Original Paper

Audiology & Neurotology

Audiol Neurotol 2009;14:315–326
DOI: 10.1159/000212111

Received: June 2, 2008
Accepted after revision: December 22, 2008
Published online: April 15, 2009

Comparison of Music Perception in Bilateral and Unilateral Cochlear Implant Users and Normal-Hearing Subjects

K. Veekmans[a, b] L. Ressel[c] J. Mueller[d] M. Vischer[f] S.J. Brockmeier[e, g]

[a]Nottingham Cochlear Implant Programme, Nottingham, UK; [b]MED-EL Medical Electronics, Worldwide Headquarters, Innsbruck, Austria; [c]MED-EL Germany, Starnberg, [d]ENT Department, University of Würzburg, Würzburg, [e]Department of Otolaryngology, Head and Neck Surgery, Technical University Munich, Munich, Germany; [f]Department of Otolaryngology, Head and Neck Surgery, Bern, and [g]Department of Otolaryngology, Head and Neck Surgery, University Basel, Basel, Switzerland

Key Words
Cochlear implantation · Bilateral implantation · Music perception and appreciation · Postlingually deafened adults

Abstract
Music plays an important role in the daily life of cochlear implant (CI) users, but electrical hearing and speech processing pose challenges for enjoying music. Studies of unilateral CI (UCI) users' music perception have found that these subjects have little difficulty recognizing tempo and rhythm but great difficulty with pitch, interval and melody. The present study is an initial step towards understanding music perception in bilateral CI (BCI) users. The Munich Music Questionnaire was used to investigate music listening habits and enjoyment in 23 BCI users compared to 2 control groups: 23 UCI users and 23 normal-hearing (NH) listeners. Bilateral users appeared to have a number of advantages over unilateral users, though their enjoyment of music did not reach the level of NH listeners.

Introduction

Music plays an important role in the everyday life of normal-hearing (NH) people as well as hearing-impaired people. People associate music with certain life events, stages and even moods. Music is used for entertainment, enjoyment and relaxation [Pankseep, 1995], either independently or in a social setting. The social enjoyment of music is often missing in the lives of people with profound or severe hearing loss (HL) [Gfeller and Knutson, 2003].

Previous studies indicate that cochlear implant (CI) users also consider experiencing music important for quality of life [Schulz and Kerber, 1994]. Electrical hearing, however, is known to be very different from acoustic hearing. Earlier studies found that electrical hearing produces a much narrower dynamic range, much steeper loudness growth, temporal pitch limited to several hundred Hertz and much broader or no tuning [Zeng, 2004]. Despite these limitations, in the last 15 years, studies have shown a steady improvement in speech understanding with improved coding strategies. Many people currently using unilateral CIs (UCIs) have good speech understanding in quiet, and as many as 54% can converse on a

KARGER
Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

© 2009 S. Karger AG, Basel
1420–3030/09/0145–0315$26.00/0

Accessible online at:
www.karger.com/aud

Kim Veekmans
Nottingham Cochlear Implant Programme
Ropewalk House, 113 The Ropewalk
Nottingham NG 1 6HA (UK)
Tel. +44 115 948 5549, Fax +44 115 948 5560, E-Mail kim.veekmans@nuh.nhs.uk

mobile telephone [Anderson et al., 2006]. However, CI users' performance on speech tasks drops dramatically in adverse signal-to-noise ratios. The same holds true for music perception. Due to a more complex sound spectrum, a wider range of frequencies, a wider dynamic range and less redundancy of the signal, music is much more prone to the limitations of electrical hearing than speech. Furthermore, music perception is more complex than speech perception. Gfeller et al. [1997] stated that musical perception and appreciation with a CI are influenced by a number of important factors beyond personal taste. Several variables have a probable impact: the structural characteristics of the music, individual user differences and technical features of the device or processing scheme.

Over the past decade, music perception and music appreciation in UCI users have been assessed using various methods. Studies using questionnaires and rating scales [Schulz and Kerber, 1994; Gfeller et al., 2000; Brockmeier et al., 2002; Brockmeier et al., 2007] have shown that music habits and appreciation vary greatly and are influenced by the factors already mentioned. Gfeller et al. [2002a] surveyed 65 CI users with the Iowa Musical Background Questionnaire and found that musical enjoyment is influenced by the listening environment and features of the music. General enjoyment was positively correlated with the time spent listening to music after implantation. Results from the Iowa Musical Background Questionnaire were that 75% of CI users enjoyed and listened to music extensively prior to HL, but 83% reported a decline in musical enjoyment after implantation [Gfeller et al., 2000]. Results from the Munich Music Questionnaire (MUMU) in 103 adults using the COMBI 40/40+ device [Brockmeier et al., 2002] showed that 65% of subjects regularly listened to music, with 51% of subjects describing it as 'pleasant' and only 31% as 'natural'. These results are consistent with other reports [Schulz and Kerber, 1994; Pijl and Schwartz, 1995; McDermott and McKay, 1997; Leal et al., 2003].

The complexity of the music also seems to play a role. Gfeller et al. [2003] developed a test for measuring the appraisal of complex yet common, naturalistic musical stimuli. They found that not only were CI users significantly less familiar with the items used in the test than the NH subjects, but CI users also appraised listening to complex songs quite differently. Unlike NH subjects, CI users did not show distinct stylistic preferences or preferences for familiar items across genres. Gfeller et al. [2003] concluded that for CI users, there are most likely other factors related to device features affecting complexity appraisal. However, Brockmeier et al. [2007] showed that although it is necessary to consider the speech coding strategy, subjects in their study using both older (SPEAK) and more modern (ACE, CIS+) speech coding strategies rated their musical activities and preferences similarly.

Several studies have investigated music perception in UCI users using objective testing. These suggest that CI users have little or no difficulty recognizing tempo and rhythm. On average, CI users perceive rhythm about as well as NH listeners [Kong et al., 2004; McDermott, 2004; Szelag et al., 2004], and CI users' tempo discrimination is also very similar to that of NH subjects [Kong et al., 2004]. However, when a rhythm identification task is used rather than a discrimination task, performance levels drop [Leal et al., 2003; Kong et al., 2004]. Melody, timbre and pitch tasks are also much more difficult for CI users [McDermott, 2004; Zeng, 2004]. Melodies with a distinctive rhythmic pattern are generally easier to identify or recognize, but when no rhythmic cues are available, performance is reduced to chance [Schulz and Kerber, 1994; Gfeller et al., 2000; Kong et al., 2004]. Studies suggest that tune or melody recognition by CI users improves when lyrics are present [Fujita and Ito, 1999; Leal et al., 2003; Looi et al., 2004]. Melodic pattern recognition experiments with no rhythmic or verbal cues [McDermott, 2004] pose great problems for CI users. This is because at the time of these studies, CI users had to extract the pitch information from either the temporal envelope or the spectral pitch associated with the electrode position [Zeng, 2004]. Finally, the results of several investigations into instrument discrimination and identification indicate that this is also problematic for CI users, even on closed-set tests using a small number of instruments [Schulz and Kerber, 1994; Gfeller et al., 2002b; McDermott and Looi, 2004].

