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Temporal Stability of Music Perception and Appraisal Scores of Adult Cochlear Implant Recipients

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Abstract

Background: An extensive body of literature indicates that cochlear implants (CIs) are effective in supporting speech perception of persons with severe to profound hearing losses who do not benefit to any great extent from conventional hearing aids. Adult CI recipients tend to show significant improvement in speech perception within 3 mo following implantation as a result of mere experience. Furthermore, CI recipients continue to show modest improvement as long as 5 yr postimplantation. In contrast, data taken from single testing protocols of music perception and appraisal indicate that CIs are less than ideal in transmitting important structural features of music, such as pitch, melody, and timbre. However, there is presently little information documenting changes in music perception or appraisal over extended time as a result of mere experience.

Purpose: This study examined two basic questions: (1) Do adult CI recipients show significant improvement in perceptual acuity or appraisal of specific music listening tasks when tested in two consecutive years? (2) If there are tasks for which CI recipients show significant improvement with time, are there particular demographic variables that predict those CI recipients most likely to show improvement with extended CI use?

Research Design: A longitudinal cohort study. Implant recipients return annually for visits to the clinic.

Study Sample: The study included 209 adult cochlear implant recipients with at least 9 mo implant experience before their first year measurement.

Data Collection and Analysis: Outcomes were measured on the patient's annual visit in two consecutive years. Paired *t*-tests were used to test for significant improvement from one year to the next. Those variables demonstrating significant improvement were subjected to regression analyses performed to detect the demographic variables useful in predicting said improvement.

Results: There were no significant differences in music perception outcomes as a function of type of device or processing strategy used. Only familiar melody recognition (FMR) and recognition of melody excerpts with lyrics (MERT-L) showed significant improvement from one year to the next. After controlling for the baseline value, hearing aid use, months of use, music listening habits after implantation, and formal musical training in elementary school were significant predictors of FMR improvement. Bilateral CI use, formal musical training in high school and beyond, and a measure of sequential cognitive processing were significant predictors of MERT-L improvement.

Conclusion: These adult CI recipients as a result of mere experience demonstrated fairly consistent music perception and appraisal on measures gathered in two consecutive years. Gains made tend to be modest, and can be associated with characteristics such as use of hearing aids, listening experiences, or bilateral use (in the case of lyrics). These results have implications for counseling of CI recipients with regard to realistic expectations and strategies for enhancing music perception and enjoyment.

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Key Words: Cochlear implant, cognitive, music, speech perception

Abbreviations: Agetest = age at time of testing; AIC = Akaike's information criterion; CI = cochlear implant; FMR = familiar melody recognition; HA = hearing aid; LPD = length of profound deafness; MBQpost = music listening habits after implantation; MEAM-I = musical excerpt appraisal measure, instrumental; MEAM-L = musical excerpt appraisal measure with lyrics; MERT-I = musical excerpt recognition test, instrumental; MERT-L = musical excerpt recognition test with lyrics; MOU = months of use; NH = normal hearing; T1 = amount of formal music instruction in elementary school; T2 = amount of formal music instruction in high school and beyond; TR = timbre recognition; VMT1 = visual monitoring task 1; VMT2 = visual monitoring task 2; YrImp = year of implantation

The cochlear implant (CI) is a hearing prosthesis developed primarily to assist persons with profound hearing loss in verbal communication. Most current CI processors transmit the temporal envelopes extracted from 6 to 22 frequency bands; only coarse spectral information is provided. This level of spectral information is adequate to support speech perception in quiet (Wilson, 2000) with group data indicating that most CI recipients are able to attain significant improvements in speech perception within 3–6 mo of everyday use. Longitudinal studies indicate that adult CI recipients show considerable improvement within the first 9 mo, and continued but slower rates of improvement 24 mo following implantation; some adult recipients continue to demonstrate improvement in speech perception as long as four to five years following implantation (Tyler and Summerfield, 1996; Tyler et al, 1997; Ruffin et al, 2007).

