed, synthetic temporal envelope roughly resembling that of a piano. Additional details of the stimulus construction for the CAMP were presented by Nimmons et al (2008). These harmonic complexes were selected to have a controlled temporal envelope and duration but also to have many natural characteristics depicting “real-world” musical tones. Each tone lasted 760 ms. The test used three fundamental frequencies (262, 330, 391 Hz), corresponding to middle C, and the E and G above. Four practice trials with feedback were provided to ensure that the participant understood the test instructions and procedures. Subsequent testing was done without feedback. Thresholds were measured with a one-up, one-down tracking procedure (Levitt, 1971). Three interleaved adaptive tracks of the three frequencies were administered such that listeners heard a sequence of two-tone trials in which the order of fundamental frequencies presented was randomly selected, but presented within the course of three independent and interleaved adaptive tracking histories, one tracking history for each fundamental. The final threshold was calculated as the mean of the last 6 of 8 reversals for each adaptive track. These were averaged across the three repetitions and then across the three frequencies to obtain the final measure of pitch direction discrimination ability. Tracks began with an interval of 12 semitones (an octave) and the step size was one semitone. If the listener was correct when there was a 1-semitone difference, a reversal at 0 semitones was automatically added and they were tested again at 1 semitone. Thus, if listeners were 100% correct at 1 semitone, their estimated threshold was 0.5 semitones. Twelve semitones was the largest interval tested such that if listeners got an incorrect answer at 12 semitones, the tracked frequency difference stayed at 12 semitones. In practice, less than 1% of participants were at this level of performance.

This method was intended to be rapid for clinical use. This approach has been criticized because it estimates a point near the left most end of the psychometric function near chance levels; however, the method has been shown to be highly reliable (Kang et al, 2009) with a test-retest Chronbach's alpha of 0.91. Furthermore, the Spearman-Kärber method (Ulrich & Miller, 2004) was used by Won et al (2010) to compare thresholds from the mean-of-reversals approach to an approach based on extracting the raw psychophysical data from the tracking history. Percent correct was calculated at each pitch difference visited during the tracking history by collapsing data over all trials. These data were used to estimate a point at 75% on a psychometric function using the Spearman-Kärber method. The mean-of-reversals scores from the CAMP correlated extremely highly (r = 0.97) (Won et al, 2010) with threshold estimates for 75% correct. Additionally, pitch thresholds measured with this method correlated significantly with a "gold" clinical standard of consonant nucleus consonant (CNC) word recognition ($r_P = 0.56$, $p < 0.001$) and with speech understanding in noise (Won et al, 2010). All of these factors indicate this pitch test provides highly reliable and clinically meaningful results. Of particular importance is the utility of the test, as demonstrated by the growing evidence of its effectiveness, reproducibility, and validity (Kang et al, 2009, Won et al, 2010). In the clinical setting, the brief time required for administration outweighs theoretical concerns that are arguably inconsequential for this specific test.

Melody recognition test—The melody recognition test consisted of a closed set of 12 isochronous melodies known to be familiar to the general US population, created using the complex tones from the pitch tests. Each listener was required to listen to each melody two times prior to testing by clicking on a box with the melody name. The melody stimuli were presented as 16 eighth notes at 60 beats per minute. Rhythmic cues were removed by using the isochronous presentation, using tones of equal duration A longer tone, such as a half note, would be converted to four repeated eighth notes. In this way, each melody differed only in fundamental frequencies. The melodies included the familiar tunes "Frère 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". Fundamental frequencies ranged from 257 to 523 Hz. Additional details of the melody stimuli are presented in Nimmons et al (2008). Each melody was presented three times in a random order. Listeners identified the melody they heard by clicking on one of 12 boxes, each labeled with a melody name. Results were scored as percent correct, with chance performance equal to 8.25%.

Timbre test—The timbre test assessed the listener's ability to recognize eight commonly heard musical instruments in a closed-set task. The stimuli consisted of eight recorded musical instruments: piano, violin, cello, acoustic guitar, trumpet, flute, clarinet, and saxophone. The instrumentalists performed a standardized, melodic pattern with five equal-duration, separated tones, C4, A4, F4, G4, C5, spanning the F0 range 262 to 523 Hz The amplitudes of each tone were normalized to a constant rms. Listeners were presented with each timbre two times prior to testing by clicking on a picture of the instrument twice, once for each presentation. Each instrument was presented three times in a random order. Listeners selected the name of the instrument they heard in the closed-set task. Results were scored as percent correct, with chance performance of 12.5%. Additional details about the stimuli are in Nimmons et al (2008).

Iowa musical background questionnaire (IMBQ)

Ninety-seven of the 145 participants completed the IMBQ. This questionnaire was developed to quantify music training, listening experiences, sound quality, and attitudes regarding music prior to and following implantation. A large proportion of questions in this measure were based upon an earlier version of the music background questionnaire (MBQ), described in detail by Gfeller et al (2000), but modified to focus on more general life experiences with music than on specific research questions addressed in the MBQ. Because questionnaire data from CI recipients (Looi & She, 2010) indicate distinct differences in music experiences between the time prior to hearing loss, and after hearing loss, but before implantation, self-report items specific to the pre-implant period of hearing loss were integrated into the IMBQ.

The questions in the IMBQ were selected and refined through collaborative input of CI recipients and professionals possessing familiarity with cochlear implants as well as expertise in disciplines of clinical psychology, biostatistics, music education, music therapy, and audiology. Initial drafts of the IMBQ were completed by a group of adult CI recipients, while the test administrator noted any problems with content or clarity. The revised draft was given to three audiologists and three adult implant recipients, who evaluated the document for clarity, appropriateness, and comprehensiveness of the items. After revisions were made, the manuscript was reviewed once again by two audiologists, three adult implant recipients, and four professionals involved in the research and design of CIs. The final version, which was a computerized version of the questionnaire, consisted of 15 items including multiple choice questions, Likert-type rating scales, visual analog scales, and open-ended questions. The computer version permitted access by clinicians using a password-protected website. The time to complete the assessment ranged from 15–25 minutes.

The final IMBQ included several categories of questions, as follows:

Music training and involvement—Questions regarding music training and involvement measured both the type(s) (e.g. lessons, classes), and extent of musical training or formal participation in years (e.g. band, choir, orchestra) at various ages/levels of education: elementary school, junior high, senior high school, college, and after formal education. Each of these age/educational levels is characterized by different cognitive and social development, as well as different educational objectives.