There is currently very little research on the music perception abilities of bilateral CI (BCI) users. Research on speech understanding in adult CI users did establish very early on that bilateral users can combine information from both CIs into one hearing sensation [Van Hoesel et al., 1993; Van Hoesel and Clark, 1995] and use this information to gain significantly increased speech understanding [Mawman et al., 2000; Mueller et al., 2000] both in quiet and noise [Mueller et al., 2002; Brown and Balkany, 2007; Tyler et al., 2007; Wackym et al., 2007; Buss et al., 2008]. Mueller et al. [2002], and later Schoen et al. [2002], Schleich et al. [2004] and Litovsky et al. [2006b], concluded that BCI users benefit from all the effects known from normal acoustic hearing: the head shadow effect, squelch effect and binaural summation effect. Although speech and musical signals are processed differently and very little is known about bilateral music perception, there may still be some bilateral advantage for music processing.

The aim of this investigation was to gain insight into BCI users' music perception. This was done using a custom designed questionnaire querying subjective music habits, perception and enjoyment. Surveys are commonly used in studies of musical preference and enjoyment [Boyle and Radocy, 1987]. Results from BCI subjects were compared to those from both unilaterally implanted and NH subjects. We also aimed to assess whether subjects experience music differently after receiving a second device (CI 2).

Methods

The Questionnaire

The version of the MUMU (developed by Dr. S.J. Brockmeier with input from patients, statisticians, musicians and music scientists) used in the current study of BCI subjects was adapted from the original (32 questions), used in a study of UCI users and NH controls [Brockmeier et al., 2002]. The current version of the MUMU questionnaire for unilaterally implanted CI users is available at www.medel.com/english/50_Rehabilitation/Free-download/index.php?navid=41.

For this study, the MUMU included 30 questions on music behavior, appreciation, perception, experience and education, and the role of music during the subjects' lives, i.e. in childhood and adulthood for NH subjects, and for CI subjects, before the onset of HL, immediately before implantation and after implantation. The BCI version of the MUMU contained follow-up questions on the subjects' experiences after receiving CI 2, as this is the BCI group's current situation. One extra question was added to the questionnaire in order to directly compare listening to music with 1 versus 2 CIs. The version for NH subjects contained the same number of questions to keep the questionnaire equivalent to the length of the CI groups' versions. The only difference was that retrospective questions ('before hearing loss' and 'before implantation') queried childhood and adolescence. The only NH group responses presented were those pertaining to 'your adulthood'.

Subjects

Subjects included 23 BCI users, 23 UCI users and 23 NH listeners (table 1). CI subjects were all postlingually deafened, native German-speaking adults familiar with the musical genres mentioned in the questionnaire. They were recruited from the following centers: Technical University of Munich and University of Würzburg, Germany, and University of Bern, Switzerland. They used MED-EL devices in one or both ears, either the MED-EL COMBI 40/40+ device or the PULSARCI^{100} device with the CIS(+) speech coding strategy. The BCI subjects were all those who had been implanted in the participating centers at the beginning of this study. None of the sequentially implanted BCI subjects were subjects in the original evaluation study. UCI and NH subjects were recruited from a large group of subjects (103 UCI subjects and 97 NH subjects) from a study by Brockmeier et al. [2002]. All subjects had at least 12 months' experience in their current CI condition at the time of questionnaire completion.

All but one BCI subject received CI 2 after at least 6 months of experience with their first CI (CI 1). The time between receipt of CI 1 and CI 2 ranged from 0.62 to 9.01 years (average 2.54, standard deviation 2.25). One subject was implanted simultaneously. This subject's data were treated as missing data in the retrospective, within-subject analysis because retrospective comparison for this subject was not possible in the same way that it was for sequentially implanted subjects. However, the subject felt capable of making that comparison (of listening with 1 vs. 2 CIs) at the time.

Matching Criteria

All 3 groups were matched for age and listening to music, playing an instrument and/or singing before their HL (for BCI and UCI users) or in adulthood (for NH subjects). Additionally, the CI users were also matched for listening to music before CI 1 and for their musical experiences since CI 1 (table 1). If no perfect match could be found, age was used as the main criterion.

Data Analyses

Data were analyzed in 3 different ways. Firstly, to assess whether BCI subjects experience music differently after CI 2 as compared to CI 1, we performed a within-subject comparison. Secondly, to objectively assess any differences between uni- and bilateral cochlear implantation, we compared BCI and UCI subjects' results with those of NH subjects as a control (between-group comparison). Thirdly, we investigated possible associations between different subtopics in the BCI subjects' responses and possible correlations between subtopics and BCI subject demographics. In the second analysis, by comparing the UCI and BCI subjects in their current situation, which does not require any retrospection, control for a potential positive (spurious) bias in the first analysis, due to the BCI subjects receiving an additional intervention alone, is exercised. However, to not lose sight of the norm, we also matched a group of NH subjects as a second control group to the BCI group (between-group comparison). All 3 groups were compared simultaneously as matched triads. For statistical analysis, we changed the answer categories in the questionnaire to a 5-level, ordinal Likert scale. Current situations were compared for all 3 groups: BCI subjects after CI 2, UCI subjects after CI 1 and NH subjects in adulthood.

Statistics

Associations between different subtopics for BCI responses and correlations with BCI demographics were evaluated using Spearman's correlation coefficient. The Mann-Whitney U test and Wilcoxon signed rank tests were conducted to compare data where normal distribution could not be assumed. The Kruskal-Wallis H test and Jonckheere-Terpstra test were used for ordered data with more than 2 groups. The Jonckheere-Terpstra test was applied when the assumption of equal numbers of subjects in each group was fulfilled.

One-way analysis of variance (ANOVA) was performed to examine mean group values for normally distributed data. To look for statistically significant differences between pairwise combinations of the mean group values, post hoc tests, such as the Schef-

Table 1. Overview of the matching criteria and data for each of the 3 groups

Group parameter	Statistic	BCI	UCI	NH
Total number of subjects	n	23	23	23
Listened to music prior to HL/adulthood	n	21	23	23
Played an instrument/sang prior to HL/adulthood	2 × n	27	22	28
Listened to music before CI 1	n	8	7	–
Listened to music since CI 1	n	18	17	–
'How long did/do you listen to music after CI 1?'	median[1]	2.00	2.00	–
	25th	1.00	1.00	–
	75th	3.00	3.25	–
'What role does/did music play after CI 1?'	median[2]	4.00	3.00	–
	25th	2.00	2.00	–
	75th	4.00	4.00	–
'When did you start listening to music after CI 1?'	median[3]	2.00	3.00	–
	25th	1.00	1.00	–
	75th	4.00	4.00	–
Age at testing, years	mean	49.12	49.30	49.09
	SD	13.76	14.78	13.46
	range	22–74	19–74	23–73
Age at implantation with CI 1, years	mean	43.49	43.91	–
	SD	12.59	14.87	–
	range	16–65	15–69	–
Length of experience with CI 1, years	mean	5.62	5.57	–
	SD	2.63	3.84	–
	range	1–10	1–19	–

SD = Standard deviation; 25th = 25th percentile; 75th = 75th percentile.
[1] Likert scale used: 1 = <30 min; 2 = 30 min–1 h; 3 = 1–2 h; 4 = >4 h.
[2] Likert scale used: 1 = no role; 2 = little role; 3 = average role; 4 = big role; 5 = very big role.
[3] Likert scale used: 1 = after first fitting; 2 = after a week; 3 = after a month; 4 = after 3 months; 5 = after 6 months; 6 = after a year; 7 = after 2 years; 8 = later.

fé test for data with equal variances and the Tamhane's T2 test for data with unequal variances, were carried out.