The extent to which implants are effective in transmitting music depends on several factors, including the particular structural features of music in a given musical sound. Studies indicate that adult CI recipients perform with accuracy similar to normal-hearing (NH) adults on discrimination of simple rhythmic patterns presented at a moderate rate (Dorman et al, 1991; Gfeller and Lansing, 1991, 1992; Schultz and Kerber, 1994; Gfeller et al, 1997; Looi, 2008). However, adult CI users are significantly less accurate than NH adults on various perception tasks associated with spectral information, including timbre recognition (musical instrument recognition), timbre appraisal (sound quality rating) (Gfeller and Lansing, 1991; Gfeller et al, 1997, 1998, 2002b, 2002c, 2005, 2006; McDermott, 2004; Looi, 2008), frequency difference limens, pitch ranking, or discrimination of brief pitch patterns (Gfeller et al, 2002a; Kong et al, 2004, 2005; Laneau et al, 2004; Looi et al, 2004; McDermott, 2004; Gfeller et al, 2007; Looi, 2008). Because melodies and harmonies are comprised of sequential and concurrently presented pitches respectively, it is not surprising that CI recipients are less accurate than NH adults on discrimination of melodies, or recognition of melodies with or without harmony (Schultz and Kerber, 1994; Pijl, 1997; Fujita and Ito, 1999; Gfeller et al, 2002a; Leal et al, 2003; Kong et al, 2004; McDermott, 2004; Galvin et al, 2007; Looi, 2008).

The aforementioned studies indicate that CI recipients generally perform less accurately than NH persons on measures of pitch, melody, and timbre perception. That said, it is important to note there is considerable inter- and intrasubject variability with regard to music perception and enjoyment by CI users (Gfeller et al, 2008). For example, some CI recipients may be fairly accurate recognizing musical instruments (timbre recognition) that have distinctive spectral differences, while others may hear all instruments as noise. With regard to appraisal of sound quality, some CI recipients describe music as harsh, shrill, thudding, or unpleasant noise, while other CI recipients find the same music to be quite pleasant.

While the majority of published studies indicate that CI recipients are less accurate than NH adults in perception of pitch, melody, and timbre, some attributes of music perception and/or appraisal can be enhanced by focused listening (training) or more time spent listening postimplantation (Fujita and Ito, 1999; Gfeller et al, 2000a; Gfeller, 2001; Galvin et al, 2007). In addition, both perceptual acuity and appraisal can be enhanced through simultaneous use of a CI and hearing aid (which is referred to in some studies as "bimodal stimulation"), in which residual low-frequency hearing is exploited through a hearing aid in conjunction with the CI (Gantz et al, 2005; Gfeller et al, 2007; Looi, 2008).

Most studies have typically examined the accuracy or appraisal of CI recipients for particular structural features of music under particular testing conditions (e.g., comparing different devices or signal processing schemes). A recent study by Gfeller et al (2008) was designed to examine the complex relations among musical variables (varying perception and appraisal tasks of pitch, melody, and timbre) in conjunction with subject characteristics (e.g., hearing history, musical training, etc.) and devices to better understand individual differences in music perception by CI users. The Gfeller et al (2008) study used results from a battery of tests completed by adult CI recipients that assessed perceptual accuracy and appraisal of musical stimuli ranging from simple computer-generated stimuli to complex blends of "real-world" music. The participants in the study used a variety of long-electrode devices manufactured by Advanced Bionics or the Cochlear Corporation, in unilateral or bilateral configurations, and their typical signal processing strategy; some used a hearing aid in conjunction with the CI.

The dependent variables regarding music perception and appraisal included pitch perception, recognition of simple computer-generated and recorded complex melodies with or without lyrics, timbre recognition, and appraisal of complex melodies. These variables were examined in relation to individual differences among participants including age when tested, duration of profound deafness, months of use, speech perception scores, and cognitive test scores. In addition, the analysis examined the contribution of type of device, strategy used, unilateral or bilateral CI, and use of a hearing aid. Finally, the dependent variables were examined in relation to the amount of musical training in elementary and secondary school and time dedicated to music listening prior to and after implantation.

