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Fuller, Christina Diechina

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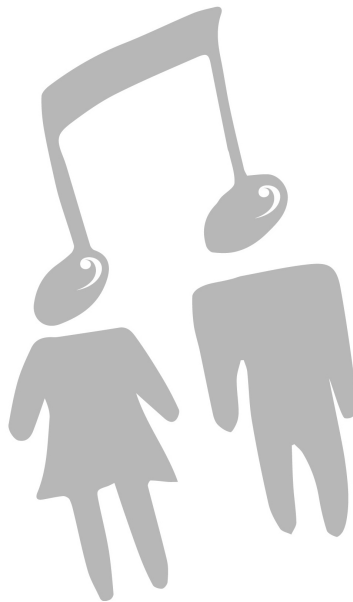
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Chapter 3

Self-reported music perception is related to quality of life and self-reported hearing abilities in cochlear-implant users

Christina Fuller ^{1,2} Rolien Free ^{1,2} Bert Maat ^{1,2} and Deniz Başkent ^{1,2}

Under revision



1 Department of Otorhinolaryngology/Head and Neck Surgery, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands

2 Graduate School of Medical Sciences (Research School of Behavioural and Cognitive Neurosciences), University of Groningen, The Netherlands.

ABSTRACT

Objective: We hypothesized that cochlear implant (CI) users' music listening habits, music quality ratings and music perception would be related with: 1) quality of life (QoL) and 2) speech perception and hearing ability.

Design: Post-lingually deafened CI participants evaluated themselves in terms of music perception, QoL, and hearing abilities using questionnaires. Additionally, speech perception was behaviorally measured.

Study Sample: Ninety-eight post-lingually deafened CI users.

Results: Music perception after cochlear implantation was significantly related with QoL and self-reported hearing ability.

Conclusions: The findings suggest some relationship between CI user's music perception and self-reported QoL and hearing ability. Music training programs and/or device improvements that improve music perception may also improve QoL and hearing ability in CI users.

INTRODUCTION

Cochlear implants (CIs) are auditory prosthetic devices that restore hearing to individuals with profound to severe sensorineural hearing impairment. CIs are able to provide good levels of speech perception in quiet and a general increase in quality of life (QoL) post-implantation (Faber, Aksel, and Grøntved 2000; Krabbe, Hinderink, and van den Broek 2000; Zhao, Bai, and Stephens 2008). However, music perception and enjoyment are still not satisfactory (Drennan and Rubinstein 2008; Gfeller et al. 2000; Philips et al. 2012).

Perception of the four basic elements in music -pitch, rhythm, melody and timbre- is less accurate and more variable in CI users compared to normal hearing (NH) listeners (Drennan and Rubinstein 2008; McDermott 2004). This discrepancy is partially due to differences between acoustic and electric hearing. CI users' music perception is limited by the coarse spectral resolution (due to the limited number of stimulation sites in the cochlea) and speech processing strategies that retain slowly varying spectro-temporal information but not the spectro-temporal fine structure information (for review, see McDermott 2004). The coarse spectral resolution limits CI users' pitch, melody and timbre perception, where fine structure cues are important (Shannon et al., 2004; Gfeller et al. 2002; Kong et al. 2009; Looi et al. 2008). Only rhythm perception appears to be similar between NH and CI listeners (Gfeller et al. 2007; Kong et al. 2004).

However, the limited *music perception* does not necessarily limit CI users' *music appreciation*, as factors that contribute to music perception and appreciation may be different (Fuller et al. 2013; Gfeller et al. 2000; Gfeller et al. 2008; Gfeller et al. 2010; Lassaletta et al. 2008; Looi et al. 2008; Looi and She 2010; Looi, Gfeller, and Driscoll 2012; Mirza et al. 2003; Wright and Uchanski 2012). Therefore, evaluation of CI outcomes in terms of music should be more comprehensively investigated by evaluating not only behaviorally measured music perception, but also self-reported perception and enjoyment of music. Music is a pervasive art form, an environmental sound and a potent pleasurable stimulus that can positively affect emotional state (Gfeller et al. 2000; Looi, Gfeller, and Driscoll 2012; Salimpoor et al. 2011). Music therapy has been shown to improve QoL in some patient groups (Hilliard 2003; Walworth et al. 2008); such therapy might also have a positive effect for CI users. Therefore, it is important to understand factors that make some CI users appreciate music and others not. Such knowledge would be useful in designing rehabilitation protocols that include music perception and appreciation for CI users.