A χ^2 test was carried out to compare frequencies. For 2 × 2 tabulations of frequencies when expected counts were below 5, Fisher's exact test was used. Statistical analysis was performed with SPSS version 16.0 for Windows (Chicago, Ill., USA, http://www.spss.com). The level of significance was set to 0.05.

Results

BCI Group Comparison after CI 1 and CI 2 (Within-Subject Comparison)

The responses of BCI subjects mostly showed an improvement in music listening abilities and habits from CI 1 to CI 2. When asked to make a direct comparison of music quality between CI 1 and CI 2, 95.5% of the BCI subjects reported that music generally sounds better, 90% reported it is more natural and 85% reported it is more pleasant after CI 2. If it was not better than with one implant, it was worse; no subjects answered that the quality stayed the same after receiving CI 2.

We also found a significant increase (p = 0.016) in the role music plays in BCI subjects' lives after CI 2 compared to after CI 1. Furthermore, we found that BCI subjects start listening to music significantly faster after CI 2 than after CI 1 (p = 0.025). However, even though subjects reported listening to music a little earlier after CI 2, there is evidence that, for part of the group (33%), a second period of acclimatization was still required. An increase in 'yes' answers was found for the question 'Which categories of music do you listen to?' across all categories from CI 1 to CI 2, though this was only significant for classical music (p = 0.004). There was a highly statistically significant increase in the number of categories listened to from CI 1 to CI 2 (p = 0.001). Only 3 subjects reported listening to fewer categories of music after receiving CI 2; 9 subjects reported the same number and 11 subjects reported an increase after CI 2. BCI subjects also reported

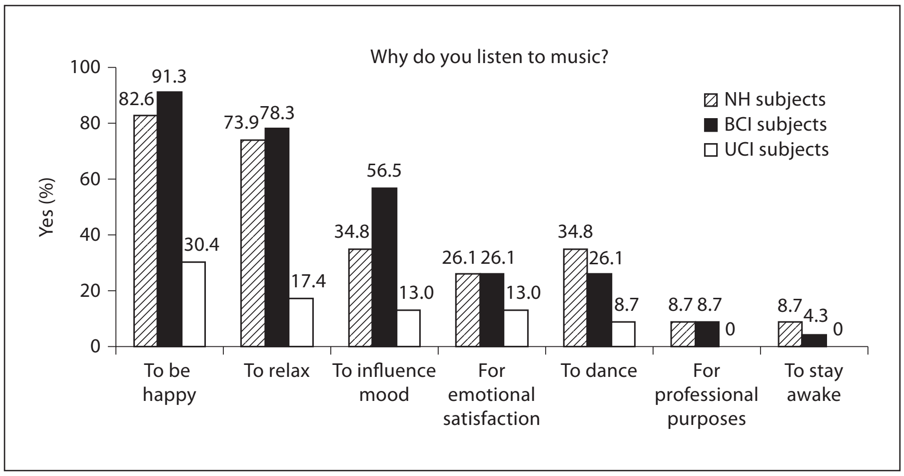

Fig. 1. The x-axis describes the various reasons why a person would listen to music; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

listening to music for longer periods of time after CI 2 than after CI 1, though this difference was not significant.

Comparison of All 3 Groups (Between-Group Comparisons – Matched Triads)

Some of the questions were specifically related to listening to music through (a) CI(s), and for these, there are no NH responses. We found that more BCI than UCI subjects described music as 'natural' and 'pleasant'; 82.6% of BCI subjects said music sounds 'natural' versus 39.1% of UCI subjects, and 80% of BCI subjects said music sounds 'pleasant' versus 56.5% of UCI subjects. Of these responses, only the difference for naturalness is significant (p = 0.006).

Although no significant difference was found for the question 'What does music sound like through your CI(s)?', a larger percentage of BCI than UCI subjects reported being able to distinguish between high and low frequencies (100 vs. 87%), recognize rhythm (100 vs. 90.9%) and recognize melody (78.3 vs. 63.6%). A smaller percentage of BCI than UCI subjects reported that music sounds like 'unpleasant noise' (15.8 vs. 31.8%) or even 'pleasant noise without melody' (44.4 vs. 63.6%).

As mentioned above, BCI subjects started listening to music significantly sooner after CI 2 than they had after CI 1. As both groups were matched for this question (after CI 1), it was also found that BCI subjects started listening to music significantly sooner (after CI 2) than UCI subjects (p = 0.012).

As expected, a significant difference was found between the 3 groups for the question 'Do you listen to music?' (p = 0.018). All NH subjects reported listening to music, while 21 BCI and only 17 UCI subjects did. Even though there were 2 BCI subjects who reported not listening to music, both reported they had tried and then answered the rest of the questions in a manner consistent with a 'no' response on this question. Post hoc testing yielded a significant difference between UCI and NH subjects (p = 0.032). There was no significant difference between groups for the 'time spent listening to music'.

Significant differences between groups were found for the following responses to the question 'Why do you listen to music?' (fig. 1): 'to be happy' ($p < 0.001$), 'to relax' ($p < 0.001$) and 'to influence my mood' (p = 0.007). Post hoc testing for the response 'to be happy' revealed a significant difference between the BCI and UCI subjects ($p < 0.001$), as well as the NH and UCI subjects (p = 0.001). Both the NH and BCI subjects selected 'to be happy' significantly more often than UCI subjects. For the response 'to relax', another significant difference between BCI and UCI subjects ($p < 0.001$) and NH and UCI subjects ($p < 0.001$) was found. Again, the UCI subjects selected this response significantly less often than the other 2 groups. For the response 'to influence mood', a significant difference was only found between the UCI and BCI subjects (p = 0.005). In general we can say, though, that group membership (NH, BCI or UCI) played a role. One difference between the CI groups was that BCI subjects selected significantly more reasons in total for listening to music ($p < 0.001$) than UCI subjects did. Most BCI subjects chose 2–4 reasons for listening to music, whereas 70% of the UCI subjects chose none.

