Multicentre evaluation of music perception in adult users of Advanced Bionics cochlear implants

Doris Adams[1], Khalid Mohamed Ajimsha[2], Manuel Tomás Barberá[3], Dzemal Gazibegovic[4], Javier Gisbert[5], Justo Gómez[6], Eyal Raveh[7], Christine Rocca[4,8], Philipe Romanet[9], Yvonne Seebens[10], Andrzej Zarowski[11]

[1]Medical University Hannover, Hannover, Germany, [2]Advanced Bionics India Pvt Ltd, Bangalore, India, [3]Hospital Son Dureta, Palma de Mallorca, Spain, [4]Advanced Bionics, Clinical Research Department, Cambridge, UK, [5]Hospital de la Ribera, Alzira, Spain, [6]Hospital Central de Asturias, Oviedo, Spain, [7]Schneider, Petach-Tikva, Israel, [8]Mary Hare School, London, UK, [9]Hôpital Général, Dijon, France, [10]CIC Rhein-Main, Friedberg, Germany, [11]University Hospital St. Augustinus, Wilrijk, Belgium

Objectives: To document musical listening and enjoyment in recipients of Advanced Bionics cochlear implants (CIs) and to compare musical perception in those using early coding strategies with subjects using the newer HiRes and HiRes 120 strategies.

Methods: A questionnaire was completed by 136 adult subjects, including questions on the ability to identify specific musical features. The subjects were in three groups: those using early coding strategies ($n = 29$), HiRes ($n = 59$), and HiRes 120 ($n = 48$), and results were compared with a group of 84 normally hearing (NH) subjects.

Results: Of the CI users, 79% reported listening to music. The NH group rated listening frequency and enjoyment higher than the CI users. Thirty-five users reported that they sang and this group had significantly higher overall performance. There were no significant differences in overall perception of specific musical features among the strategy groups, though some individual questions showed significantly higher performance in the HiRes 120 users.

Discussion: Users of current CI technology show a high level of musical appreciation, though still significantly less than NH subjects. Frequency of listening and enjoyment were significantly correlated and active participation in musical activities, specifically singing, resulted in significantly higher overall performance scores.

Keywords: Cochlear implants, Music, Questionnaire, Sound coding

Introduction

When commercial cochlear implant (CI) systems were first available the principal goal was to help severely or profoundly deaf individuals understand speech (NIH Consensus, 1995). With the evolution of CI technology and the widening of candidacy inclusion criteria speech understanding, both in quiet and noise, has improved over time (Krueger *et al.*, 2008). The primary goal of satisfactory speech understanding may be considered to have been largely achieved, but the quality of music perception is still reported by many CI users as poor (Looi and She, 2010; McDermott, 2004; Migirov *et al.*, 2009; Mirza *et al.*, 2003). Despite this some CI users continue to listen to and enjoy music with a few individuals achieving high levels of music performance. In recent years more studies have looked at the abilities of CI users to identify specific features of music such as rhythm, melody, and timbre and these features are perceived with varying levels of accuracy and quality (Limb and Rubinstein, 2012). McDermott (2004) reported that CI users could easily follow basic rhythms of up to 160 beats per minute, while the differentiation of rhythmical patterns appeared to be more challenging. In a more recent study looking at the more complex task of internal rhythmical clocking, CI users performed equivalently to normal hearing (NH) listeners, further demonstrating that rhythm seems to be the musical feature best preserved by implants (Kim *et al.*, 2010). Moderate results were obtained by McDermott (2004) in identifying individual musical instruments (timbre) and the most difficult tasks appeared to be the differentiation of pitch (including the identification of melodies without rhythmical cues) and the perception of harmonic content of

Correspondence to: Dzemal Gazibegovic, Advanced Bionics, Cambridge, UK. Email: dzemalg@abionics.fr

DOI 10.1179/1754762813Y.0000000032

music. In a later series by Kang *et al.* (2009) a new music evaluation test, the CAMP, was evaluated in a group of 42 implant recipients. Pitch identification was assessed by measuring the size of the semitone difference that could be detected accurately. Results showed that implant users' pitch discrimination was poor, at a mean of three semitones compared to the normal group at a mean of one semitone. The range of performance was large, 1–8 semitones; however, some users clearly performed as well as some of the normal listeners. Melody identification was similarly poor for the implanted group (mean of 25%, range 0–94%) compared to the normal group (mean 87%) but again some users did perform within normal limits.