Music listening hours—Questions regarding amount of time spent in music listening were broken out into two time periods: prior to hearing loss and after implantation. Questions specific to music listening habits quantified the respondent's usual amount of music listening in a typical week.

Sound quality ratings—This section asked respondents to describe the sound quality of music through their CI using six bipolar adjectives (rating of 0 to 10) identified in prior research as relevant to musical sounds (Gfeller et al, 2000; Gabrielsson et al, 1990) (e.g. empty vs. full; unpleasant vs. pleasant; clear vs. fuzzy). These six items were condensed into an overall sound quality rating score. Listeners were asked to provide the ratings within the context of specific listening circumstances (e.g. over a car radio, in a concert, in place of worship). A 7th bipolar adjective of complex-simple was determined through preliminary analyses to be unrelated to the other six bipolar adjectives. Therefore, complex-simple was presented in the analysis as a separate variable. Responses were tallied as either positive (+), neutral (0), or negative (−).

Attitudes about music—Respondents were asked for a general assessment of attitude toward music before hearing loss (BHL), after hearing loss and before implantation (AHL), and after receiving a cochlear implant (ACI). The responses for attitudes about music were: (1) avoided, (2) never listened, (3) listened but unimportant, (4) listened but difficult, (5) listened and important, (6) listened and enjoyed. Respondents were instructed to select all options that apply. For analysis, the responses were categorized as positive, neutral, and negative.

The four categories of variables listed above which were derived from the IMBQ include combined scores or scores derived from factor analyses of several questionnaire items. The acronyms and description of the variables derived from the IMBQ appear in Table 1.

Results

Demographic variables

Demographic variables for the population are shown in Table 2. These variables include mean age at the time of testing (AGE), duration of profound deafness in years, and duration of CI use in years (USE).

Music perception scores and their distribution

Pitch direction discrimination is reported as the average scores for the three F0s tested. The distribution for the test is shown in Figure 1. Average discrimination performance was 2.95 semitones with a median of 2.31 semitones. Scores ranging from a 0.5 semitone (the minimum) to an 11.8 semitone difference required for discrimination. Mean scores for individual frequencies were 3.15, 2.59, and 3.11 semitones for F0 = 262, 330, and 391 Hz, respectively. A statistically significant difference was found comparing 262 Hz ($p = 0.023$) and 391 Hz ($p = 0.019$) each with 330 Hz, but not between 262 and 391 Hz ($p = 0.863$). The two significant comparisons remained statistically significant after Bonferroni-Holm (Holm, 1979) correction for Type 1 familywise errors. These differences, however, were not consistent across studies. Kang et al (2009) reported 2.9, 3.4, and 2.5 semitones for 262, 330, and 391 Hz, respectively ($N = 33$), but did not report p values. The small differences observed with this larger cohort have no clinical significance, so only average data were considered in subsequent analyses.

The standard deviation of the distribution ($N = 145$) was 2.4. The skewness for the pitch distribution was 1.34 and the standard error was 0.20, indicating that the distribution was not symmetric. The kurtosis was 1.43 with a standard error of kurtosis of 0.40, indicating the distribution was more peaked than a normal distribution.

Figure 2 shows the distribution of performance for the melody recognition test. Performance averaged 26.2 percent correct with a median of 19 percent correct. Scores ranged from 0 to 94% correct with a standard deviation of 19.9. The melody distribution had a skewness of 1.31 with standard error 0.20, indicating the distribution was not symmetric. Kurtosis was 1.31 with a standard error of 0.40, indicating that the distribution was more peaked than a normal distribution. The upper bound of the 95% confidence interval denoting chance for a single repetition of the melody test is 19%, i.e. there was less than a 2.5% chance that listeners performing above 19% correct were guessing. Thus, about half of the listeners were performing at chance levels.

The distribution of the timbre recognition test is shown in Figure 3. The mean timbre score was 43.2 percent correct with median performance being 42 percent correct. Performance ranged from 12 to 83 percent correct with a standard deviation of 22%. Skewness was 0.37 with a standard error of 0.20, indicating there was not a significant skew. Kurtosis was 0.39 with a standard error of 0.40, indicating no significant peaking. The upper bound of the 95% confidence interval for chance performance was 29 percent correct. Seventy-eight percent of the participants scored above chance levels.

Table 3 shows performance means for each decile of the tested population on each test. The first decile shows the mean for listeners among the least sensitive 10%. The tenth decile is the mean performance for the top 10%.

Significant correlations were found among the CAMP measures. These confirm previous reports, e.g. Kang et al (2009) and Won et al (2010), but the present manuscript included about four times as many listeners. Spearman, non-parametric correlations were used because the distributions were skewed. Pitch performance was moderately correlated with melody performance, Spearman $r_s = -0.51$ ($p < 0.0005$). The scatter plot (Figure 4) indicates that with few exceptions, pitch direction discrimination ability was required but not sufficient for melody identification. The correlation between melody and timbre was significant ($r_s = 0.36$, $p < 0.0005$). A weaker but significant relationship was found between melody and pitch direction discrimination ($r_s = -0.27$, $p < 0.001$).

Distribution of scores on the Iowa musical background questionnaire (IMBQ)

Musical training—Years of musical training were recorded for grade school (MT1) and for high school, college and beyond (MT2). For MT1, respondents averaged 2.3 years of training with a standard deviation of 1.7 years. For MT2, respondents averaged 1.2 years of training with a standard deviation of 1.6 years.

Music listening hours—Music listening hours were reported categorically as listening hours per week with five categories: 0 is “none”, 1 is “less than 2”, 2 is “3–6”, 3 is “6–9”, and 4 is “greater than 9”. Figure 5 shows the distribution of listening hours before loss and after implantation. The median number of listening hours before loss was about 9 hours, whereas the median number of listening hours after implantation was about 2 hours. The before-loss distribution of listening hours was significantly skewed to the high end (skewness = −0.61; standard error 0.20), whereas after implantation, the distribution was significantly skewed to the low end (skewness = 0.48; standard error 0.20).

Sound quality—Rating scales were used to evaluate the appraisals of the quality of music after implantation. Table 4 shows the means and standard deviations of the main appraisal questions. The unpleasant vs. pleasant rating in Table 4 compares average pleasantness ratings for a variety of situations including at a concert, on the radio, in worship, when making music, and with background music.