The relations among these variables were analyzed to help identify those factors in combination best predicting performance in the recognition and appraisal of musical stimuli of the sort heard in everyday life. Importantly, neither type of CI nor processing strategy was a strong predictor of music perception. The analyses revealed the importance of distinguishing between perceptual accuracy and appraisal when using music as an index of implant success. Furthermore, lyrics emerged as an important moderator variable. Speech perception scores emerged as strong predictors of perceptual accuracy of several tests of music with lyrics but not music without lyrics. While length of implant use is typically an important predictor for speech perception scores (Tyler and Summerfield, 1996; Ruffin, et al, 2007), months of implant use was a significant predictor for only one variable, recognition of real-world songs that had lyrics. Length of implant use did not predict benefit for any measures that were comprised only of musical structures (pitch, rhythm, timbre). Use of bilateral implants was a significant predictor for only one variable: appraisal (sound quality rating) of complex songs with lyrics. For music perception and appraisal measures without lyrics, concomitant use of a hearing aid and a measure of cognitive processing were the strongest predictors of accuracy.

The Gfeller et al (2008) study identified the importance of different types of music perception and appraisal tasks in assessing music listening by CI users, and the extent to which individual differences, technical factors, and experiential variables contribute to variability among CI recipients listening to music. However, the study did not examine expressly whether CI users might realize some change in music perception and appraisal over time as a result of more experience and to what extent those changes could be predicted. To date, research regarding music perception and appraisal by CI users has not provided a longitudinal perspective in addressing such questions as Do CI users show significant improvement in music perception or appraisal as a result of more extended use? To what extent are scores of music perception and appraisal stable over time? If there are significant individual differences in improvement over time, what factors might identify those individuals likely to evidence improvement? Using the data from the Gfeller et al (2008) study as a baseline, the present study examines changes in performance on different measures of music perception and appraisal over a one-year interval and whether stability or change can be predicted.

METHOD

Participants

The participants were 209 adult long-electrode CI users enrolled in a clinical trial from 1986 to 2006 with at least 9 mo of CI experience when first tested (mean months of use = 42.3). Participants ranged in age from 23.7 to 92.5 yr (M = 60.2, SD = 15.4). Recipients used one of the following devices: CI22, CI24M, Contour, Ineraid, Clarion, HiFocus, CIIHF1/2, and 90K. The following speech processing strategies were used as appropriate to the device: MPEAK, SPEAK, ACE, Analog SAS, CIS, HiRes, and Conditioner (Rubinstein et al, 1999). None of the participants changed devices between the two points of data collection. All were native English-speaking adults culturally affiliated with the United States; two had college-level music training. The sample is described in greater detail in Gfeller et al, 2008. Testing occurred during annual visits to the clinic; because of personal circumstances, or acute illnesses, not all participants completed all measures.

Data Description

The dependent variables in these analyses included six measures of music perception or appraisal (sound quality rating) collected twice approximately one year apart. The measures were (1) familiar melody recognition (FMR), which involved open-set recognition of 12 familiar melodies without lyrics (synthesized piano sounds prepared using MIDI technology); (2) timbre recognition (TR), which involved closed set recognition of eight different musical instruments (recordings of solo instrumentalists playing a standardized melody); (3) musical excerpts recognition of real-world instrumental music (no lyrics) (MERT-I); (4) musical excerpts recognition of real-world music with lyrics (MERT-L); (5) appraisal of musical excerpts of real-world instrumental music (no lyrics) (MEAM-I); and (6) appraisal of excerpts of real-world music with lyrics (MEAM-L). The recordings in the MERT and MEAM tests (I and L versions) were comprised of excerpts representative of three musical styles: classical, pop, and country.