Longitudinal studies have not shown any improvement in music perception ability over time with standard, auditory exposure (Gfeller *et al.*, 2010). However the introduction of music training programs as part of the rehabilitation process has shown that performance may be improved through specific training approaches (Looi and She, 2010) and it seems increasingly clear that musical experience leads to better performance in implant users in comparison with individuals without musical experience (Limb and Rubinstein, 2012). There is also evidence to support the hypothesis that the addition of low frequency hearing, as well as changes to the way the sound is processed can improve performance (Chang *et al.*, 2009; Gifford *et al.*, 2010; Kasturi and Loizou, 2007; Sucher and McDermott, 2009).

Various test batteries have been developed to assess musical ability; some are based on well controlled psychophysical measures of musical perception and others on questionnaire-based materials, focusing on subjective measures of enjoyment and appreciation. While less well validated and not necessarily an accurate measure of perception abilities (Gfeller *et al.*, 2005), these subjective measures are easy to administer in a wide variety of clinical settings and produce informative data about a subject's perception of their musical enjoyment.

A number of questionnaire-based studies have been conducted: Mirza *et al.* (2003) assessed 35 CI users through a survey on their musical listening habits. Of their 35 subjects, only 16 (46%) reported listening to music post implantation. The enjoyment of music prior to deafness was rated as an average of 8.7 on a scale of 1–10 but was only 2.6 following implantation. The mean rating for the enjoyment of the 16 users who reported to listen to music was 5.6, which was also significantly lower than before deafness. Comparable findings were reported by Gfeller *et al.* (2000), who investigated 65 CI users through self-report. Of the 65 individuals, 23% indicated that music with the CI sounded similar to their recollection before deafness, 43% felt that music was improving over time, and 23% were disappointed with their perception of music. Migirov *et al.* (2009) conducted a study of 53 implant recipients, nine of which were pre-lingually deafened. Seventy-four percent of their participants indicated that they still listened to music with a satisfaction rating of 6 on a scale of 1–10. However, enjoyment before the onset of deafness and after implantation was significantly decreased, with 51% rating it as worse after implantation.

The HiRes coding strategy was introduced by Advanced Bionics in 2002 with the intention of improving both spectral and temporal resolution (Battmer *et al.*, 2003; Buechner *et al.*, 2006). Anecdotal reports received by Advanced Bionics indicated that music seemed more natural when listening with the HiRes 120 speech processing strategy. Although limited, there is some published evidence to support this finding. A study by Firszt *et al.* (2009) reported a significant improvement in the pleasantness of music and distinctivness of instuments when using HiRes 120. In another study on a group of seven children, there was a small but significant improvement in tone discrimination with HiRes 120, a parameter found by Wang *et al.* (2012) to be significantly correlated with music pitch perception (Chang *et al.*, 2009). These results highlighted the need for more data to support these findings and to explore the hypothesis that there is a difference in how music is perceived by subjects using different generations of sound coding strategies.

The focus of this study was to investigate the subjective level of music appreciation in a large number of users of Advanced Bionics technology using a newly developed, non-validated, self-reported questonnaire of musical enjoyment and listening habits. Results were compared across four groups of subjects; those with NH, those using a conventional CIS/MPS/SAS (C1) strategy, those using HiRes, and those using HiRes120.