Attitudes about music—General attitudes about music were divided into three categories: positive (2), neutral (1), and negative (0). Averages scores were 1.70 BHL, 0.78 AHL, and 0.90 ACI. Thus, attitude improved slightly after implantation but not nearly to the level observed BHL.

Relationships between the CAMP and IMBQ

Musical training—Individually, elementary school (MT1), and high school/adult musical training (MT2) before implantation showed little to no correlation with CAMP scores. There was a weak correlation between MT2 and pitch direction discrimination (Spearman $r_s = -0.139$, $p = 0.048$, $N = 144$).

Given the large variations in CAMP performance as a function of musical training, the metrics were combined and the group was divided into quartiles for analysis. The underlying hypothesis was that the quartile with the most music training would have the best perception scores. About half of the listeners had no training in the MT2 category (high school and adult training), so the group was sorted by MT2 first, then by MT1. Table 5 shows mean performance for each music perception test as a function of quartile with the 95% confidence intervals. Non-parametric Kruskall-Wallis tests showed that musical training experience had a relationship with timbre recognition ($p = 0.026$). Musical training thus appears to have a small effect on timbre perception, but did not show any significant effect on pitch or melody perception.

Sound quality ratings—Table 6 shows Spearman correlations between the three CAMP measures and sound quality ratings (SQR). Using a Bonferroni-Holm (Holm, 1979) adjustment, only two Spearman correlations were statistically significant. The unnatural-natural scale was correlated with timbre at $r_s = 0.35$, and the not-like-music vs. like-music scale was correlated with pitch direction discrimination at $r_s = -0.32$. Other weak trends with p values less than 0.05 are shown on the table. These non-bold values did not hold as statistically significant after the Bonferroni-Holm (Holm, 1979) corrections, but stringent application of these rules could result in Type 2 errors—namely concluding that there was no relationship when there really was a relationship. It is clear though that all of the relationships between quality ratings and CAMP results were weak.

Attitudes about music—Attitudes about music BHL, AHL and ACI were classified as positive, negative, or neutral. BHL: 77% of the participants had positive attitudes toward music, 16% were neutral, and 7% negative. AHL: only 28% reported positive attitudes, while 23% neutral and 49% negative. ACI: the number of participants with positive attitudes toward music increased slightly to 35.5%. Those groups indicating neutral and negative attitudes fell slightly to 19.5% and 45%, respectively. A large, significant relationship was found between music listening hours after implantation and attitude toward music. For CI users, the Cochran-Mantel-Haenzael trend test of row means in Table 7 showed a highly significant relationship ($p < 0.0001$) between listening hours and general positive or negative attitude toward music.

Music listening hours (MLH)—Small but statistically significant correlations were found between music listening hours after implantation (MLH-ACI) and all three CAMP tests: MLH-ACI and pitch direction discrimination thresholds ($r_s = -0.200$, $p = 0.049$, N = 97); MLH-ACI and melody performance ($r_s = 0.227$, $p < 0.025$, N = 97); MLH-ACI and timbre ($r_s = 0.267$, $p < 0.008$, N = 97. No CAMP tests were significantly correlated with MLH-BHL.

Age, duration of deafness, and duration of implant use (USE)—A significant negative correlation was found between AGE at time of testing and timbre at the time of testing ($r_s = -0.36$, $p < 0.0003$). Younger people had better timbre scores. AGE was also correlated with MLH-ACI ($r_s = -0.43$, $p < 0.0001$), suggesting that younger people also listened to music more often. Given that MLH-ACI was also correlated with melody and timbre performance, it is not entirely clear if age, listening hours, or both influence music perception ability. A small correlation was found between melody and USE, $r_s = -0.21$ ($p < 0.04$). No relationship was found between duration of deafness and any of the CAMP measures.

Discussion

The present study verifies that the CAMP translates well into a clinical setting. Results were consistent with previously published reports of laboratory-based CAMP results (Kang et al, 2009; Nimmons et al, 2008). The present study enrolled a cohort about four times larger, and tests were successfully administered in multiple clinical settings. The larger cohort provides additional evidence of the generalizability of the distributions of scores for each subtest. Mean values in the present study were close to those reported by Kang et al (2009). For pitch-direction discrimination, the mean was 2.93 semitones in Kang et al vs. 2.95 in the present study; the mean melody recognition score was 25.1% in Kang et al vs. 26.2% in the present study. Average timbre score was 45.3% in Kang et al vs. 43.2% in the present study.

The correlations among CAMP measures were all statistically significant and in the same direction as those reported by Kang et al, who used Pearson correlations; therefore, the correlations in this data set were recalculated using Pearson correlations for comparison. The following Pearson correlations were reported in the Kang et al study (r_K) results and in the present study (r_D): Pitch vs. melody $r_K = -0.57$, $r_D = -0.41$; pitch vs. timbre, $r_K = -0.64$, $r_D = -0.24$; timbre vs. melody, $r_K = 0.68$ vs. $r_D = 0.42$. A meta-analysis showed no statistically significant difference between the pitch vs. melody correlations ($p = 0.34$), marginally significantly lower correlations were found for pitch vs. timbre ($p = 0.02$), and for timbre vs. melody ($p = 0.05$). This might be related to this study's use of multiple centers, which would introduce different testing chambers with different speakers, and multiple clinicians for testing.

CAMP results are consistent with other more time-consuming assessments of music perception intended for clinical use, e.g. the musical sounds in cochlear implants perception test (Brockmeier et al, 2011) and the MBEA (Peretz et al, 2003; Wright & Uchanski, 2012), which both require about 90 minutes to administer. The melody and timbre tests of the MuSIC test showed similar differences between NH and CI users as the CAMP showed. The interval test from the MBEA (Wright & Uchanski, 2012) and the melodic contour identification test (Galvin et al, 2007) showed CI results similar to the CAMP. The appreciation of music in cochlear implantees (AMICI) (Spitzer et al, 2008; Cheng et al, 2013) offers a clinically viable duration (< 30 minutes), but uses a different focus with tests for musical style and musical piece identification extracted from "real-world" recordings, unlike the more controlled CAMP tests. With the AMICI, it is possible for CI users to employ rhythm cues to identify melodies. The CAMP was designed to test pitch pattern discrimination, using common melodies with an isochronous rhythm. Rhythm discrimination ability is known to be nearly normal in CI users (Gfeller et al, 1997; Brockmeier et al, 2011; Drennan & Rubinstein, 2008; Shannon, 1993; Leal et al, 2003; Kong et al, 2004; McDermott, 2004); therefore, evaluating melody perception with rhythm cues available provides limited information about CI users' abilities to discriminate pitch patterns. Without the use of isochronous melodies, it is not possible to determine if the CI user is using pitch information or rhythmic information to do the task. The results from the AMICI however show moderate correlations with speech understanding like the CAMP, and the AMICI yields timbre discrimination differences between NH and CI users similar to the CAMP test. CAMP results are also largely consistent with findings from other more extensive laboratory-based perceptual testing (Kong et al, 2004; Gfeller et al, 2002a, 2002b). Previous reports with different measures of pitch, timbre, and melody perception found similar relationships (Gfeller et al, 1998, 2005, 2007; Olszewski et al, 2005).