In addition to having a positive effect on emotional state and QoL, music experience has also been shown to have a positive effect on hearing and speech perception abilities in NH listeners (Parbery-Clark, Skoe, and Kraus 2009; Parbery-Clark et al. 2009). However, musical training and involvement before cochlear implantation did not affect CI users' post-implantation speech perception performance (Fuller et al. 2012). It is possible that other factors related to the CI (e.g., functional spectral resolution) may contribute more strongly

to CI outcomes and may have obscured potential music training benefits. As such, CI listeners should not be discouraged to improve their music perception and appreciation, as this may lead to greater CI use, which may lead to better overall performance.

To gain more insight, Lassaletta et al. (2007) and Philips et al. (2012) studied CI users' self-reported perception and enjoyment of music and their association with QoL and speech perception, respectively. Lassaletta et al. used a music questionnaire and a generic QoL questionnaire [Glasgow Benefit Inventory (GBI), which assesses patient benefit after otolaryngological procedures; Robinson, Gatehouse, and Browning 1996] in 52 CI recipients. They found that the self-reported quality of music was correlated with the time spent listening to music with the CI, and with QoL. However, no data on speech perception was collected, and therefore it was unclear how music enjoyment related to speech perception performance. Philips et al. (2012) investigated the relationship between self-reported quality/enjoyment of music and speech perception. Forty CI users answered a newly developed questionnaire on music appreciation and 15 of these participants were subsequently tested for speech perception in quiet and in noise. Music quality and enjoyments were significantly correlated with speech reception thresholds (SRTs) in quiet and in noise. However, as speech perception scores were available only from 15 out of 40 participants (38%), the generalizability of the findings was limited.

The present study investigated potential relationships among music listening habits, self-reported perception of music, QoL, self-reported hearing ability and behaviorally measured speech perception in a large sample ($n=98$) of post-lingually deafened CI users. We hypothesized that music listening habits, music quality, and music perception would be significantly related with QoL, self-reported hearing ability, and speech perception scores. Questionnaires were used to investigate music listening habits, quality and perception, as well as health-related QoL and hearing ability; behaviorally measured phoneme-in-word recognitions scores were used to quantify speech perception.

MATERIALS & METHODS

Study population

The study population of this study was the same as in Fuller et al. (2012). Two hundred fourteen CI users, selected from patients implanted and/or monitored at the University Medical Center Groningen, were sent three questionnaires. The inclusion criteria were based on: current age (older than 18 years), age at the onset of profound hearing loss (6 years or older to ensure post-lingual deafness; Goorhuis-Brouwer and Schaeerlaekens 2000) and more than one year of CI experience. To include as many patients as possible and thus to study a general and representative CI population, etiology and speech perception performance were not used as inclusion criteria. Ninety-eight (46%) replies were received. The demographics of the participants are shown in Table 1. The levels of education refer

to the highest completed educational level: low refers to elementary school only, middle refers to middle school or higher, high refers to at least a bachelor's degree. Except for one CI user, all were unilaterally implanted. A comparison was made between the demographics of respondents and non-respondents to ensure that the respondents were indeed a good representation of the larger CI population who were originally sent the questionnaires. Confirming this, no significant differences were observed for age, CI experience, and gender (T-test: $t = -1.038$, $p = 0.301$, $t = -1,314$ $p = 0.191$, Chi-square-test: $\chi^2 0.041$, $p = 0.840$, respectively).

TABLE I: Demographics of the study participants. N refers to number of participants in each table and figure.

Total participants (n)	98
Gender (n)	
Male	39
Female	59
Mean age (y)	65.6 ± 11.9
Level of education	
Lower	12
Middle	67
Higher	14
Mean duration of impaired hearing (y)	37.9 ± 18.6
Mean CI use since implantation (m)	65.7 ± 33.0
Mean CI use per day (h)	15.0 ± 2.6
Hearing aid on the contra-lateral ear	36 (35%)
Implant type (n)	
CI22M ^a	1
CI24R CA ^a	24
CI24R k ^a	5
CI24RE CA ^a	27
CI24R CS ^a	16
HiRes90K Helix ^b	26
Speech processor type (n)	
Esprit3G ^a	31
Freedom ^a	42
Harmony ^b	26
Phoneme recognition in quiet (presented at 65 dB SPL)	65% (std=24%)
Phoneme recognition in quiet (presented at 75 dB SPL)	70% (std=21%)

^a Cochlear Ltd, Macquarie University, Australia. ACE speech strategy.