Methods

Participants

CI users of both previous and current generations of Advanced Bionics implants and sound processing who were older than 16 years, had a minimum of 6 months experience with their current sound processing strategy, and were able to complete the questionnaire were invited to participate in the evaluation. One hundred and thirty-six CI users from seven European clinics and one Indian collaborative group participated in the study. A group of NH individuals ($n = 84$) was also invited to participate, and was recruited on an opportunity basis from staff and students at the Medizinische Hochschule Hannover, and some Advanced Bionics field staff. All participants signed written consent forms and the study was conducted

Table 1 Demographical details of study participants

	Normal hearing group		HiRes120		HiRes		C1	
	n = 84	%	***n*** = 41	%	***n*** = 44	%	***n*** = 28	%
Age completion (years)								
16–20	10	11.9	0	0.0	2	3.4	7	24.1
21–30	17	20.2	4	8.3	3	5.1	1	3.4
31–40	23	27.4	5	10.4	5	8.5	1	3.4
41–50	16	19.0	13	27.1	14	23.7	6	20.7
51–60	8	9.5	8	16.7	12	20.3	6	20.7
61+	10	11.9	18	37.5	23	39.0	8	27.6
Duration of deafness (years)								
<1			2	4.2	3	5.1	1	3.4
1–2			4	8.3	4	6.8	0	0.0
3–10			13	27.1	8	13.6	4	13.8
11–20			5	10.4	11	18.6	17	58.6
21–40			14	29.2	19	32.2	6	20.7
41+			9	18.8	14	23.7	1	3.4
Duration of use (years)								
<1			21	43.8	18	30.5	0	0.0
1–5			23	47.9	22	37.3	0	0.0
>5			3	6.3	19	32.2	29	100.0
Use of hearing aids								
No			25	52.1	39	66.1	26	89.7
Yes			22	45.8	20	33.9	3	10.3

in accordance with the PAHO international code of ethics.

Demographical information on the subjects was obtained from the first section of the music questionnaire (see below). Age, duration of deafness before implantation, duration of CI use, and post-operative use of hearing aid (in the contralateral ear) were divided into the categories shown in Table 1. The table lists the numbers of subjects responding for each category. The shaded categories indicate the median category for each subject group.

Music questionnaire

The evaluation was based on a questionnaire developed by Advanced Bionics, which consists of 43 questions divided into four main sections: (i) subject's profile (demographics), (ii) experience with music prior to hearing loss, (iii) current experience with music, and (iv) perception of specific musical features. The questionnaire includes questions relating to use of accessories and other ergonomic hardware features, and has been used by Advanced Bionics for a range of user-feedback purposes. For this particular study, a subset of questions was used as follows:

1. Assessment of frequency of listening to music and an overall judgment of enjoyment. Both these questions required a rating from 0 ('not at all') to 10 ('very much'). CI users rated both questions with respect to their current status and to their recollections prior to hearing loss.
2. Participation in musical activities was assessed by two questions: 'Do you sing?' and 'Do you play a musical instrument?' (yes or no). CI users provided responses with respect to their current status and to their recollections prior to hearing loss.
3. Perception of specific musical features was assessed by a set of nine questions, each of which required a rating on a scale from 0 ('not at all') to 10 ('very often'). These questions were only completed by the subjects (NH or CI users) who indicated that they currently listen to music:
   - How often are you able to recognize the musical style when listening to a piece of music for the first time? For example, pop, rock, classical, folk.
   - How often are you able to hear if there is a singer when listening to a new piece of music?
   - How often are you able to hear if the singer is female or male?
   - If there is a singer, how often are you able to understand the words when listening to a NEW song in your native language?
   - How often are you able to understand the words when listening to a KNOWN song in your native language?
   - How often are you able to tell how many instruments are playing together when listening to a NEW piece of music with several instruments?
   - How often are you able to tell how many instruments are playing together when listening to a KNOWN piece of music with several instruments?
   - How often are you able to tell which instrument is playing solo when listening to a NEW piece of music?
   - How often are you able to tell which instrument is playing solo when listening to a KNOWN piece of music?

Questionnaires in the local language were given to subjects and were completed during a routine review visit. One clinic opted to conduct the evaluation as an interview.

Statistical methods

All statistical analyses were performed using Statistica version 9.1 (StatSoft, Inc., Tulsa, USA).

Differences between the CI and NH group in demographics (age, duration of deafness, and use of hearing aids) were assessed using a two-tailed Kruskal–Wallis test. If any of the effects was found significant a multiple comparison of mean ranks was conducted and a difference between groups was found to be statistically significant if the P value was equal to or below 0.05.