The percentage of songs recognized correctly in the MERT-I and MERT-L measures were computed based on the number of songs that the participant knew before testing rather than the total number of songs included in the test. More detailed descriptions of the measures can be found in Gfeller et al, 2008.

The stability of performance over time was determined by calculating the differences of the six measures from the second year to the first year, which resulted in a positive difference score if participants improved over time. The demographic variables and predictors available from the first year included the following variables related to participant characteristics and hearing history: age at time of testing (agetest), whether the patient used bilateral implants (Y or N), whether the patient used hearing aids in addition to their CI (HA, Y or N), length of profound deafness prior to implantation (LPD), year of implantation (YrImp), and months of implant use at time of testing (MOU).

Predictors related to musical training and experience included: music listening habits prior to implantation (MBQpre), music listening habits after implantation (MBQpost) (Gfeller et al, 2000b), amount of formal music instruction in elementary school (T1), and amount of formal music instruction in high school and beyond (T2). Predictors related to cognitive functioning included: two visual monitoring tasks that measured efficiency of cognitive processing of rapidly changing sequential information (VMT1, VMT2; Knutson et al, 1991; Knutson, 2006), the *Raven Progressive Matrices*, a standardized nonverbal test of intelligence (Raven et al, 1977), and a test of sequential learning (SLT, Simon and Kotovsky, 1963).

Predictors related to speech perception performance included three standardized tests: *Consonant-Nucleus Consonant* test (CNC, Tillman and Carhart, 1966), the *Iowa Consonant Test* (ICT, Tyler et al, 1987), and the *Hearing in Noise Test* (HINT, Nilsson et al, 1994). These predictors were used to assess any significant change from year 1 to year 2 on the outcome measures.

Methods

The Pearson correlation coefficient was used to assess the correlation between year 1 and year 2 values. A paired t-test was used to test if the amount of change was significantly different from zero. If a significant change from year 1 to year 2 was identified, a linear regression model was fit to predict how well the amount of change from year 1 to year 2 could be described by the demographic variables. The amount of change was the outcome variable; to adjust for the effect of the baseline measurement, we also included the first years' value as a covariate in the regression model.

The predictor variables in the model were first screened individually in bivariate tests with the outcome measures. In testing the Pearson correlation between the outcome and predictor variables, only the predictor variables with a p value less than 0.15 were considered for modeling. This strategy was adopted for two reasons. The first was to remain consistent with the multiple regression analysis in Gfeller et al (2008). The second concerned the large amount of missing data. Only 22 cases out of 209 had complete values for all the predictor variables. By screening out the nonsignificant predictors, more cases remained for analysis. After the candidate predictors were selected, Akaike's information criterion (AIC) was adopted in order to select the final model for parameter estimation. Model diagnostics were performed to check the assumptions of the residuals and to identify overly influential cases and outliers. A series of preliminary analyses were conducted to determine whether device or processing strategy contributed to any of the music listening variables and whether subgroup analyses would be required. Importantly, no device differences or strategy differences ($p > .25$) emerged from those analyses as being related to the outcome measures (see Tables 1 and 2 for a listing of device types and strategies used).

Results

Correlation Coefficients across a One-Year Interval

The scores from all six music measures in the second year were significantly correlated with the scores from the previous year. Among the six measures, FMR had the highest correlation between year 1 and year 2 ($r = .82$) while MEAM-L had the lowest correlation ($r = .34$).

Significant Difference between Measurement for Year 1 and Year 2

Table 3 presents differences between measurements in year 1 and year 2. FMR and MERT-L were the only two measurements yielding a significant amount of change from year 1 to year 2.