The construct validity of the CAMP has been further supported in ongoing FDA trials of the Nucleus Hybrid-L implant (ClinicalTrials.gov, NCT00678899) and the CI422 (ClinicalTrials.gov, NCT01867008). Data published by the FDA (Cochlear, 2013) on the Hybrid trial (N = 50) showed that when residual hearing was preserved in hybrid implantation, performance on the pitch direction discrimination was not statistically different from the normal hearing performance reported by Kang et al (2009). However, when residual hearing was lost, i.e. when there was no acoustic information available, performance thresholds averaged about 3 semitones, similar to CI performance. This observation supports the construct validity of the test, i.e. the test is behaving as expected given the condition of the patient. More specifically, the finding supports discriminate validity of the CAMP, because it can successfully differentiate different subgroups.

Concerning potential international use, it should be noted that these tests were conducted in English-speaking North America. The pitch direction discrimination test is appropriate for international use. The timbre test uses instruments that are common in many countries across multiple continents, although some modification might be required for instruments if the instruments are not common in the country in which the test is to be used. The melody test is the most culturally specific, although some of the melodies are common internationally. The melody test should be modified for different languages and international use to ensure a higher probability of familiarity for the intended group of patients. Version of the CAMP have been made in Korean (Kim et al, 2012; Jung et al, 2010), Japanese and Dutch (unpublished) using melodies common to those countries, including some melodies that were in the original CAMP. The MCI test (Galvin et al, 2007) offers generic, unfamiliar pitch contours, although it has not yet been formally validated.

CAMP confidence intervals

Kang et al (2009) demonstrated good test-retest reliability for the CAMP and established content and construct validity; however, that study did not report confidence intervals for a single run of the test in a single listener, nor did it analyse a possible test-retest learning effect. The Kang et al data were reanalysed by calculating the difference in scores between the first and second run on each subtest and determining the mean and confidence intervals.

The pitch direction discrimination *test-retest difference scores* (N = 27) had a mean of 0.01 semitones with a standard deviation of 1.24 semitones, indicating no learning. The 95% confidence interval was estimated as twice the standard deviation equal to 2.48 semitones. Thus, if an individual listener takes the CAMP in two different conditions, a threshold difference of more than 2.48 semitones would be considered significant. For groups of listeners in clinical research, the confidence interval would likely be smaller, dependent upon group variance. Supporting the reliability and validity of the pitch direction discrimination test, a paired t-test of the two runs showed no learning ($p = 0.83$). Additionally, the data correlated well with standardized speech tests ($r_s = -0.55$ with monosyllabic words).

For the melody test, the mean difference of the first to second run was 2.70 percent correct with a standard deviation of 9.47 percent and confidence interval of 8.9 percent correct. A paired t-test of the difference scores (N = 35) showed no statistically significant learning ($p = 0.10$).

For the timbre test, the mean difference (N = 35) between the first and second run was 6.07 percent correct with a standard deviation of 14.02, corresponding to a 95% confidence interval for an individual of about 28%. A paired t-test showed a statistically significant learning effects ($p = 0.016$). The larger variance for this measure might be partly due to fewer trials (24 in the timbre test vs. 36 in the melody test). The test-retest variability and learning effect limits the utility of the timbre test for testing individuals with a single run. Multiple runs might mitigate the effect, but the number of repetitions needed to reach asymptotic performance remains to be determined. When testing in clinical research, however, the order of testing different conditions can be randomized, mitigating the effect.

IMBQ results and their relationships with CAMP data

This multi-clinic sample of CI users yielded a distribution of IMBQ scores for sound quality, time spent listening after CI use, and general attitudes about music consistent with the prior studies (Gfeller et al, 2000, 2008, Looi et al, 2012). More detailed discussion of the relationships between the IMBQ and the CAMP are listed below.

Musical training—This study found weak relationships between high school and college music training (MT2) and music perception on the timbre and pitch tasks. Consistent with these results, Gfeller et al (2008) found that MT2 contributed to the variance of timbre recognition and pitch ranking, using non-clinical perception measures in a large cohort. Gfeller et al also found that MT2 contributed to familiar melody recognition and musical expert recognition, but this was not observed with the CAMP's melody recognition test. This might be due to the CAMP melody test having controlled, synthesized stimuli without isochronous rhythm.

Sound quality rating—Wright and Uchanski (2012) used the CAMP test with a small number of CI users (10) and reported little to no significant relationship between perceptual acuity and appraisal measures. This study verified this preliminary result with a substantially larger cohort. Statistically significant correlations were found between CAMP's timbre test and music appraisal results, but the relationships were weak. Previous work by Gfeller et al (2008) using different, laboratory-based tests for pitch ranking, timbre and melody perception, also did not find any predictive power of perceptual abilities for appraisal ratings. Gfeller et al (2008) reported, however, that hearing-aid use influenced appraisal measures. The CAMP in this study was conducted *without* hearing aids, even if patients used them regularly. This might account for some of the lack of relationship between these measures, as the appraisal ratings might be influenced by hearing-aid use. Another factor that might have contributed to the lack of relationship between appraisal and perception measures is that pitch and melody tests of the CAMP did not use "real-world" stimuli. The CAMP was designed to use simple, controlled stimuli to assess basic music perceptual abilities such as pitch contour identification, whereas the IMBQ was a subjective test based on "real-world" experiences. "Real-world" music stimuli such as polyphonic music, music in a reverberation room or dynamic music (covering a broad range of sound levels) were not used in the CAMP. It is clear though that musical perceptual acuity is not closely related to quality ratings. This might not necessarily be due to the CAMP's controlled stimuli differing from the "real world", but the fact that CI users can have poor perceptual abilities and still like music or vice versa. Acuity and appraisal are both important clinical outcomes, one addressing patient function (acuity) and the other addressing patient feeling, satisfaction with aesthetic aspects of sound (appraisal). Thus, in order to provide a holistic clinical assessment, both types of testing should be used, as noted by Gfeller et al (2008).