A one-way between-subjects ANOVA was conducted to assess the effect of the CI users before deafness and the NH on the frequency and enjoyment. To compare the effect of the sound coding on the frequency and enjoyment in the NH, HiRes 120, HiRes, and C1 conditions, a one-way between-subjects ANOVA was conducted.

A principal component analysis was performed on the nine questions relating to specific musical features. The results of the principal component analysis revealed that the main inertia of the nine individual questions can be well represented on one new axis (Eigen value 5.1 for CI subjects, 4.9 for NH subjects). Projections of the nine variables over the new axis showed that each variable was correlated ($r = 0.6$; $P < 0.05$) with this new axis, which was then considered as the size axis and was used as a measure of overall musical performance.

The new variable 'overall musical performance' was constructed as the average score of the nine questions listed in the Methods section. The distribution of the overall musical performance variable was tested with the Kolmogorov–Smirnoff normality test and it was not significantly different from an expected normal distribution (K–S, $d = 0.07$; $P > 0.2$).

For assessing the effect of sound coding on the musical performance overall a one-way between-subjects ANOVA was conducted for the conditions: NH, HiRes 120, HiRes, and C1.

For the NH group a main effects ANOVA (MANOVA) was conducted to assess the effect of age and musical activities: singing and playing an instrument on the overall performance.

To analyse the effect of demographical factors: age, duration of deafness, duration of CI use, and hearing aid use and musical activities: singing and playing an instrument on the musical performance overall a MANOVA was conducted for the CI group.

If in any of the ANOVA models any of the effects were found significant, the level of significance was estimated performing the Bonferroni *post hoc* comparisons and it was assumed that a difference was statistically significant when P was equal to or below 0.05.

All correlations were assessed using the Pearsons Product-Moment analysis.

Results

Demographics

Based on the results of the Kruskal–Wallis test there is a significant difference between the average age between the groups (Table 1, $H = 24.05$, df = 3, $P < 0.05$). Multiple comparisons of the mean ranks of the age groups between the strategies and the NH group indicated that the NH group was significantly younger than the two HiRes and HiRes 120 groups ($P < 0.01$). The age difference between the NH and the C1 group was not reaching the level of significance. However, the differences between HiRes, HiRes 120, and C1 groups were not significant. All three strategy groups had a similar duration of deafness (Kruskal–Wallis test, $H = 1.17$, df = 2, $P > 0.05$). The C1 group had a significantly longer duration of use over the other two strategy groups (Kruskal–Wallis test, $H = 44.44$, df = 2, multiple comparisons of the mean ranks $P < 0.01$).

Listening frequency and enjoyment

Fig. 1 illustrates how often subjects listened to music before deafness and after implantation. It appears that the CI subjects did not listen to music before deafness (M = 5.9, SD = 3.1) as often as the NH control group (M = 7.6, SD = 2.1, one-way ANOVA, df = 1, $F = 17.0$, $P < 0.001$). However, this result may not be reliable as the musical listening habits for the CI users prior to deafness were rated retrospectively. The NH group rated their listening frequency significantly higher than any of the CI groups post-operatively (one-way ANOVA, df = 3, $F = 6.8$, $M_{NH} = 7.6$, SD = 2.1 vs. $M_{HiRes\ 120} = 5.3$, SD = 2.7, Bonferroni

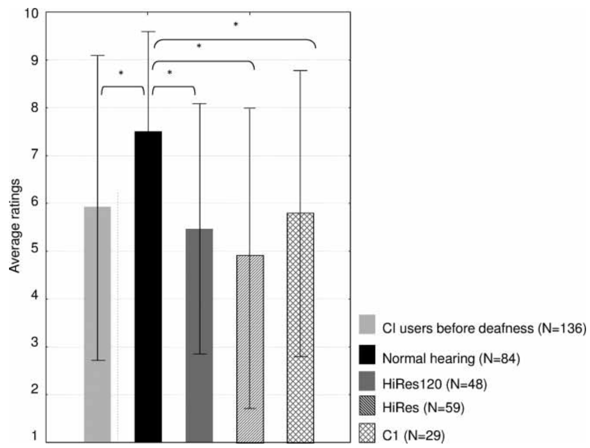

Figure 1 Frequency of listening to music: the normal hearing group indicates higher listening frequency than any of the CI groups. Marked differences are significant at level $P < 0.001$.