^b Advanced Bionics Corp., California, USA device. HiRes speech strategy.

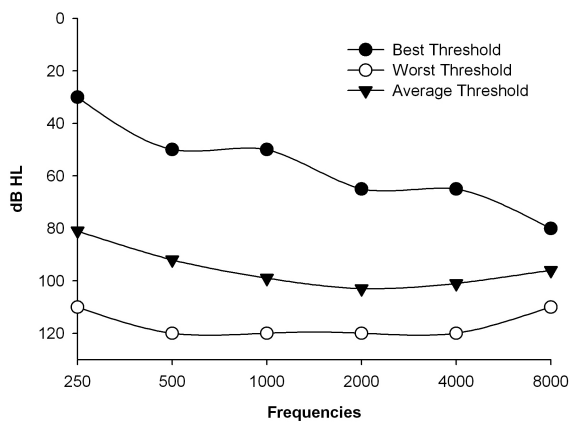


FIGURE 1. Best, worst and average hearing thresholds (across 92 CI participants) measured in the contra-lateral ear before cochlear implantation.

Figure 1 shows the best, average and worst residual acoustic hearing thresholds measured for the contra-lateral ear before implantation. Even though some CI users show useful acoustic hearing at some frequencies, the average thresholds indicate severe hearing loss. To not complicate an already large comprehensive study further, and because the participants were a good representation of typical CI users, it was decided not to additionally analyze the potential effects of residual hearing.

The study was approved by the Medical Ethical Committee of the University Medical Center Groningen. The study was conducted in accordance to the principles expressed in the Declaration of Helsinki. Detailed information about the study was provided to the participants and written informed consent was obtained. Participation was purely voluntary and no financial reimbursement was provided.

Dutch Musical Background Questionnaire

The first questionnaire, the Dutch Musical Background Questionnaire (DMBQ), is a translated and edited version of the Iowa Musical Background Questionnaire (IMBQ) developed by Gfeller et al. (2000)¹. The questionnaire was translated by a professional translator with assistance from the first author, and was further revised by audiologists, an Ear-, Nose- and Throat surgeon and a psychologist. For the present study only the sections regarding music listening habits, music quality, and perception of basic elements of music were used.

1. Music listening habits

The first part of DMBQ assessed music listening habits. Music listening habits before and after implantation were scored in two items. The first item evaluated the interest in listening

¹ Translated by M. Trommelen and C. Fuller.

to music via the statement: *I would describe myself as a person who often chooses to listen to music*. Respondents indicated their agreement with the statement on a one ('strongly disagree') to four ('strongly agree') rating scale. The second item scored the hours spent listening to music per week and was scored on a one to four rating scale: one = 0 to 2 hours, two = 3 to 5, three = 6 to 8 hours, and four = more than 9 hours. Adding the scores from the two items, two cumulative scores were calculated for music listening habits: one pre-implantation and one post-implantation. The total score thus ranged from 2 to 8. Note that not all 98 participants filled all sections of all questionnaires; therefore the numbers of participants (N) for specific sections will be indicated explicitly in text, figures, and tables. Seventy-four participants completed this part of the DMBQ.

2. Subjective quality of music

The second part of DMBQ assessed music quality with the CI. The recipients were asked to indicate how music sounds under the best conditions with their CI. Seven visual analogue scales (VASs), each ranging from 0 (worst) to 100 (best), were used. The extremes of each VAS were coupled to opposite adjective descriptors (*unpleasant-pleasant, mechanical-natural, fuzzy-clear, does not sound like music-sounds like music, complex-simple, difficult to follow-easy to follow, dislike very much-like very much*). An overall mean score between 0 and 100, calculated by averaging across the seven scales, was used to quantify the subjective quality of music. Ninety-seven participants completed this section.