Using ANOVA, significant differences between the 3 groups were found for the recognition of instruments (fig. 2), i.e. for violin (p = 0.002), guitar (p = 0.037), flute

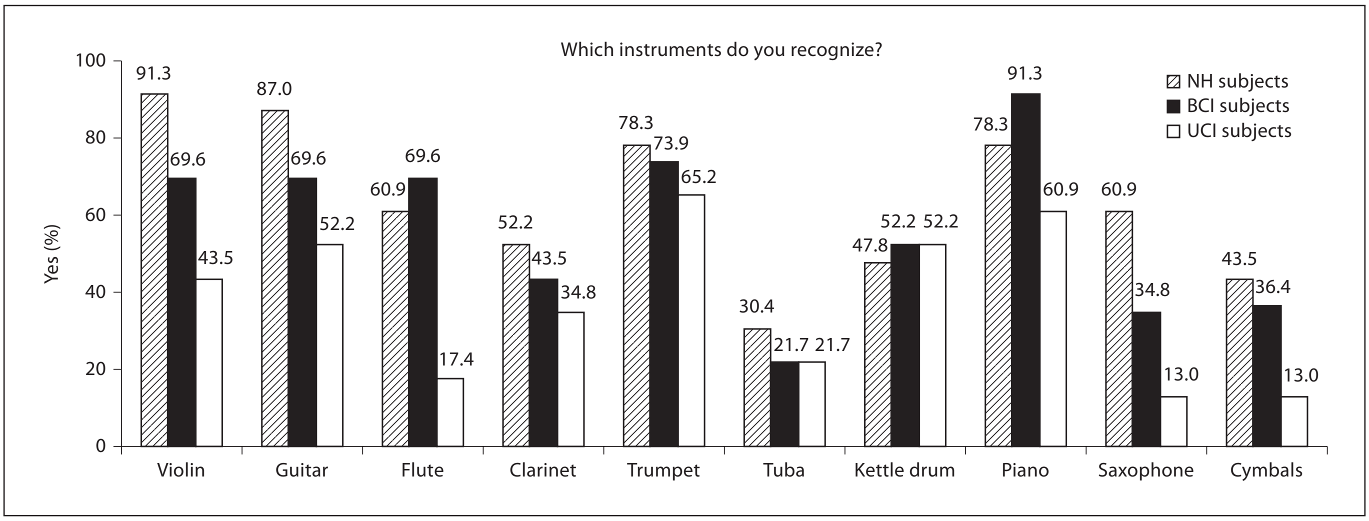

Fig. 2. The x-axis describes the various instruments to be recognized in musical pieces; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

($p < 0.001$), piano ($p = 0.049$) and saxophone ($p = 0.003$). Post hoc testing showed that the difference in the reports for violin and guitar was between the UCI and NH subjects ($p = 0.001$, $p = 0.030$), with fewer UCI subjects recognizing these instruments than NH subjects. For the flute, the difference between UCI subjects and both of the other groups was significant. Only 17.4% of the UCI group reported recognizing the flute, compared with 60.9% of NH subjects ($p = 0.006$) and 69.6% of BCI subjects ($p = 0.001$). Significantly more BCI than UCI subjects reported recognizing the piano ($p = 0.047$). The difference for the saxophone is again mainly explained by the difference between UCI (13%) and NH subjects (60.9%) ($p = 0.002$). Again, the difference between the 2 CI groups was not only in which instruments they reported recognizing, but also in the number of instruments (BCI subjects reported recognizing more). Even though these highly recognized instruments showed a moderate to high correlation with the instruments (table 2) that BCI subjects reportedly like, this seems to be of little import, as UCI and BCI subjects mostly reported liking the same instruments, except for the saxophone (fig. 3 and next paragraph).

Table 2. Correlation coefficients (Spearman's r) for BCI subjects (n = 23) between Question 10 ('Which instruments do you recognize?') and Question 11 ('Which instruments do you like?') for each instrument

Instruments	r	p value
Violin	0.438	0.037
Guitar	1.000	0.000
Flute	0.633	0.001
Clarinet	0.833	0.000
Trumpet	0.521	0.011
Tuba	0.735	0.000
Kettle drum	0.439	0.036
Piano	0.797	0.000
Saxophone	0.763	0.000
Cymbals	0.628	0.001

All p values are statistically significant ($p < 0.05$).

Significant differences were also found in the appreciation of instruments between each of the 3 groups (fig. 3). Some instruments, like the violin, were liked more by NH subjects, while others seem to be liked more by CI subjects (e.g. the trumpet, clarinet, tuba, kettle drum and cymbals). Significant differences were found for the violin ($p = 0.003$) and saxophone ($p = 0.038$). For the violin, significant mean group differences were found between the NH group and both the BCI ($p = 0.009$) and UCI groups ($p = 0.014$). NH subjects reported liking the violin significantly more often than BCI and UCI subjects. Finally, a significant difference in preferences for the saxophone was found between BCI (47.8%) and UCI subjects (13.6%) ($p = 0.036$).

In answer to the question, 'Where do you listen to music?' (fig. 4), NH subjects tended to select more locations than BCI subjects, and BCI subjects selected more than

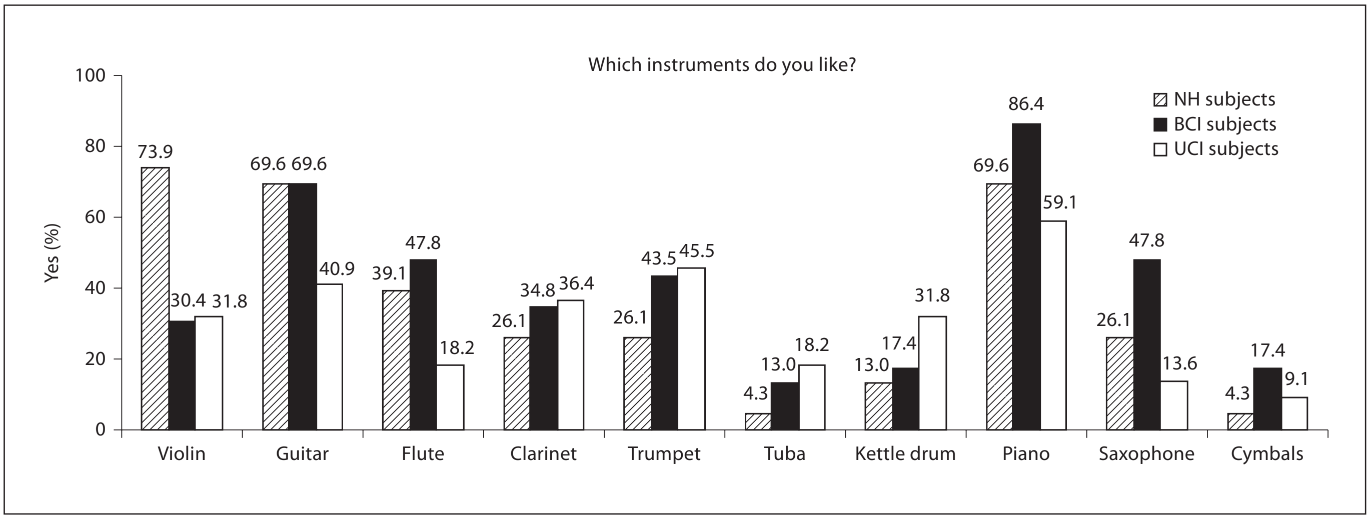

Fig. 3. The x-axis describes the various instruments to be liked in musical pieces; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