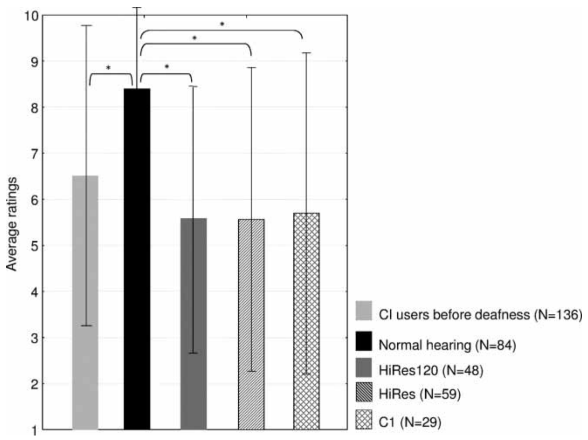

Figure 2 Enjoyment of music: the normal hearing group shows significantly higher level of enjoyment than the CI users. Marked differences are significant at level $P < 0.001$.

post hoc $P = 0.004$, vs. $M_{HiRes} = 4.9$, SD = 3.1, $P < 0.001$, vs. $M_{C1} = 5.8$, SD = 3.0, $P < 0.001$). Other differences between groups were not significant.

Fig. 2 illustrates how much subjects enjoyed music before deafness and after implantation. The CI subjects apparently did not enjoy music before deafness (M = 6.4, SD = 3.2) as much as the NH control group (one-way ANOVA, df = 1, $F = 26.0$, M = 8.4, SD = 1.8, Bonferroni $P < 0.001$). Current enjoyment of music was also rated significantly higher by the NH group (one-way ANOVA, df = 3, $F = 12.1$, $M_{NH} = 8.4$, SD = 1.8) than ratings of the C1 (M = 5.7, SD = 3.4, $P < 0.001$), HiRes (M = 5.5, SD = 3.3, $P = 0.002$), and HiRes 120 groups (M = 5.5, SD = 2.8, $P < 0.001$), while the differences among the CI groups were not significant.

Of the 136 CI users, 28 reported not listening and enjoying music at all and were excluded from all subsequent analyses. Nine out of these 28 users were prelingually deafened. The remaining 108 subjects were postlingually deafened and included 27 C1, 42 HiRes, and 39 HiRes 120 users.

Perception of specific musical features

Fig. 3 shows the overall musical performance split by the sound coding strategies.

The NH group scored significantly higher (M = 8.0, SD = 1.3) than HiRes 120 (M = 5.9, SD = 1.8), HiRes (M = 5.3, SD = 1.9), and C1 (M = 5.1, SD = 2.1, one-way ANOVA, df = 3, $F = 35.3$, Bonferroni $P < 0.001$). The differences among the individual CI groups were not significant.

Influence of demographics and musical activities on the performance, enjoyment, and listening frequency

NH subjects

The overall musical performance for those who played an instrument (M = 8.7, SD = 0.79) was significantly higher than for those who did not (M = 7.8, SD = 1.4, MANOVA, df = 1, $F = 6.92$, Bonferroni $P = 0.006$). Out of 84 NH participants, 20 indicated that they play an instrument. The age (MANOVA, df = 5, $F = 1.91$, $P = 0.1$) as whether the subjects indicated to sing or not (MANOVA, df = 1, $F = 0.05$, $P = 0.8$) had no significant influence on the musical performance overall.