3. Elements of music

The third part of DMBQ investigated the ability to perceive the elements of music (rhythm, melody and timbre), to differentiate vocalists, and to follow the lyrics of a song. The questions were scored on a seven-point scale ranging from 1 (never) to 7 (always). The values 1 to 3 thus indicated a 'negative' ability, 4 a 'neutral' ability and 5 to 7 a 'positive' ability. The specific questions were:

1. *Can you hear the difference between singing and speaking?*
2. *Are you able to differentiate between a male and a female vocalist?*
3. *Are you able to follow the rhythm of a music piece?*
4. *Are you able to recognize the melody of a music piece?*
5. *Are you able to differentiate the instruments in a piece of music?*
6. *Can you follow the lyrics of a song?*

A total mean score between 1 and 7 was calculated by averaging the scores from all six questions used to quantify the ability to perceive music elements. Eighty-seven participants completed this section.

Nijmegen Cochlear Implant Questionnaire

The second questionnaire, the Nijmegen Cochlear Implant Questionnaire (NCIQ), is a validated CI specific, health-related QoL questionnaire (Hinderink, Krabbe, and Van Den Broek 2000). The NCIQ has three categories in which six domains are allocated: *physical functioning (sound perception-basic, sound perception-advanced, and speech production)*, *social functioning (activity, social functioning)*, and *psychological functioning (self-esteem)*. Scores range from 0 (worst) to 100 (best) per domain. A total mean score between 0 and 100 was calculated by averaging across all six domains. Ninety-two participants completed the NCIB.

Speech, Spatial and Qualities Questionnaire

The third questionnaire, the Speech, Spatial and Qualities of hearing scale (SSQ)², is a measure of hearing performance, validated for hearing-impaired listeners and CI users (Gatehouse and Noble 2004). The Dutch translated version 3.1.2 (2007) was used in this study. The SSQ covers three domains of hearing: *speech, spatial, and other qualities*. Respondents rated themselves with scores varying from 0 (worst) to 10 (best). A total mean score between 0 and 10 was calculated by averaging scores across all three domains. Seventy-three participants completed the SSQ.

Recognition of phonemes in words

Recognition of phonemes in words was measured during the regular outpatient visits by trained clinical audiologists. Meaningful and commonly used consonant-vowel-consonant words were presented at 65 and 75 dB SPL in quiet (Bosman and Smoorenburg 1995). One list of twelve words was played per dB-level in free field. A list was presented using an audiometer (Equinox 2.0 from Interacoustics; Lanarkshire, Scotland) via a power amplifier (AP 12 Ritmtom; Samsun, Turkey) with the patient facing the speaker (DALI, Interacoustics; Lanarkshire, Scotland) at 2.5 meter in an audiometry booth. The ratio of correctly repeated phonemes to the total number of phonemes presented was used to calculate the percent correct score. Speech perception scores were available for 71 participants at 65 dB SPL and for 72 participants at 75 dB SPL.

Statistics

Multiple linear regression analyses were used to compare results from NCIQ, SSQ and speech perception to the music measures from the DMBQ. A level of $p < 0.05$ (two tailed) was considered significant. Statistical analyses were run using SPSS 20.

² Developed by William Noble (University of New England, Australia) and Stuart Gatehouse (MRC Institute of Hearing Research, Scotland), translated by Liesbeth Royackers (ExpORL, K.U.Leuven, Belgium) and this translation was evaluated by Sophia Kramer (VU MC, Amsterdam, The Netherlands), Wouter Dreschler (AMC, Amsterdam, The Netherlands), Hans Verschuure (Erasmus MC, Rotterdam, The Netherlands), William Damman (AZ St. Jan, Brugge, Belgium), Astrid van Wieringen (ExpORL, K.U.Leuven, Belgium) and Heleen Luts (ExpORL, K.U.Leuven, Belgium)

RESULTS

Dutch Musical Background Questionnaire

Music listening habits

Figure 2 shows the results of the music listening habits part of the DMBQ. The upper panel shows the interest in listening to music, the middle panel the time spent listening to music per week, and the bottom panel the total scores of the music listening habits before and after implantation ranging from 2 (worst) to 8 (best). Figure 2 shows a significant decline in music listening habits after implantation, reflected in all three panels (all $p < 0.000$, from top to bottom panels, $z = -5.008$, $z = -5.738$, $z = -5.673$, respectively, by Wilcoxon signed rank test). The interest in listening to music and the hours spent listening to music (top and middle panels, respectively) were significantly correlated before ($r = 0.538$, $p < 0.001$) and after implantation ($r = 0.567$, $p < 0.001$).