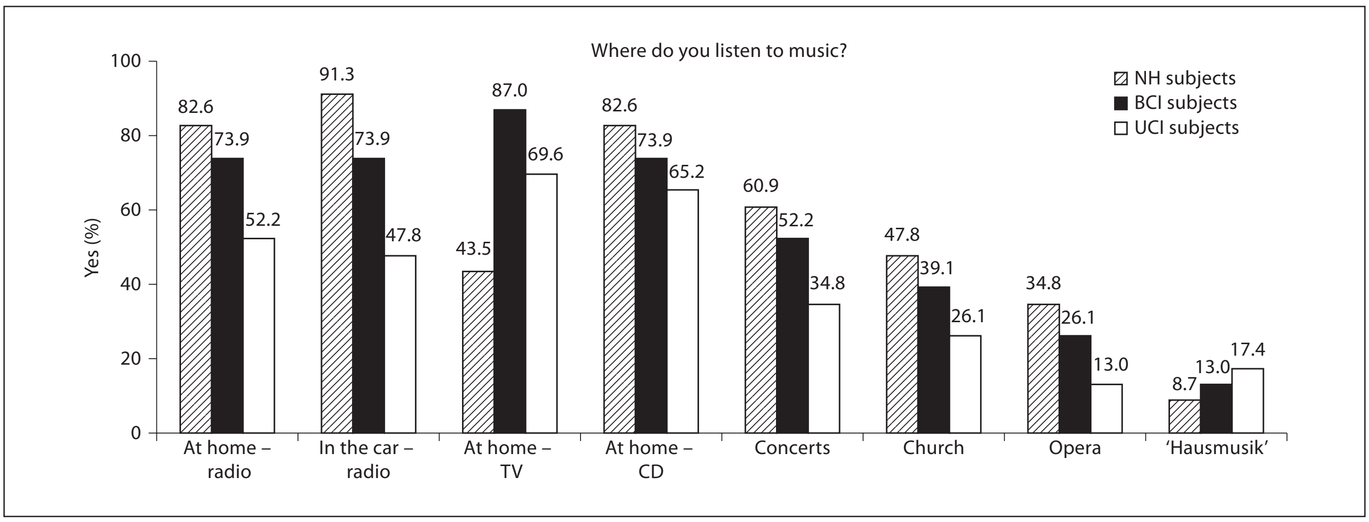

Fig. 4. The x-axis describes the places (ways) for listening to music; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

UCI subjects. A significant difference between the 3 groups was found for the categories 'in the car – radio' (p = 0.004) and 'at home – TV' (p = 0.006). NH subjects reported listening to the radio in the car significantly more often than UCI subjects (p = 0.003), while BCI subjects listened to music on TV significantly more often than NH subjects (p = 0.005).

There was a trend for more complex categories of music (e.g. classical, religious and opera) to be more popular with NH subjects and less complex categories (e.g. 'Schlager', a style of music prevalent in central and western Europe, containing emotional lyrics, a simple melody and pop and folk elements, techno and folk) to be more popular with CI subjects (fig. 5). A significant difference was found between groups for more complex categories like classical (p = 0.027) and religious music (p = 0.022); opera was not quite significantly different between the groups (p = 0.054). A larger gap for listening to classical

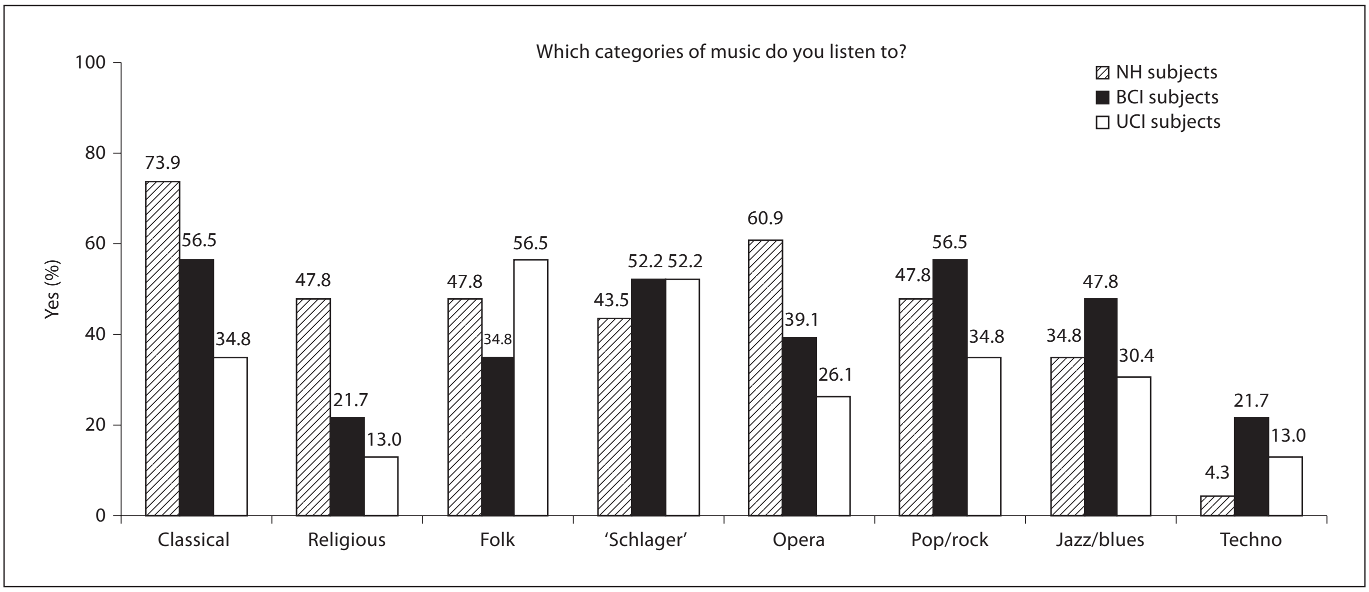

Fig. 5. The x-axis describes the various musical genres; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

music was seen in the significant difference between the responses of NH subjects and those of UCI subjects ($p = 0.021$), while the responses of BCI subjects lay in between. For religious music, NH subjects responded significantly more often with 'yes' than UCI subjects ($p = 0.030$), while the responses of BCI subjects were again in between.

No significant difference was found between groups for playing an instrument, though there was a significant difference for singing ($p = 0.016$). Ten of 23 BCI and 8 of 23 UCI subjects reported never singing versus only 1 NH subject. The differences were significant between the NH and UCI subjects ($p = 0.011$) as well as the BCI subjects ($p = 0.034$). Differences were also found in where people like to sing. In general, NH subjects selected more places than CI subjects (fig. 6). Between the 3 groups there was a significant difference in answers for singing with friends ($p = 0.034$). Post hoc testing showed that this difference came from the difference in responses between the NH and UCI subjects (43.5 and 13%; $p = 0.023$). A significant difference was also found between the groups for singing in church ($p = 0.017$). Significantly more NH than UCI subjects reported singing in church ($p = 0.013$).