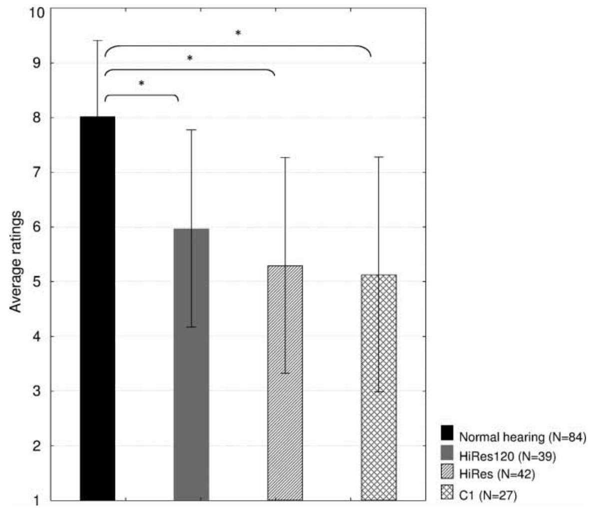

Figure 3 Overall performance: the normal hearing group scored significantly higher on the overall performance than any of the CI group ($P < 0.001$).

There were significant correlations between the following variables:

- Frequency of listening and enjoyment ($r = 0.74$, $n = 84$, $P < 0.001$).
- Frequency of listening and overall performance ($r = 0.51$, $n = 84$, $P < 0.001$).
- Enjoyment and overall performance ($r = 0.72$, $n = 84$, $P < 0.001$).

CI users

There were significant correlations between the following variables:

- Frequency of listening and enjoyment before deafness ($r = 0.87$, $n = 113$, $P < 0.001$).
- Frequency of listening and enjoyment with the CI ($r = 0.78$, $n = 113$, $P < 0.001$).

However, duration of device use (MANOVA, df = 2, $F = 0.62$, $P = 0.\ 53$), age (df = 5, $F = 1.54$, $P = 0.18$), duration of deafness (df = 5, $F = 0.95$, $P = 0.45$), and the use of hearing aids (df = 1, $F = 0.12$, $P = 0.72$) had no significant influence on the musical performance overall.

Out of 108 CI users (from all strategy groups), 35 indicated they sang. This sub-group scored significantly higher on the overall musical performance (singing = 6.3, SD = 1.9 vs. not singing = 5.1, SD = 1.8, MANOVA, df = 1, $F = 8.4$, Bonferroni $P = 0.004$) and on 'identifying lyrics in new music' (singing = 5.1, SD = 2.7 vs. not singing = 3.9, SD = 2.2, MANOVA, $F = 5.3$, $P = 0.02$). Only seven CI users indicated that they played a musical instrument and their scores were not significantly different from those who did not play an instrument (MANOVA, df = 1, $F = 1.03$, $P = 0.31$).

Discussion

The above results, collected from 136 subjects, provide interesting insights into the behaviour of CI users with respect to music, particularly in comparison with a NH control group. It was notable to observe that the majority of cochlear implantees (79.4%) listen to music regularly; this is similar to the 74% reported by Migirov *et al.* (2009). An average listening frequency of 5.7 on the 1–10 scale was recorded, slightly lower than the frequency of listening before deafness (6.2). A similar listening frequency following cochlear implantation (4.58) was recently reported by Looi and She (2010) for their study population, in contrast to an earlier report by Mirza *et al.* (2003), in which less than half of their subjects (46%) indicated listening to music using their implant. Enjoyment of music of our CI population was also rated higher than in the study populations reported (using similar scales) by both Mirza *et al.* (2003) and Looi and She (2010), i.e. 2.6 and 5.15, respectively.

The pre-deafness listening frequency and enjoyment ratings for our CI subjects were both lower than those in the NH group (Figs. 1 and 2), whereas if the groups were well matched they might be expected to be similar. However, the NH group was significantly younger than the CI group and a trend towards greater frequency of listening in younger subjects has been previously shown (Migirov *et al.*, 2009). The ratings from the CI subjects may also have been under-estimates due to the fact that these were retrospective ratings (more than 10 years in the majority of subjects). In reality, therefore, the real reduction in listening frequency and enjoyment following deafness and implantation is probably greater than is indicated by the scores obtained here.