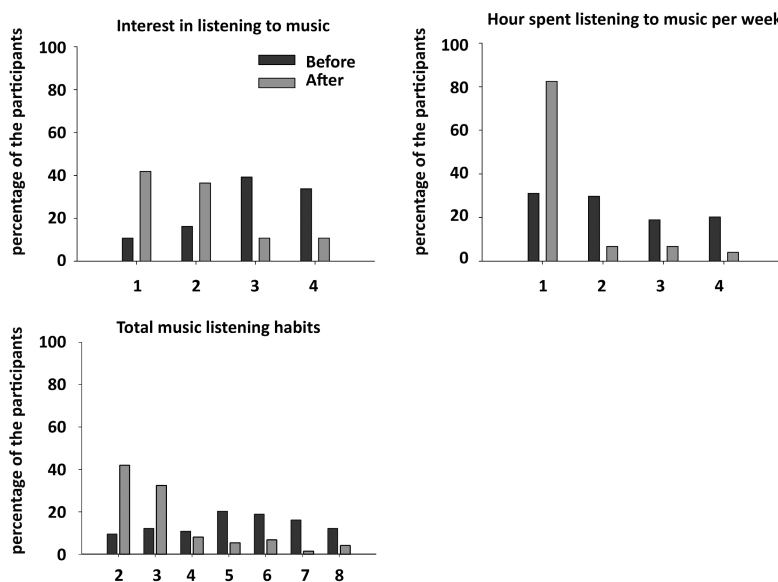


Figure 2: Self-reported music listening habits before and after implantation. The upper right panel shows the results from the first item, the interest in listening to music expressed via agreement with the statement: I would describe myself as a person who often chooses to listen to music. The upper left panel shows the time spent listening to music per week. The bottom right panel shows the total scores for music listening habits, calculated by adding the scores of the two top panels. The total scores thus ranged from 2 (minimum music listening habits) to 8 (maximum music listening habits).

Subjective quality of music

Figure 3 shows the average results (across all participants) for the subjective quality of music with the CI on a 0 (worst) to 100 (best) scale, for the individual adjectives (orange bars), as well as the total quality of music (blue bar). All mean scores were below 50, on the negative half of the scale.

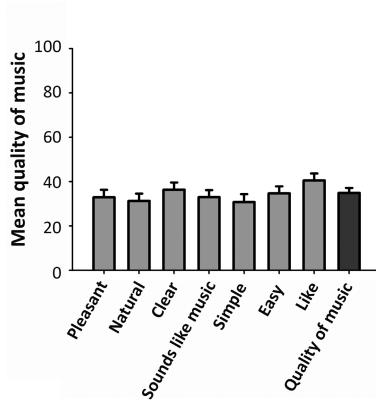


FIGURE 3: The self-reported quality of music, scored between 0 (worst) and 100 (best) and shown separately for the seven descriptor pairs. The combined total score, averaged across the seven scales, is shown by the rightmost column. The error bars denote one standard error.

Elements of music

Figure 4 shows the results of the subjective perception of the elements of music, reported in percentages of the participants. The majority of the respondents reported to be able to differentiate between singing and speaking (58%) and between a female or male vocalist (53%). From the structural elements of music (i.e. rhythm, melody and timbre) the CI recipients reported to be best able to recognize rhythm. Forty-four percent of the recipients were able to follow the rhythm, 23% recognize the melody and 15% identify musical instruments. The recipients reported the lyrics as the most problematic of these elements to follow. None (0%) of the CI users was *always* able to follow the lyrics and 44% were *never* able to follow the lyrics.

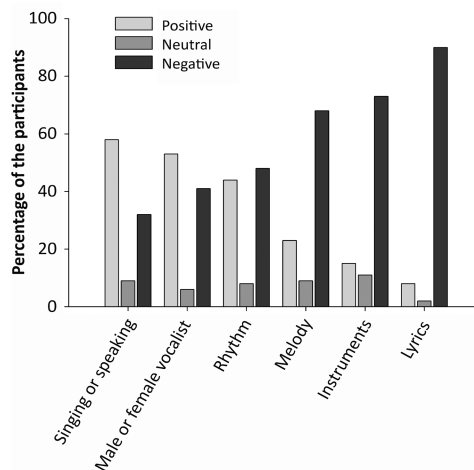


FIGURE 4: The differentiation and recognition of the elements of music, shown in percentages of the respondents who reported a positive, neutral, or negative ability.

NCIQ questionnaire

Table II shows the mean scores per domain and the total score for the NCIQ. There was a wide range in total NCIQ scores, ranging from 20 to 88, with a mean of 62, on a 0 (minimum health-related QoL) to 100 (maximum health-related QoL) scale.