The above comparison focused on each group's current situation, i.e. NH subjects in their adulthood, UCI subjects after CI 1 and BCI subjects after CI 2. To further understand the differences or similarities between the NH and BCI subjects, we also compared the NH subjects to the BCI subjects before HL and after CI 1. The only clear finding was that although no significant difference was found between the 2 groups in their current situations with regard to musical tastes (categories listened to), there were significant differences when considering the BCI subjects before HL. The BCI subjects listened less often to classical music ($p = 0.017$), religious music ($p = 0.007$) and opera/operetta ($p = 0.075$). This difference was even more pronounced when comparing the NH subjects with the BCI subjects after CI 1 in the category of classical music ($p = 0.002$), but was minimized after CI 2 (table 3).

Correlations with Subject Demographics and Associations between Sub-Questions (for the BCI Subjects)

No strong correlations were found between BCI subject characteristics (age or implant experience) and any of the responses given. A moderate positive correlation was found between the subjects' ages and their responses to the statement: 'I only hear unpleasant noise (when listening to music)'. Older subjects answered 'yes' more often than younger subjects, though not significantly more ($p = 0.10$). Older subjects were significantly less likely to report enjoying pop/rock music than younger subjects ($r_s = -0.521$, $p = 0.016$).

Several associations were found between the different sub-questions for the BCI subjects. Most interactions were found between Question 2 ('How long did/do you

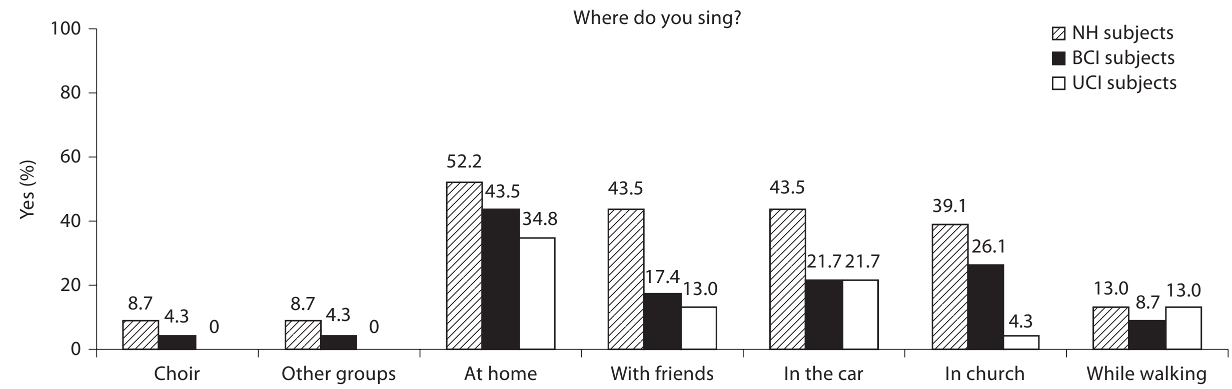

Fig. 6. The x-axis describes the various places people sing; the y-axis is the percentage of 'yes' answers for the NH, BCI and UCI subjects.

Table 3. Question 13: 'Which kind(s) of music did/do you listen to?'

	Classical	Religious	Folk	'Schlager'	Opera/operetta	Pop/rock	Jazz/blues	Techno	Total
NH	17	11	11	10	14	11	8	1	83
BCI before HL	8	2	9	16	7	13	7	2	64
BCI after CI 1	5	4	4	7	7	10	8	2	47
BCI after CI 2	13	5	8	12	9	13	11	5	76

The number of 'yes' answers for each musical category/genre and the sum of the answers are shown here for each group, i.e. NH subjects in adulthood and BCI subjects before the onset of HL and after CI 1 and CI 2.

listen to music?'), Question 3 ('How does music sound?'), Question 9 ('Which elements of music do you recognize?') and Question 23 ('What role did/does music play?'). We found that if the subject already listened to music for longer periods after CI 1, there was a trend for music to play a larger role after CI 2 ($p = 0.080$). If the subject listened to music longer after CI 2, they more often reported recognizing melody ($p = 0.052$) and also reported a larger role of music in their life after CI 2 ($p = 0.009$). χ^2 testing showed there was also a significant association between music sounding 'natural'/'pleasant' and reports of recognizing the melody ($p = 0.001$ for both). Another finding was that when music played a large role in the subject's childhood, they were more likely to report that music sounds 'unnatural' ($p = 0.028$) and 'unpleasant' ($p = 0.022$) with their CIs. In cases where music played a smaller role before implantation, subjects tended to report that music sounded 'natural' ($p = 0.082$) and 'pleasant' ($p = 0.066$) with their implant. However, this was only an observed trend, as there was no significant association between both questions.

Discussion

BCI subjects are generally more positive about their music listening experiences than UCI subjects, reporting a general improvement in the perception and appreciation of music after CI 2. For most MUMU questions, BCI responses more closely resembled NH responses than UCI responses, though there were some questions for which BCI responses were closer to UCI responses.

One advantage for the BCI subjects was that they started listening to music sooner after CI 2 than CI 1 (and sooner than the UCI group did after receiving a CI). There may be several reasons for this: (1) that adapting to music through 2 CIs is easier than adapting to music through the first CI; (2) BCI subjects might have been more motivated to start listening to music because of their experience with CI 1, or (3) BCI subjects already had one experienced ear to utilize for music listening, even if the second ear was not contributing at that point. Some BCI users do still need a period of acclimatization to music listening, similar to that needed with speech understanding when starting to listen with CI 2. From the authors' clinical experience working with sequentially implanted subjects, these tend to be subjects with a longer time between CI 1 and CI 2. One BCI subject reported needing more time to start listening to music after CI 2. Because there were no open-ended questions, the reason remains unknown. However, it is possible that the ear implanted last was the poorer ear or that, initially, listening to music bilaterally was distorted compared to listening with CI 1 only.

Another self-reported advantage for most BCI subjects was that they recognize elements of music such as melody, rhythm, high and low frequencies and instrument timbre, whereas UCI subjects only reported recognizing rhythm. This concurs with existing reports of UCI users using more objective assessment tools [Schulz and Kerber, 1994; Gfeller et al., 2002b; Gfeller and Knutson, 2003; McDermott and Looi, 2004; Zeng, 2004]. Interestingly, 44.4% of the BCI subjects still reported hearing pleasant noises without melody. As more BCI subjects reported being able to distinguish between high and low pitches and recognizing melody, it is probable that they reported music to be more natural and pleasant as a result. When asked to make a comparison between listening to music with 1 versus 2 implants, the BCI subjects reported that it sounds better, more natural and more pleasant with 2. Rhythm is reportedly heard by both UCI and BCI subjects and does not seem to contribute to music quality. These findings seem to support the theory that it is necessary for a person to hear the different elements of music in order to recognize it as music and find it natural and pleasant.