Taking these factors into consideration the scores for both frequency of listening and enjoyment for the CI groups were still significantly lower than the scores for the NH subjects, highlighting the common finding that music appreciation is still an issue for CI users. Nonetheless, the scores obtained in this study are encouraging and are more positive than those reported in many earlier papers. The apparent increase in frequency of listening and perceived quality may be due to several factors. Firstly, broadening of candidature requirements for implantation has resulted in subjects often having more residual acoustic hearing (and, hence, better neural survival) than was the case 10–20 years ago. Thus, speech understanding scores have improved as well as music appreciation (Wilson and Dorman, 2008). Secondly, there has been an increased awareness in recent years that music appreciation may be improved through specific training approaches (Looi and She, 2010; Phillips *et al.*, 2011). The subjects in this study were from several implant centres and so guidance and training directed towards musical listening were not consistent. In our study population only 28 out of 136 subjects (20.6%) indicated that they did not listen to music at all after implantation. Of these 28, the majority (23) did listen to music before deafness, suggesting that they would have continued to do so if quality with the CI was adequate. However, it is possible that appropriate counselling and rehabilitation might have decreased the proportion of subjects who do not listen to music at all.

The third factor that the study was designed to investigate was if the signal processing strategy used had any effect on music appreciation. The overall results showed no significant difference between the three CI groups, a similar finding to that of Gfeller *et al.* (2005). The mean listening 'overall musical performance' scores for the newest strategy (HiRes 120) showed a trend for higher scores than for the older strategies, though these differences did not reach statistical significance. Nonetheless, this study indicates that signal coding technology is still an area which may yield improvements in music appreciation and requires continued investigation, with new developments which could lead to further improvements in the future.

There were significant correlations between the frequency of listening and enjoyment within the CI ($r = 0.78$, $P < 0.001$, product-moment correlation) and NH groups ($r = 0.74$, $P < 0.001$). Users who enjoy music appear to listen more frequently to it, as might be expected. In the NH group frequency of listening also correlated with overall performance, but this was not shown for the CI group.

Out of 108 CI users (from all strategy groups), 35 indicated that they continued to sing. This sub-group scored significantly higher on overall musical performance and on 'identifying lyrics in new music' indicating that musical experience may indeed have an effect on performance; however, only seven CI users indicated that they played a musical instrument and their scores were not significantly different from those who did not play an instrument.

Among the 108 CI listeners who listened to music in this study there were 24 who also used a contralateral hearing aid. Hearing aid use was not found to correlate significantly with the overall musical performance, several studies, however, have shown better musical perception when acoustic stimulation is available as well as the electrical signal. Looi and She (2010), for example, reported that the use of combined bimodal hearing (CI and contralateral hearing aid) had a significant positive effect on the perceived quality and musical performance, and Gfeller *et al.* (2006) reported better song and melody identification in users of electroacoustic devices than in those using conventional implants. In this study population the sub-group of bimodal users showed a trend for higher ratings, but this was not statistically significant, so it might be that this particular group was not sufficiently represented and therefore there was insufficient statistical power to assess this particular aspect.

Conclusions

- Eighty percent of CI users investigated in this study were listening to music on a regular basis. Both the frequency of listening and level of enjoyment reflect highly positive trends for CI users with current technology. Nevertheless, these scores were still significantly lower than the ratings of the NH group. There was also a larger variability in the musical experience and behaviour within the CI group than within the NH group.
- There was no significant improvement in overall scores for the HiRes 120 users compared to the other implanted groups. However, there was an overall trend towards higher scores for this group compared to the two other groups of CI users.
- Although the effects of formal musical training were not investigated in this study, frequency of listening and enjoyment were significantly correlated and active participation in musical activities, specifically singing, resulted in significantly higher overall performance scores.

References

Battmer R., Buechner A., Frohne C., Popp P., Lenarz T. 2003. The Clarion CII high resolution mode: experience after 6 months. *Cochlear Implants International*, 4: 23–24.

Buechner A., Frohne C., Gaertner L., Lesinski-Schiedat A., Battmer R., Lenarz T. 2006. Evaluation of Advanced Bionics high resolution mode. *International Journal of Audiology*, 45: 407–416

Chang Y.T., Yang H.M., Lin Y.H., Liu S.H., Wu J.L. 2009. Tone discrimination and speech perception benefit in Mandarin-speaking children fit with HiRes fidelity 120 sound processing. *Otology and Neurotology*, 30(6): 750–757.