TABLE II: Mean scores and standard deviations of the domains and total scores of the NCIQ (between 0 and 100).

NCIQ	Mean (standard deviation)
Sound perception basic	55 (21)
Sound perception advanced	47 (19)
Speech production	76 (16)
Self esteem	63 (17)
Activity limitations	65 (20)
Social interactions	65 (16)
Total NCIQ	62 (15)

SSQ questionnaire

Table III shows the scores per domain and the total score for the SSQ. The total SSQ scores ranged from 0 to 7.6, with a mean of 3.5, on a 0 (no hearing ability) to 10 (maximum hearing ability) scale.

TABLE III: Mean scores and standard deviations of the domains and total scores of the SSQ (between 0 and 10).

SSQ	Mean (standard deviation)
Speech	3.2 (1.8)
Spatial	3.0 (2.1)
Qualities of hearing	3.9 (1.9)
Total SSQ	3.4 (1.7)

Speech perception scores

Mean recognition of phonemes in words was 54% correct (range: 0-97) at 65 dB SPL and 67% correct (range: 0-97) was at 75 dB SPL.

Regression analyses

Because not all participants completed all questionnaires, separate multiple linear regression analyses were performed between the DMBQ music measures and the NCIQ, SSQ, and speech measures (Table IV). Significant relationships were observed between the DMBQ and the NCIQ and SSQ measures ($p < 0.05$ in both cases). Because the number of subjects differed across measures, it was not possible to strictly correct for family-wise error associated with multiple comparisons. However, using a Bonferroni adjustment to

the significance level ($0.05/4 = 0.0125$), the significant relationships persisted between the DMBQ and the NCIQ and SSQ measures. Only the elements of music was found to contribute significantly to the regression ($p = 0.001$ in both cases). There was no significant relationship between either speech measure and the music measures ($p > 0.05$ in both cases).

TABLE IV: Multiple linear regressions between CI outcome measures and DMBQ measures.

	Regression fit			Pre-CI		Post-CI		Quality		Elements	
	n	r	p	t	p	t	p	t	p	t	p
NCIQ	67	0.50	0.001	-0.59	0.558	-0.23	0.822	0.44	0.663	3.54	0.001
SSQ	55	0.50	0.007	-0.94	0.351	-1.36	0.160	0.22	0.830	3.70	0.001
Speech 65	51	0.31	0.303	-0.51	0.611	0.23	0.820	0.78	0.442	1.11	0.771
Speech 75	52	0.34	0.209	0.37	0.713	-0.10	0.924	0.81	0.425	1.54	0.130

DISCUSSION

In the present study, self-reported music perception (DMBQ) in post-lingually deafened CI users was investigated and compared to outcome measures in terms of self-reported QoL (NCIQ), self-reported hearing ability (SSQ), and behaviorally measured speech perception (phoneme-in-word recognition at 65 and 75 dB SPL). We hypothesized that listening habits, better quality, and perception of music would be associated with the NCIQ, SSQ, and speech perception. While significant relationships were found between the music measures and the NCIQ and SSQ, these were largely driven by perception of elements of music; no significant relationships were observed between the DMBQ and speech perception.

Note that the same study population was used as in Fuller et al. (2012), presented in Chapter 6. The hypotheses of these studies were different. In Fuller et al. (2012), we hypothesized that formal music training before implantation (measured with different questions of the DMBQ) would affect QoL, self-reported hearing ability, and speech perception. In this study, the music measures were not sensitive to formal music training, and represented general music listening experience, quality, and perception. Because the hypotheses were different, and to present the data more clearly, the two studies are presented in different chapters of the thesis and were submitted as different papers.

Music factors

In accordance with literature, a decline in the music listening habits after implantation has been previously reported in post-lingually deafened CI users (Gfeller et al. 2000; Lassaletta et al. 2007; Lassaletta et al. 2008; Looi and She 2010; Migirov, Kronenberg, and Henkin 2009; Mirza et al. 2003; Philips et al. 2012). In this and these previous studies, music quality with the CI was rated negatively in general.