Predicting Change over Time

Because a significant change was identified from year 1 to year 2 on the FMR and MERT-L, an initial

Table 1. Distribution of Device Types

Device	Frequency	Percent
CII	49	23.4
Clarion, HiFocus	31	14.8
CI24M and CI24R	87	41.6
CI22	21	10.0
90K	9	4.3
Ineraid	12	5.7

Table 2. Distribution of Processing Strategies

Strategy	Frequency	Percent
CIS, ModCIS, HRPS	67	32.37
SAS and Analog	8	3.86
SPEAK	51	24.64
MPEAK	1	.48
HiRes	30	14.49
ACE	50	24.15

screening of variables was conducted in order to determine those factors influential in that change. To predict the change from year 1 to year 2 for the FMR, seven variables were selected for further consideration ($p < 0.15$). They were age at time of testing (agetest), use of an HA, *Iowa Consonant Test* (ICT), MBQpost, months of implant use (MOU), T1, and YrImp. For MERT-L, only four candidate predictors met the screening criteria. The predictors were use of an HA, LPD, T2, and two measures of sequential cognitive processing (VMT1 and VMT2).

Four variables were selected for the regression model based on the AIC selection method (Table 4). FMR1 indexes the year 1 measurement for FMR. It was included in the final model as an adjustment for the baseline effect.

On average, and with all other factors held fixed, for every one unit increase in the first year measurement in FMR, we expect a 0.16 unit increase in the FMR after one additional year of use. When examining change in FMR scores from year 1 to year 2, those participants without hearing aids will have 8.31 units lower than the group with hearing aids. Months of use has a slightly negative influence on change in FMR, while every one-year increase in MBQpost scores predicts a 2.55 point increase in FMR from year 1 to year 2. Finally, a one-unit increase in T1 leads to a 0.63 unit increase in FMR from year 1 to year 2.

There were no concerns of multicollinearity among these significant predictors, and the residual analysis showed the normality assumption was also satisfied with no outliers and influential cases found.

Table 3. Paired *t*-test

Variable names	Effective cases	Improvement (year 2 − year 1)	*p* value
TR	136	−1.059	0.4047
FMR	146	3.556	0.0026*
MERT-I	137	0.007	0.7318
MERT-L	137	0.040	0.0117*
MEAM-I	131	1.246	0.1827
MEAM-L	131	0.961	0.2170

Note: TR = timbre recognition; FMR = familiar melody recognition; MERT-I = musical excerpt recognition test, instrumental; MERT-L = musical excerpt recognition test with lyrics; MEAM-I = musical excerpt appraisal measure, instrumental; MEAM-L = musical excerpt appraisal measure with lyrics.

*Significant at level 0.05.

Table 4. Final Model for FMR

Parameter	Estimate	*t* value	*p* value
Intercept	3.71	0.84	0.4005
FMR1	−0.13	−2.26	0.0260
HA	−8.31	−2.56	0.0118
MOU	−0.05	−1.92	0.0577
MBQpost	2.55	3.51	0.0007
T1	0.63	2.67	0.0089

Note: FMR1 = familiar melody recognition, year 1 (from Gfeller et al, 2008); HA = hearing aid; MOU = months of use; MBQpost = music Listening habits after implantation; T1 = amount of formal music instruction in elementary school.

The AIC selection method for change in MERT-L yielded a model containing baseline MERT-L, bilateral use, T2, and cognitive processing (VMT1) (see Table 5). A higher baseline score of MERT-L corresponds to a smaller increase from year 1 to year 2 in MERT-L. This is because someone with a score of 90% at baseline can only increase 10%, while someone who scored 50% at baseline has the potential to improve by 50%. The bilateral variable is coded as not wearing bilateral CIs, so having bilateral implants results in an average increase of 9% in MERT-L from year 1 to year 2. T2 has a slight negative effect on change in MERT-L while every increase in one VMT1 yields a 16% increase in MERT-L on average.

Discussion

This study indicates that adult cochlear implant recipients demonstrate relatively stable music perception and appraisal scores when tested in two consecutive years. In addition, there were no significant differences as a function of device type (brand or model) or processing strategy. These data replicate and extend the findings of Gfeller et al (2008). All six music measures in the second year were highly correlated to the measures made in the previous year. Only two of the six dependent variables evidenced a significant amount of change from year 1 to year 2: familiar melody recognition and musical excerpt recognition of items with lyrics. Although it is largely the same sample, it still underscores the robustness of the original results.