Firszt J.B., Holden L.K., Reeder R.M., Skinner M.W. 2009. Speech recognition in cochlear implant recipients: comparison of standard HiRes and HiRes 120 sound processing. *Otology and Neurotology*, 30: 146–152.

Gfeller K., Christ A., Knutson J.F., Witt S., Murray K.T., Tyler R.S. 2000. Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. *Journal of the American Academy of Audiology*, 11(7): 390–406.

Gfeller K., Olszewski C., Rychener M., Sena K., Knutson J.F., Witt S., *et al.* 2005. Recognition of 'real-world' musical excerpts by cochlear implant recipients and normal-hearing adults. *Ear and Hearing*, 26(3): 237–250.

Gfeller K., Olszewski C., Turner C., Gantz B., Oleson J. 2006. Music perception with cochlear implants and residual hearing. *Audiology and Neurootology*, 11Suppl 1): 12–15.

Gfeller K., Jiang D., Oleson J.J., Driscoll V., Knutson J.F. 2010. Temporal stability of music perception and appraisal scores of adult cochlear implant recipients. *Journal of the American Academy of Audiology*, 21(1): 28–34.

Gifford R.H., Dorman M.F., Brown C.A. 2010. Psychophysical properties of low-frequency hearing: implications for perceiving speech and music via electric and acoustic stimulation. *Advances in Otorhinolaryngology*, 67: 51–60.

Kang R., Nimmons G.L., Drennan W., Longnion J., Ruffin C., Nie K., *et al.* 2009. Development and validation of the University of Washington Clinical Assessment of Music Perception test. *Ear and Hearing*, 30(4): 411–418.

Kasturi K., Loizou P.C. 2007. Effect of filter spacing on melody recognition: acoustic and electric hearing. *Journal of the Acoustical Society of America*, 122(2): EL29–34.

Kim I., Yang E., Donnelly P.J., Limb C.J. 2010. Preservation of rhythmic clocking in cochlear implant users: a study of isochronous versus anisochronous beat detection. *Trends in Amplification*, 14(3): 164–169.

Krueger B., Joseph G., Rost U., Strauss-Schier A., Lenarz T., Buechner A. 2008. Performance groups in adult cochlear implant users: speech perception results from 1984 until today. *Otologyand Neurotology*, 29: 509–512.

Limb C.J., Rubinstein J.T. 2012. Current research on music perception in cochlear implant users. *Otolaryngol Clin North Am.*, 45(1): 129–140.

Looi V., She J. 2010. Music perception of cochlear implant users: a questionnaire, and its implications for a music training program. *International Journal of Audiology*, 49: 116–128.

McDermott H. 2004. Music perception with cochlear implants: a review. *Trends in Amplification*, 8(2): 49–82.

Migirov L., Kronenberg J., Henkin Y. 2009. Self-reported listening habits and enjoyment of music among adult cochlear implant recipients. *Annals of Otology, Rhinology, and Laryngology*, 118(5): 350–355.

Mirza S., Douglas S., Lindsey P., Hildreth T., Hawthorne G. 2003. Appreciation of music in adult patients with cochlear implants: a patient questionnaire. *Cochlear Implants International*, 4: 85–95.

NIH Consensus Conference. 1995. Cochlear implants in adults and children. *JAMA*, 274(24): 1955–1961.

Sucher C.M., McDermott H.J. 2009. Bimodal stimulation: benefits for music perception and sound quality. *Cochlear Implants International*, 10(Suppl 1): 96–99.

Wang S., Liu B., Dong R., Zhou Y., Li J., Qi B., *et al.* 2012. Music and lexical tone perception in Chinese adult cochlear implant users. *Laryngoscope*, 122(6): 1353–1360.

Wilson B.S., Dorman M.F. 2008. Cochlear implants: a remarkable past and a brilliant future. *Hear Res.*, 242(1–2): 3–21.