For music perception with the CI, participants reported that they were most able to differentiate between singing and speaking and between a female and a male vocalist. The

latter was scored even more positively than the ability to follow the rhythm. This is surprising because the differentiation between a female or a male vocalist depends mostly on voice pitch and to a lesser extent on timbre; CI users' voice gender recognition has been shown to be more difficult than rhythm identification (Fu, Chinchilla, and Galvin 2004; Gfeller et al. 2007). Consistent with our findings, Philips et al. (2012), using questionnaires, reported that 53% of CI subjects indicated they were able to distinguish between male and female voices (compared to 58% in this study), while only 30% were able to follow the rhythm (compared to 44% in this study). Thus, while CI users seem to be able to follow simple rhythms in behavioral studies, they subjectively report they are unable to follow the rhythm in musical pieces. This difference could be due to the 'rhythm-only excerpts' used in behavioral studies compared to the overall perception of rhythm music encountered in daily life (Drennan and Rubinstein 2008; Gfeller et al. 2007; Kong et al. 2004; Won, Drennan, and Rubinstein 2007).

Considering the basic elements of music - rhythm, timbre and melody- the order of rating for the ability to perceive them was as expected. Rhythm was reported to be perceived best, followed by timbre and subsequently by melody. This is consistent with the results of both behavioral studies and subjective questionnaires (Gfeller et al. 2007; Philips et al. 2012). It was somewhat surprising that the present participants rated lyric perception in music to be most problematic, with 44% reporting that they were *never* able to follow the lyrics.

Previous CI studies have reported that lyrics were beneficial for perception and recognition of music (Gfeller et al. 2002a; Leal et al. 2003). Again, being able to follow the lyrics of short musical excerpts used for behavioral testing may be different than a more general perception of lyrics in music encountered in everyday life. In some ways, the ability to follow lyrics is akin to the intelligibility of speech in music. Consistent with our findings, speech intelligibility in background music has been observed to be poorer in CI users than in NH listeners (Eskridge et al. 2012).

Music versus quality of life

The perception of music elements was the only component of the DMBQ that was predictive of QoL, as measured with the NCIQ. Music listening habits before/after implantation and music quality were not predictive of QoL after or the quality of the sound of music was found. Fuller et al. (2012) similarly found no significant relationship between musical background before implantation and health-related QoL in the same groups of subjects.

There is some agreement between the present findings and those from previous studies. Lassaletta et al. (2007) showed a significant positive association between music listening habits, music quality, and QoL in 52 adult CI users, using different questionnaires than in the present study. Zhao et al. (2008) found that improvement in QoL was related to different variables for individual CI subjects. In 38% of CI subjects, speech communication was a key determinant of QoL; in 25% of CI subjects, music perception was and in three out of

twelve subjects improved music was a key determinant for QoL. Music perception and QoL may both be influenced by device-related factors (e.g., electrode placement, quality of electrode-nerve signal transmission, etc.) and/or patient-related factors (etiology, health of the spiral ganglia, cognitive elements, etc.).

Music versus hearing abilities and speech perception

Perception of music elements was the only component of the DMBQ that was predictive of hearing ability, as measured with the SSQ. Speech perception (as measured by phoneme recognition in quiet at 65 and 75 dB) was not significantly related to any of components of the DMBQ. The lack of relation between speech and music perception may be due to spectral resolution. While four spectral channels may be adequate for speech recognition in quiet, many more channels are required for music perception (Shannon et al., 2004). Thus, good speech performers may have rated music perception poorly, or that their music listening habits involved less time than speech perception, which is a more constant listening demand. Speech recognition in noise or pitch-based speech perception (e.g., voice gender categorization, vocal emotion recognition, etc.) may have been more strongly related to music perception. Philips et al. (2012) reported that enjoyment of music and quality were correlated with CI users' speech reception thresholds in quiet and in noise. Won and colleagues (2007; 2010) found that word recognition in quiet was related to specific music elements of melody, timbre, and pitch, suggesting that improvements in CI signal processing that improve speech perception might also improve music perception, and vice versa.

Improved music perception via music training may benefit speech perception, as music experience has been shown to relate to NH listeners' speech performance (Parbery-Clark et al. 2009). The results of the present study have important implications, as some aspects of music perception were strongly linked to QoL and self-reported hearing abilities. CIs were originally developed and optimized for speech perception. Developing CI technology to improve music perception may have a strong positive effect on QoL. Other benefits may also come from improved music perception (e.g. better performance in challenging environments, better perception of important pitch cues in speech, etc.). With improved CI technology and/or music training, improvements in music perception may have profound effects on CI outcomes.

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