Attitudes about music—After implantation, an improvement in general attitude toward music was observed over their experience while deaf, prior to CI use; however, attitudes were still much less positive than attitudes prior to hearing impairment. This is consistent with findings of Looi and She (2010) that suggest that CI users find musical experiences are better than their experiences prior to implantation, yet their music experiences with a CI were still disappointing. Looi et al (2007) also found sound quality ratings were better after implantation than prior to implantation when listeners were using hearing aids with profound hearing loss. In counseling patients, it should be noted that their music experiences will not be normal, but might be better than musical experiences after hearing loss and prior to implantation.

Music listening hours—Listening hours after implantation showed modest but statistically significant relationships with results from all three CAMP tests. Gfeller et al

(2008, 2010) also reported more listening hours were associated with higher acuity and appraisal scores. Perceptual abilities might improve with CI music training or focused music listening; however, it is not entirely clear if CI users with better music perception abilities are better because they listened more, or if they listened more because they had better perceptual abilities and better attitudes toward music. It should be noted that previous research indicates training can improve music perception and appraisal (Galvin et al, 2009; Looi et al, 2012; Looi & She, 2010). Galvin et al (2009) demonstrated melodic contour identification can sometimes improve substantially with training. Looi and She (2010) noted that patients should be advised to explore what types of music are most enjoyable to them. Focused listening to enjoyable music is likely to improve CI users' experiences.

Age, duration of deafness, and duration of CI use—Younger patients were found to have better CAMP timbre perception, consistent with prior studies using a different timbre test (e.g. Gfeller et al, 2008, 2010), and younger CI users also listen to music more. This might be related to the known effects of age on cognitive function (Harada et al, 2013; Blamey et al, 1996; CHABA, 1988; Craik & Salthouse, 2008) or because younger CI users listen more. Other factors which typically predict CI benefit for speech, e.g. the length of profound deafness and length of CI use, were not related to music perception ability, appraisal or enjoyment.

In summary, this multicenter CAMP and IMBQ trial showed that these measures can be used effectively in multiple clinical settings within North America. The study found that for CI users, the relationships between music perceptual capabilities, appraisal, and musical experiences were weak to nonexistent, demonstrating that previous findings in laboratory settings can be translated well into clinics by use of the CAMP and IMBQ. The CAMP and IMBQ each provide independent, complementary and clinically relevant information about CI outcomes, addressing patient function and satisfaction with listening experiences, respectively. Modifications to the melody section of the CAMP can be made for use in other cultures (e.g. Jung et al, 2010). Both measures provide additional information on CI outcome over and above traditional speech testing and could be useful for clinical trials, clinical research or individual assessments for patients.

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Abbreviations

ACI	After cochlear implant
AHL	After hearing loss
AMICI	Appreciation of music in cochlear implantees
BHL	Before hearing loss
CAMP	Clinical assessment of music perception
CI	Cochlear implant
CNC	Consonant nucleus consonant
IMBQ	Iowa musical background questionnaire
LPD	Length of profound deafness
M	Mean
MBEA	Montreal battery of the evaluation of amusia
MBQ	Musical background questionnaire
MCI	Melodic contour identification
MT1	Music training in grade school
MT2	Music training in high school and adulthood
MLH	Music listening hours
SD	Standard deviation
SQR	Sound quality ratings
USE	Duration of CI use in years

References

Blamey P, Arndt P, Bergeron F, Bredberg G, Brimacombe J, et al. Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants. Audiol Neurotol. 1996; 1:293–306.

Brockmeier SJ, Fitzgerald D, Searle O, Fitzgerald H, Grasmeder M, et al. The MuSic perception test: A novel better for testing music perception of cochlear implant users. Cochlear Implants Int. 2011; 12:10–20. [PubMed: 21756454]

Committee on Hearing, Bioacoustics and Biometrics (CHABA). Working Group on Speech Understanding and Aging. J Acoust Soc Am. 1988; 83:859–895. [PubMed: 3281988]

Cheng MY, Spitzer JB, Shafiro V, Sheft S, Mancusco D. Reliability measure of a clinical test: Appreciation of music in cochlear implantees (AMICI). J Am Acad Audiol. 2013; 24:269–279.

Cochlear, L. *P130016: Nucleus® Hybrid™ L24 Implant System* [Online]. 2013. Available: http://www.fda.gov/downloads/AdvisoryCommittees/CommitteesMeetingMaterials/MedicalDevices/MedicalDevicesAdvisoryCommittee/EarNoseandThroatDevicesPanel/UCM373793.pdf

Craik, FIM.; Salthouse, TA., editors. Handbook of Aging and Cognition. New York: Psychology Press; 2008.

Drennan WR, Rubinstein JT. Music perception in cochlear implant users and its relationship with psychophysical abilities. J Rehabil Res Dev. 2008; 45:779–789. [PubMed: 18816426]

Gabrielsson A, Hagerman B, Bech-Kristensen T, Lundberg G. Perceived sound quality of reproductions with different frequency responses and sound levels. J Acoust Soc Am. 1990; 88:1359–1366. [PubMed: 2229671]

Galvin JJ 3rd, Fu QJ, Shannon RV. Melodic contour identification and music perception by cochlear implant users. Ann N Y Acad Sci. 2009; 1169:518–33. [PubMed: 19673835]

Galvin JJ, Fu QJ, Nogaki G. Melodic contour identification by cochlear implant listeners. Ear Hear. 2007; 28:302–319. [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; 40:78–112. [PubMed: 14505444]

Gfeller K, Christ A, Knutson J, Witt S, Murray KT, et al. Musical backgrounds, listening habits and aesthetic enjoyment of adult cochlear implant recipients. J Am Acad Audiol. 2000; 11:390–406. [PubMed: 10976500]

Gfeller K, Jiang D, Oleson J, Driscoll V, Knutson J. Temporal stability of music perception and appraisal scores of adult cochlear implant recipients. Am Acad Audiol. 2010; 21:28–34.