Table 5. Model for MERT-L

Parameter	Estimate	*t* Value	Pr > |t|
Intercept	0.08	1.38	0.169
MERT-L1	−0.19	−2.42	0.018
Bilateral	−0.09	−2.02	0.046
T2	−0.01	−2.01	0.047
VMT1	0.16	2.52	0.013

Note: MERT-L1 = musical excerpt recognition test with lyrics, year 1 (from Gfeller et al, 2008); T2 = amount of formal music instruction in high school and beyond; VMT1 = visual monitoring task 1.

The limited improvement with extended CI use is an interesting contrast with speech perception scores, which have been reported to show at least modest improvement as a result of experience over a period as long as 4 to 5 yr (Tyler and Summerfield, 1996; Tyler et al, 1997; Ruffin et al, 2007). The consistency of music perception and appraisal scores from year 1 to year 2 may be attributable in part to reliability of the testing materials in conjunction with technical limitations of the CI for music listening, which fail to provide a framework for improvement even after 12 mo of additional experience.

Because the FMR is based on *familiar* materials, one might expect there would be a ceiling achieved. However, the data collected in year 2 show that routine experiences results in only modest gains and considerable room for further improvement. The poor technical suitability of commercially available long-electrode implants for transmitting spectral information compromises perception of pitch (and thus melody) and timbre (instrumental tone quality), both of which are important in music perception and appraisal.

Because of poor resolution of pitch and timbral features, mere exposure in everyday life appears to provide an inadequate signal through which the listener can verify the musical sounds being heard or develop an appreciation for the signal. Learning what the signal represents and enjoying that signal requires that the listener be able to extract salient features that are then associated with given sound sources. The lack of adequate detail impairs potential for paired associate learning and may also discourage CI recipients from taking advantage of possible music listening opportunities.

It is interesting to note the use of hearing aids and additional time spent in listening to music after implantation emerged as two of the four significant predictors of improved recognition of familiar melodies without lyrics. The use of hearing aids implies that the CI recipient has enough residual hearing to achieve benefit from using the hearing aid in conjunction with the CI. This suggests that more available low-frequency residual hearing, when optimized through a hearing aid, can assist in the perception of fundamental frequency, an important factor in pitch and melody perception. The positive impact of bilateral implants on the MERT-L variable may be explained in part by the presence of lyrics in the MERT-L. Some prior studies show an advantage to bilateral implant use for speech perception, including speech in background noise (which one might consider a comparable task to extracting lyrics from a background accompaniment) (van Hoesel and Tyler, 2003; Tyler et al, 2007; Noble et al, 2008; Laske et al, 2009). The improved scores of the MERT-L (with lyrics) versus the lack of improvement for the MERT-I (instrumental only) might reflect the same process that is associated with improvements (albeit modest) in speech perception over time among long-term CI users.

It is interesting to note the contrast in predictors for music with or without lyrics with regard to use of bilateral implants and use of hearing aids in light of studies regarding speech perception (e.g., Tyler et al, 2007; Noble et al, 2008). In the present study, bilateral implants were associated with some improvement in recognizing songs with lyrics, while the use of hearing aids was associated with better perception and enjoyment for instrumental music. Instrumental music, compared with speech, requires better pitch resolution and perception of fine structure (Kong et al, 2004, 2005; Gfeller et al, 2007). This advantage of hearing aids for music listening is consistent with several other studies (Looi, 2008). Thus, the role of music in everyday life, and types of preferred music may be relevant lifestyle issues for audiologists to assess when considering the relative merits of bilateral CIs versus CIs plus hearing aids.

In summary, these data collected over a two-year period indicate that adult CI recipients, following an additional year of music listening, demonstrate rather consistent music perception and appraisal over time. Any gains realized tend to be modest and may be enhanced by the availability of concomitant use of hearing aids, expanded listening experiences, or bilateral CI use (in the case of music with lyrics).

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