It is unclear why a large percentage of the BCI subjects would have reported less difficulty in recognizing melody and timbre. One possible explanation might be that with bilateral implantation the better ear is always captured. Another might be that there is more redundancy with two ears; for example, an electrode in one ear may be in a region with poor neural survival, whereas the complementary electrode in the other ear is located in a region with better neural survival. A third explanation might be that binaural effects are indeed important for music listening. This is supported by objective music testing, which showed better music perception by BCI compared to UCI subjects [Brill et al., 2005]. Unlike speech, though, music is processed in both hemispheres of the brain. Melody perception is located in the right hemisphere, while rhythm perception is mainly located in the left hemisphere [Jourdain, 1998]. This could be another reason why bilateral implantation enhances music perception.

The associations between the different questions for the BCI subjects indicate that the role music plays in the BCI subjects' lives also depends on the role music had with only CI 1. Subjects for whom music played a fairly large role with CI 1 were more likely to also attribute a large role after CI 2. This seems understandable given that music usually becomes even more enjoyable after CI 2. However, when music played a fairly large (small) role in the subject's childhood, they tended to report poor (good) quality. This leads us to believe that subjects who remember how music should sound can also easily compare music with and without CIs and find it unnatural and unpleasant with (a) CI(s). Conversely, subjects with less prior experience listening to music seem to adapt better to its sound and quality through a CI and perhaps experience greater satisfaction.

A small percentage of BCI subjects reported that music sounds worse, less natural or less pleasant after receiving CI 2. One factor may be that these subjects, although they had at least 12 months of experience with CI 2, were still acclimating to CI 2 when the MUMU was administered. It is also possible that the second ear might have a detrimental effect on perception and processing of the sound if it introduces distortion, which has been reported in some cases of bilateral hearing aid fitting or use of a hearing aid on the other ear [Litovsky et al., 2006a]. In these cases, we would expect the second device to also have a negative effect on speech understanding. There is little or no evidence in the literature indicating that a second CI might cause this; however, investigation into those who might not benefit from bilateral implantation could be worthwhile. For one of the subjects who reported a negative effect of CI 2 both on music and speech perception, a pitch reversal was found at a later stage. After reprogramming, the subject reported increased quality for all acoustic stimuli.

The questions for which the BCI answers were more similar to those of the UCI group (and thus different from NH answers) related to liking the violin, singing and listening to music on TV. The violin seems to be disliked by the majority of CI users. This could be because it produces high-pitched, complex sounds and is mostly used with a slow attack or onset time, possibly rendering perception more difficult. Gfeller et al. [2002b] also report that CI users rated stringed and higher-frequency instruments significantly more poorly than NH adults did. Singing is also more complex than enjoying simple music, because an intact feedback loop is needed to sing in tune and maintain a note. Many CI users report that their own voice sounds different through the CI, which might make self-monitoring during singing more difficult. Gfeller and Knutson [2003] also report that their CI users found it difficult to sing along to an external pitch, as they had problems perceiving pitches and recognizing melodies. However, the majority of the BCI subjects in this study reported recognizing pitch. This means that either they do not perceive the subtle pitch changes necessary to perform this kind of task or that the task involves cues beyond pitch alone. An alternative explanation may be that BCI subjects may have overestimated their own pitch recognition abilities. The difference between the CI and NH responses regarding singing in public indicates that receiving (a) CI(s) restores neither the ability nor the confidence to sing in front of others.

In the literature on music training for CI users, users are advised to take a multisensory approach to music, i.e. to utilize visual, aural, tactile and kinesthetic elements and lyrics [Farlow, 1998]. Gfeller and Knutson [2003] also conclude that videos can help hearing-impaired listeners make sense of the dialogue and music. This might explain why our BCI subjects listen to music on TV more often than matched NH subjects.

The BCI subjects also differed from NH subjects with regard to musical taste before HL and after CI 1. However, after CI 2, BCI responses more closely resembled those of NH subjects. Having a second CI seems to play a major role, because the UCI subjects did not report listening to more complex musical genres like classical, religious and opera, while both the BCI and NH groups did.

The difference found between the NH and UCI subjects for listening to music in the car is quite common. Most hearing-impaired people have difficulty listening to speech or music in the car because of the level of background noise. The fact that no significant difference was found between BCI and NH subjects might suggest either that this problem, for at least some of the BCI subjects, is solved by receiving CI 2, or that some NH listeners also struggle with music in the car. The former is supported by a number of studies showing spatial release from masking and/or bilateral redundancy in bilateral users [Schleich et al., 2004; Johnstone and Litovsky, 2006; Tyler et al., 2007].

Both NH and BCI subjects reported many reasons for listening to music, while UCI subjects clearly did not use music for certain purposes, e.g. relaxation or improving mood. This is an important finding, as music loses much of its value when it cannot be used in such ways. Even if bilateral implantation cannot fully restore music perception and appreciation, it is a great accomplishment if some BCI subjects can utilize music for relaxation, enjoyment and happiness.

Additionally, as Brockmeier et al. [2007] suggested, we need to consider the speech coding strategy used by the subjects at the time of the investigation. Currently, implant manufacturers are investing in improvements in speech coding strategies, related to pitch perception, which will hopefully lead to improvements in music perception.

We recognize the limitations of a study with a retrospective questionnaire. In future studies, a prospective design comparing MUMU results gathered after CI 1 with those gathered after CI 2 would be more ideal. In comparing the BCI group to the UCI group and a group of NH listeners, we attempted to eliminate (as much as possible) a potential bias from a second intervention (CI 2). However, a second bias may have been introduced here, as this BCI group could have been more enthusiastic about their first CI than the UCI group (who did not have a second CI at the time of the questionnaire). We also tried to eliminate this bias, again as much as possible, by matching both groups for musical experiences with CI 1. Furthermore, it is difficult to determine whether the positive outcomes for the BCI subjects are from the BCI and NH subjects having similar musical experiences or whether the questionnaire is not sensitive enough to show subtle differences between the NH group and the high performers in the BCI group. However, Brill et al. [2005] were able to show in another study that BCI subjects do perform better than UCI subjects and similar to NH subjects on the Musical Sounds in Cochlear Implants Test [Fitzgerald et al., 2006], which examines several aspects of music perception and recognition in more detail using live instrument recordings. A future multicenter study including both subjective data from the MUMU and objective data from the Musical Sounds in Cochlear Implants Test is planned.

Results from this study using the MUMU questionnaire indicate that BCI users enjoy some significant advantages over unilateral users when it comes to appreciating, perceiving and accessing music for a variety of purposes. Though objective data and data using the latest processing strategies are needed, our research indicates several areas where there could be improvement in the experience of music through 2 CIs.

References

Anderson I, Baumgartner WD, Boeheim K, Nahler A, Arnolder C, D'Haese P: Telephone use: what benefit do cochlear implant users receive? Int J Audiol 2006;45:446–453.

Boyle D, Radocy R: Measurements and Evaluation of Musical Experiences. New York, Schirmer, 1987.

Brill S, Brockmeier SJ, Ressel L, Mueller J, Helms J: Music perception in bilateral CI with clinical CIS processors. Proceedings of the 5th Asia Pacific Symposium on Cochlear Implants and Related Sciences, Hong Kong, 2005.