Gfeller K, Knutson JF, Woodworth G, Witt S, Debus B. Timbral recognition and appraisal by adult cochlear implant users and normal-hearing adults. J Am Acad Audiol. 1998; 9:1–19. [PubMed: 9493937]

Gfeller K, Oleson J, Knutson JF, Breheny P, Driscoll V, et al. Multivariate predictors of music perception and appraisal by adult cochlear implant users. J Am Acad Audiol. 2008; 19:120–134. [PubMed: 18669126]

Gfeller K, Olszewski C, Rychener M, Sena K, Knutson JF, et al. Recognition of "real-world" musical excepts by cochlear implant recipients and normal-hearing adults. Ear Hear. 2005; 26:237–250. [PubMed: 15937406]

Gfeller K, Turner C, Mehr M, Woodworth G, Fearn R, et al. Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults. Cochlear Implants International. 2002a; 3:31–55.

Gfeller K, Turner C, Oleson J, Zhang X, Gantz B, et al. Accuracy of cochlear implant recipients on pitch perception, melody recognition and speech reception in noise. Ear Hear. 2007; 28:412–423. [PubMed: 17485990]

Gfeller K, Witt S, Woodworth G, Mehr MA, Knutson J. Effects of frequency, instrumental family, and cochlear implant type on timbre recognition and appraisal. Ann Otol Rhinol Laryngol. 2002b; 111:349–356. [PubMed: 11991588]

Gfeller K, Woodworth G, Robin DA, Witt S, Knutson JF. Perception of rhythmic and sequential pitch patterns by normally-hearing adults and adult cochlear implant users. Ear Hear. 1997; 18:1–15. [PubMed: 9058033]

Harada CN, Love MCN, Triebel KL. Normal cognitive aging. Clin Geriatr Med. 2013; 29:737–752. [PubMed: 24094294]

Holm S. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics. 1979; 6:65–70.

Jung KH, Cho YS, Cho JK, Park GY, Kim EY, et al. Clinical assessment of music perception in Korean cochlear implant listeners. Act Oto-Laryngologica. 2010; 130:716–723.

Kang R, Nimmons GL, Drennan WR, Longion J, Ruffin C, et al. Development and validation of the University of Washington clinical assessment of music perception (CAMP) test. Ear Hear. 2009; 30:411–418. [PubMed: 19474735]

Kim E, Lee HJ, Kim HJ. Music perception ability of Korean adult co-chlear implant listeners. Clin Exp Otorhinolaryngol. 2012; 5(Suppl 1):S53–8. [PubMed: 22701773]

Kong YY, Cruz R, Jones JA, Zeng FG. Music perception with temporal cues in acoustic and electric hearing. Ear Hear. 2004; 25:173–185. [PubMed: 15064662]

Kong YY, Stickney GS, Zeng FG. Speech and melody recognition in binaurally combined acoustic and electric hearing. J Acoust Soc Am. 2005; 117:1351–1361. [PubMed: 15807023]

Laukka P. Music listening and psychological well being among the elderly. Journal of Happiness Studies. 2007; 8:215–241.

Leal MC, Shin YJ, Laborde ML, Calmels MN, Verges S, et al. Music perception in adult cochlear implant recipients. Acta Otolaryngol. 2003; 123:826–835. [PubMed: 14575398]

Levitt H. Transformed up-down methods in psychoacoustics. J Acoust Soc Am. 1971; 49:467–477. [PubMed: 5541744]

Limb CJ. Cochlear implant-mediated perception of music. Curr Opin Otolaryngol Head Neck Surg. 2006; 14:337–340. [PubMed: 16974148]

Limb CJ, Rubinstein JT. Current research on music perception in cochlear implant listeners. Otolaryngol Clin North Am. 2012; 45:129–140. [PubMed: 22115686]

Looi V, Gfeller K, Driscoll V. Music appreciation and training for co-chlear implant recipients: A review. Seminars in Hearing. 2012; 33:307–344. [PubMed: 23459244]

Looi V, McDermott H, McKay C, Hickson L. Comparisons of quality ratings for music by cochlear implant and hearing-aid users. Ear Hear. 2007; 28:59S–61S. [PubMed: 17496649]

Looi V, She J. Music perception of cochlear implant users: A questionnaire, and its implication for a music training program. Int J Audiol. 2010; 49:116–128. [PubMed: 20151886]

McDermott HJ. Music perception with cochlear implants: A review. Trends Amplif. 2004; 8:49–82. [PubMed: 15497033]

Nimmons G, Kang R, Drennan W, Longnion J, Ruffin C, et al. Clinical assessment of music perception in cochlear implant listeners. Otology and Neuro-otology. 2008; 29:149–155.

Olszewski C, Gfeller K, Froma R, Stordhal J, Tromblin B. Familiar melody recognition by children and adults using cochlear implants and normal hearing children. Cochlear Implants Int. 2005; 6:123–140. [PubMed: 18792330]

Peretz I, Champod AS, Hyde K. Varieties of musical disorders: The Montreal battery of evaluation of amusia. Ann Ny Y Acad Sci. 2003; 999:58–75.

Shannon, R. Psychophysics. In: Tyler, RS., editor. Cochlear Implants: Audiological Foundations. San Diego, USA: Singular Publishing, Inc; 1993.

Spitzer JB, Mancuso D, Chengt MY. Development of a clinical test of music perception: Appreciation of music in cochlear implants (AMICI). J Am Acad Audiol. 2008; 19:56–81. [PubMed: 18637410]

Ulrich R, Miller J. Threshold estimation in two-alternative forced-choice (2AFC) tasks: The Spearman-Karber method. Percept Pyschophys. 2004; 66:517–533.