Brockmeier SJ, Grasmeder M, Passow S, Mawmann D, Vischer M, Jappel A, Baumgartner W, Stark T, Mueller J, Brill S, Steffens T, Strutz J, Kiefer J, Baumann J, Arnold W: Comparison of musical activities of cochlear implant users with different speech-coding strategies. Ear Hear 2007;28(2 suppl):49S–51S.

Brockmeier SJ, Nopp P, Vischer M, Baumgartner W, Stark T, Schoen F, Mueller J, Braunschweig T, Busch R, Getto M, Arnold W, Allum DJ: Correlation of speech and music perception in postlingually deaf Combi 40/40+ users; in Kubo T, Takahashi Y, Iwaki T (eds): Cochlear Implants – An Update. The Hague, Kugler, 2002, pp 459–464.

Brown KD, Balkany TJ: Benefits of bilateral cochlear implantation: a review. Curr Opin Otolaryngol Head Neck Surg 2007;15:315–318.

Buss E, Pillsbury HC, Buchman CA, Pillsbury CH, Clark MS, Haynes DS, Labadie RF, Amberg S, Roland PS, Kruger P, Novak MA, Wirth JA, Black JM, Peters R, Lake J, Wackym PA, Firszt JB, Wilson BS, Lawson DT, Schatzer R, D'Haese PS, Barco AL: Multicenter U.S. bilateral MED-EL cochlear implantation study: speech perception over the first year of use. Ear Hear 2008;29:20–32.

Farlow PA: Use of Music Therapy for Hearing-Impaired Children with Cochlear Implants. 1998. http://www.farlowmusictherapy.com/articles/cochlear/index.htm.

Fitzgerald D, Fitzgerald H, Brockmeier SJ, Searle O, Grebenev L, Nopp P: Musical Sounds in Cochlear Implants (Mu.S.I.C) Test. Innsbruck, MED-EL, 2006.

Fujita S, Ito J: Ability of nucleus cochlear implantees to recognize music. Ann Otol Rhinol Laryngol 1999;108:634–640.

Gfeller K, Christ A, Knutson JF, Witt S, Mehr M: The effects of familiarity on appraisal of complex songs by cochlear implant recipients and normal hearing adults. J Music Ther 2003;40:72–112.

Gfeller K, Christ A, Knutson JF, Witt S, Murray KT, Tyler RS: Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. J Am Acad Audiol 2000;7:390–406.

Gfeller K, Knutson JF: Music to the impaired or implanted ear. Psychosocial implications for aural rehabilitation. 2003. http://www.asha.org/about/publications/leader-online/archives/2003/q2/f030429a.htm (accessed January 2008).

Gfeller K, Turner C, Mehr M: Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults. Cochlear Implants Int 2002a;3:29–53.

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.

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;18:252–260.

Johnstone PM, Litovsky RY: Effect of masker type and age on speech intelligibility and spatial release from masking in children and adults. J Acoust Soc Am 2006;120:2177–2189.

Jourdain R: Music, the Brain, and Ecstasy: How Music Captures our Imagination. New York, Avon, 1998.

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

Leal MC, Shin YJ, Laborde ML, Calmels MN, Verges S, Lugardon S, Andrieu S, Deguine O, Fraysse B: Music perception in adult cochlear implants recipients. Acta Otolaryngol 2003;123:826–835.

Litovsky R, Johnstone P, Godar S: Benefits of bilateral cochlear implants and/or hearing aids in children. Int J Audiol 2006a;45(suppl 1): S78–S91.

Litovsky R, Parkinson A, Arcaroli J, Sammeth C: Simultaneous bilateral cochlear implantation in adults: a multicenter clinical study. Ear Hear 2006b;27:714–731.

Looi V, McDermott HJ, McKay CM, Hickson L: Pitch discrimination and melody recognition by cochlear implant users; in: International Congress Series. Amsterdam, Elsevier, 2004, vol 1273: Cochlear Implants. Proceedings of the VIII International Cochlear Implant Conference, pp 197–200.

Mawman DJ, Ramsden RT, O'Driscoll M, Adams T, Saeed RS: Bilateral cochlear implantation – a case report. Adv Otorhinolaryngol 2000;57:360–363.

McDermott HJ: Music perception with cochlear implants: a review. Trends Amplif 2004;8: 49–82.

McDermott HJ, Looi V: Perception of complex signals, including musical sounds, with cochlear implants; in: International Congress Series. Amsterdam, Elsevier, 2004, vol 1273: Cochlear Implants. Proceedings of the VIII International Cochlear Implant Conference, pp 201–204.

McDermott HJ, McKay CM: Musical pitch perception with electrical stimulation of the cochlea. J Acoust Soc Am 1997;101:1622–1631.

Mueller J, Schoen F, Helms J: Bilateral cochlear implants – new aspects for the future? Adv Otorhinolaryngol 2000;57:22–27.

Mueller J, Schoen F, Helms J: Speech understanding in quiet and noise in bilateral users of the MED-EL COMBI 40/40+ cochlear implant system. Ear Hear 2002;23:198–206.

Pankseep J: The emotional sources of 'Chills' induced by music. Music Percept 1995;13:171–207.

Pijl S, Schwartz DW: Intonation of musical intervals by musical intervals by deaf subjects stimulated with single bipolar cochlear implant electrodes. Hear Res 1995;89:203–211.

Schleich P, Nopp P, D'Haese P: Head shadow, squelch and summation effects in bilateral users of the MED-EL COMBI 40/40+ cochlear implant. Ear Hear 2004;25:197–204.

Schoen F, Mueller J, Helms J: Speech perception thresholds obtained in a symmetrical four-loudspeaker arrangement from bilateral users of MED-EL cochlear implants. Otol Neurotol 2002;23:710–714.

Schulz E, Kerber M: Music perception with the MED-EL implants; in Hochmair-Desoyer IJ, Hochmaier ES (eds): Advances in Cochlear Implants. Vienna, Manz, 1994, pp 326–332.

Szelag E, Kolodzieczyk I, Kanabus M, Szuchnik J, Senderski A: Deficits of non-verbal auditory perception in postlingually deaf humans using cochlear implants. Neurosci Lett 2004;355:49–52.

Tyler RS, Dunn CC, Witt SA, Noble WG: Speech perception and localization with adults with bilateral sequential cochlear implants. Ear Hear 2007;28:86S–90S.

Van Hoesel RJ, Clark GM: Fusion and lateralization study with two binaural cochlear implant subjects. Ann Otol Rhinol Laryngol Suppl 1995;166:233–235.

Van Hoesel RJ, Tong YC, Hollow RD, Clark GM: Psychophysical and speech perception studies: a case report on a binaural cochlear implant subject. J Acoust Soc Am 1993;94: 3178–3189.

Wackym PA, Runge-Samuelson CL, Firszt JB, Alkaf FM, Burg LS: More challenging speech-perception tasks demonstrate binaural benefit in bilateral cochlear implant users. Ear Hear 2007;28:80S–85S.

Zeng FG: Trends in cochlear implants. Trends Amplif 2004;8:1–34.