Won JH, Drennan WR, Kang RS, Rubenstein JT. Psychoacoustic abilities associated with music perception in cochlear implant users. Ear Hear. 2010; 31:796–805. [PubMed: 20595901]

Wright R, Uchanski RM. Music perception and appraisal: Cochlear implant users and simulated cochlear implant listening. J Am Acad Audiol. 2012; 23:350–365. [PubMed: 22533978]

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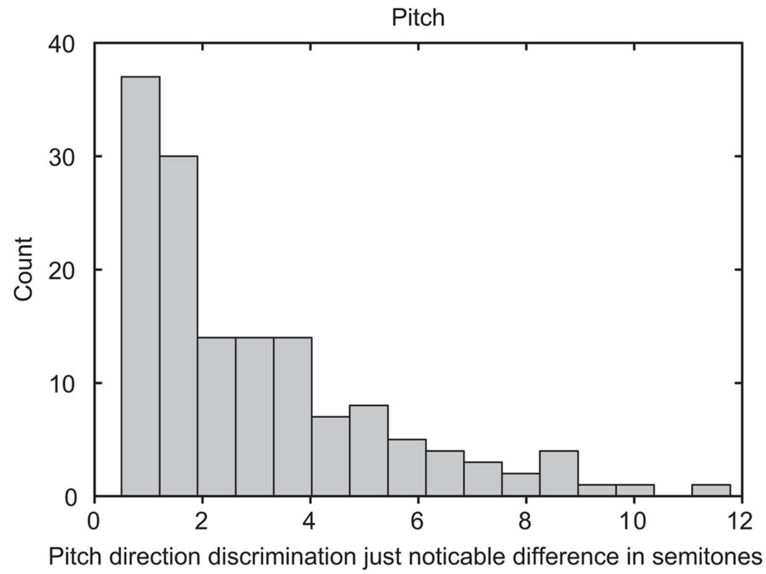

Figure 1.
Distribution of performance on the pitch direction discrimination task.

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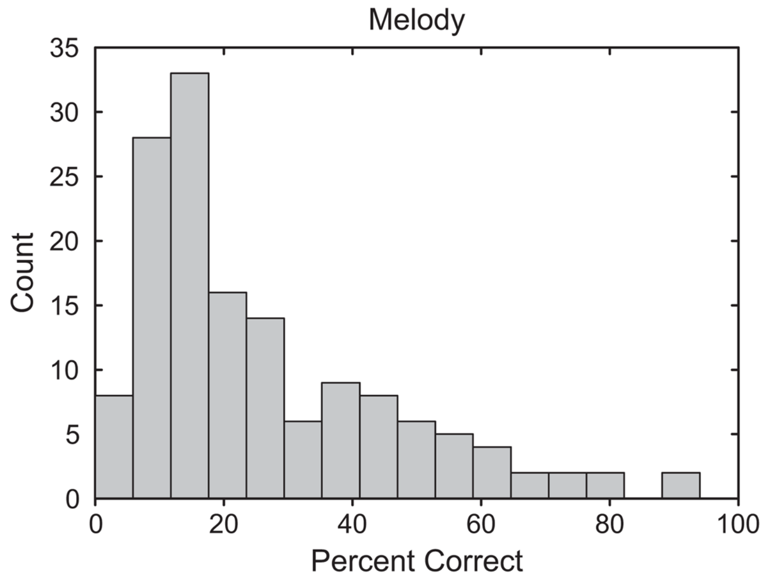

Figure 2.
Distribution of performance on the melody recognition task.

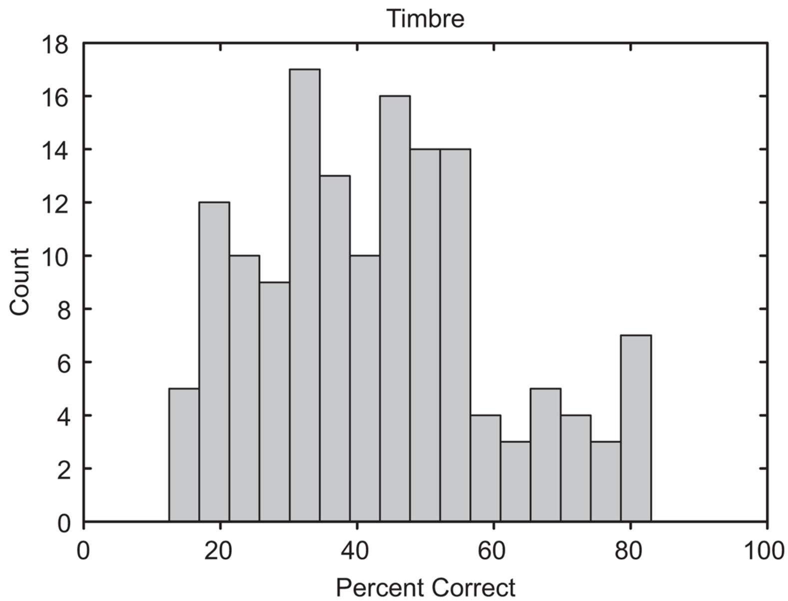

Figure 3.
Distribution of performance on the timbre recognition task.

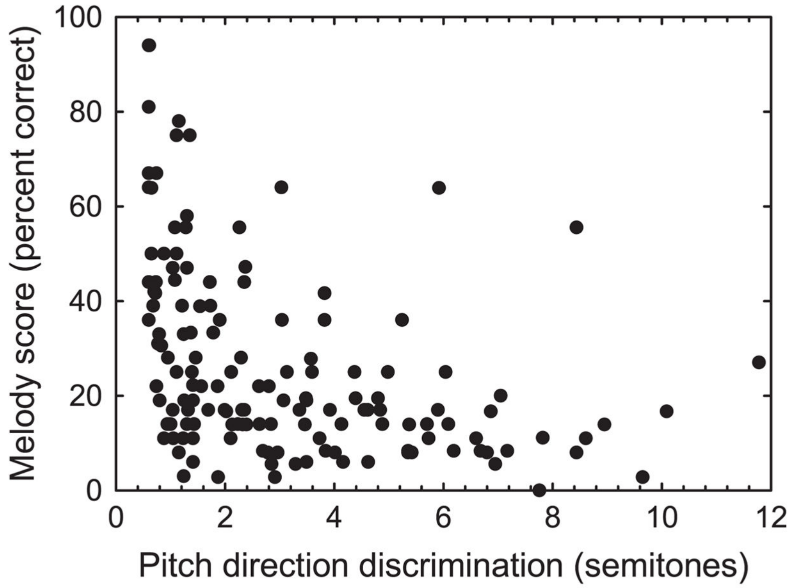

Figure 4.

Scattergram showing the relationship between pitch direction discrimination and melody recognition.

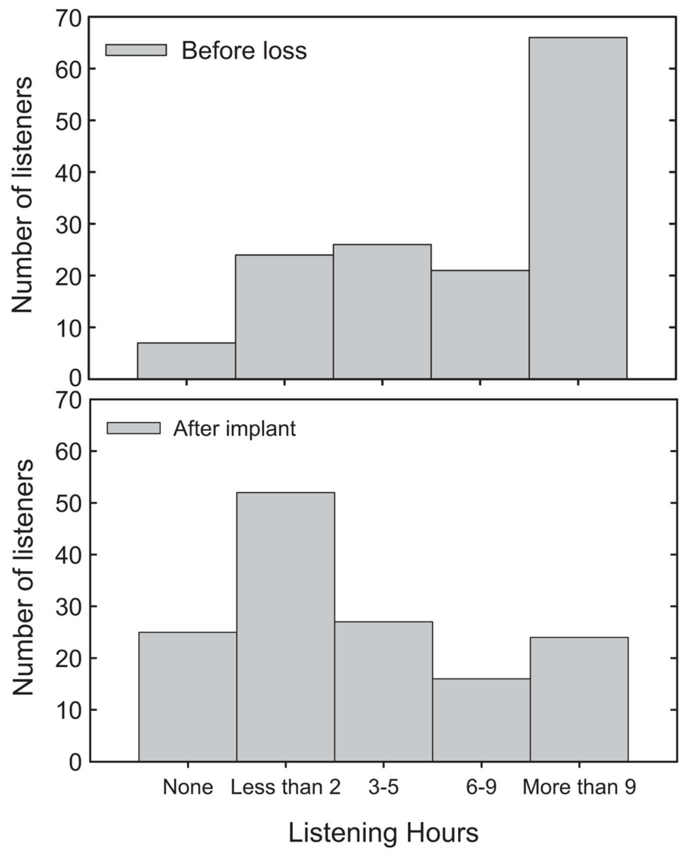

Figure 5.
Distributions of music listening hours before hearing loss and after implantation.

Table 1

A description of the IMBQ variables, and ranges when appropriate.

IMBQ variables	Description of variable	Range
I. Music training	Quantification of amount and types of music lessons, classes, ensemble participation	
a. **MT1**	Music training during elementary school and junior high school	0–6
b. **MT2**	Music training during high school, college, and after	0–4
II. Music listening hours: **MLH**	Quantification of the approximate amount of time per week spent listening to music. Five categories of least (e.g. never = 0) to most (9 hours or more = 4) listening time per week	
a. **MLH-BHL**	Category of music listening hours before hearing loss	0–4
b. **MLH-ACI**	Category of music listening hours after cochlear implant	0–4
III. Sound quality	Appraisals of sound quality	
a. **SQR**	Sound quality ratings: the average of scores on six bipolar adjectives (clear/fuzzy, easy to follow/difficult to follow, like/dislike, sound unlike music/sounds like music, unnatural/natural, unpleasant/pleasant in a variety of situations) regarding general sound quality of music post CI	0–10
b. Complex vs. Simple: **CS**	Bipolar adjective of complex (0) and simple (10) indicating how simple music listening is post CI	0–10
IV. Attitude toward music	General assessments of music at different times in hearing history	
a. **BHL**	Before hearing loss	
b. **AHL**	After hearing loss	
c. **ACI**	After cochlear implant activation	

Table 2

Average demographic data in years for the group (N = 145).

	Mean	St Dev	Min	Max
AGE	57.7	13.9	21.7	85.3
LPD	14.7	14.4	0.3	63
USE	3.9	3.7	0.5	22.5

Table 3

Mean performance for each decile of listeners.

Deciles	Pitch (semitones)	Melody (percent correct)	Timbre (percent correct)
1 (< 10th percentile)	8.18	4.87*	17.17*
2 (10–20th percentile)	5.47	8.72*	24.73*
3 (20–30th percentile)	4.08	12.46*	31.04
4 (30–40th percentile)	3.22	14.74*	34.67
5 (40–50th percentile)	2.48	17.43*	39.69
6 (50–60th percentile)	1.86	21.17	44.85
7 (60–70th percentile)	1.36	26.81	48.57
8 (70–80th percentile)	1.16	36.79	52.69
9 (80–90th percentile)	0.90	47.49	59.84
10 (> 90th percentile)	0.64	70.45	74.45

The * indicates the performance is less than the 95% confidence interval for chance.

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Table 4

Means and standard deviations of appraisals of music using a scale of 1 to 10.

Appraisal	Mean	Standard deviation
Clear (0) vs. Fuzzy (10)	4.88	3.27
Easy (0) vs. Difficult (10) to follow	5.46	3.32
Like music very much (0) vs. Dislike very much (10)	4.67	3.50
Not like music (0) vs. Like music (10)	5.69	3.49
Unnatural (0) vs. Natural (10)	4.53	3.33
Unpleasant (0) vs. Pleasant (10)	4.86	3.31
Complex (0) vs. Simple (10)	3.45	2.86

Table 5

Mean CAMP scores and 95% confidence intervals for each quartile of musical training in years during high school, college, and adult years (MT2).

	Pitch direction		Melody		Timbre	
Quartile	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
1st (most training)	2.8	0.8	30.1	7.7	49.3	5.3
2nd	3.1	0.8	28.7	6.5	42.5	5.5
3rd	2.9	0.8	25.5	6.9	44.6	5.5
4th (least training)	3.5	0.7	20.7	4.4	37.0	5.0

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Table 6

Spearman correlations between music appraisal and music perception ability. Correlations which are not significant at the 5% level are not shown. P values are shown in parentheses. Correlations which were significant after Rom (1990) corrections for possible Type 1 family-wise errors are shown in bold. The categories for appraisal have low values for the descriptor on the top and high values for the descriptor on the bottom. For example "Not Like Music" vs. "Like Music" has a scale in which the top phrase "Not Like" gets a low number and the "Like" gets a high number.

	Clear Fuzzy	Complex Simple	Easy to follow Hard to follow	Like very much Dislike	Not like music Like music	Unnatural Natural	Unpleasant Pleasant
Pitch	–	–	0.20 (0.05)	–	**−0.32 (0.001)**	–	−0.25 (0.01)
Timbre	–	–	−0.25 (0.01)	−0.21 (0.04)	0.23 (0.01)	**0.35 (0.0005)**	0.24 (0.02)
Melody	–	–	–	–	0.22 (0.03)	–	–

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Table 7

Number of participants in each listening-hour category vs. their reported attitude about music. From section C: 0 is never, 1 is < 2 hours/week, 2 is 3–5 hours per week, 3 is 6–8 hours per week, 4 is 9 or more hours per week.

Listening hours	**0**	**1**	**2**	**3**	**4**	**Total**
Negative	23	30	8	2	2	65
Neutral	2	12	7	3	4	28
Positive	0	10	12	11	18	51
Total	25	52	27	16	24	144