other unhealthy lifestyle issues such as obesity, alcohol, stress, smoking, etc., and consequently campaigns directed at lowering exposure to loud music should take this factor of pleasure/addiction into account when designed.

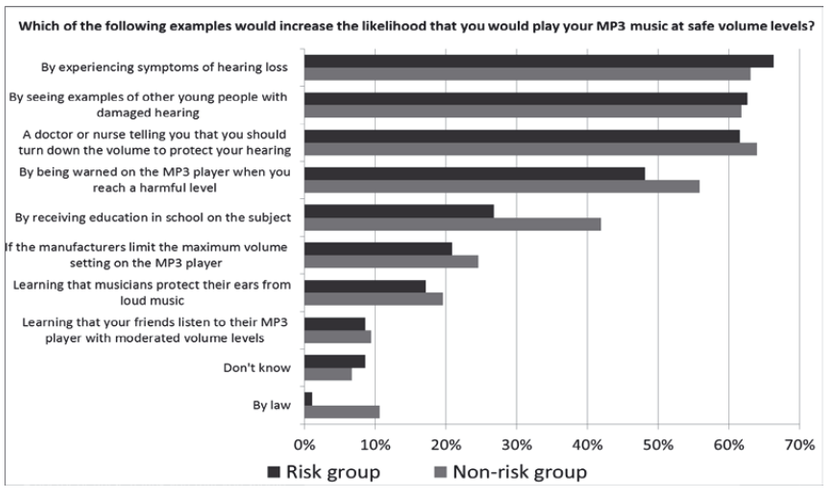

Fig. 6: The most effective ways of prophylaxis.

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Aspects of music with cochlear implants – Music listening habits and appreciation in Danish cochlear-implant users

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Cochlear-implant users differ significantly from their normal-hearing peers when it comes to perception of music. Several studies have shown that structural features – such as rhythm, timbre, and pitch – are transmitted less accurately through an implant. However, we cannot predict personal enjoyment of music solely as a function of accuracy of perception. But can music be pleasant with a cochlear implant at all? Our aim here was to gather information of both music enjoyment and listening habits before the onset of hearing loss and post-operation from a large, representative sample of Danish recipients. A hundred and sixty three adult cochlear-implant users (101 females, 62 males) completed a survey containing questions about musical background, listening habits, and music enjoyment. The results indicate a wide range of success with music, but in general, the results show that the CI users enjoy music less post-implantation than prior to their hearing loss. Nevertheless, a large majority of CI listeners either prefer music over not hearing music at all or find music as pleasant as they recall it before their hearing loss, or more so.

BACKGROUND

A cochlear implant (CI) is a neural prosthesis that restores hearing sensation in deaf individuals. The clinical impact of the evolution of CIs has been nothing less than extraordinary, and over 250,000 individuals worldwide use the device (Peters *et al*. 2010). While the majority of adult CI users achieve good speech perception in quiet, auditory processing in general and music perception in particular are hampered. This is supported by several studies showing that discrimination of pitch, melody, timbre, and emotional prosody is significantly poorer in CI-users than in normally-hearing controls (Gfeller *et al*., 2007; Cooper *et al*., 2008; Petersen *et al*., 2012).

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Nevertheless, some users seem to overcome the technical limitations of the implant and enjoy music immensely (Gfeller *et al*., 2000). Because music is an important part of our everyday life with great emotional and social aspects, it is reasonable to evaluate the extent of music listening in CI users and identify possible factors that impacts music appreciation. With this study, we aimed to gather information about music listening habits and music appreciation before the onset of hearing loss and after receiving an implant from a large, representative sample of Danish CI users. Furthermore, we aimed to correlate this information with self-reported measures of quality of life (QOL).

PARTICIPANTS

All adult CI recipients (≥ 18) implanted at the ENT department, Aarhus University Hospital, between January 1st 2000 and December 31st 2010, were invited to take part in the study. Of the 250 patients, 163 responded (101 female; M_{age} = 56.4 y; *SD* = 15.7; age range: 18 to 86 y; 65% response rate). A hundred and seventeen respondents filled out the questionnaire online, while 46 requested the printed version. The implant experience ranged from 0.4 years to 11.2 years (*M* = 4.3 y, *SD* = 2.65). One hundred and thirty seven (84%) participants used an implant from Cochlear® and 26 (16%) participants used an implant from Advanced Bionics®. The demographic data of the respondents are listed in Table 1.

Respondents (M/F)	**Mean age (years)**	**Duration of profound deafness**	**Mean CI experience**
163 (62/101)	56.44 (±15.7; 18-86)	34.5 (± 18.2; 75.3-1.1)	4.3 (± 2.6; 0.4-11.2)
Unilateral users (R/L)	**Bilateral users**	**Users of hearing aid on non-implanted ear**	**Able to speak on the phone**
147 (108/39)	16	73	106

Table 1: Demographic data for the 163 respondents in the study.

METHOD

The questionnaire used in the study was a modified, Danish version of the IOWA Musical Background Questionnaire (Gfeller *et al.*, 2000). The 21 questions in the survey included multiple-choice, Likert rating scales, visual analog scales, and open-ended questions concerning musical background, listening habits, the quality of musical sound heard through the implant, and music enjoyment prior to hearing loss and after cochlear implantation. In addition, respondents were required to fill out two questionnaires concerning their quality of life (QOL) post-implantation: the

Short Form 36 (SF 36, Ware and Sherbourne, 1992) and the Glasgow Benefit Inventory (GBI, Robinson *et al.*, 1996). Here, the QOL data were used for correlational analyses.

RESULTS

Musical background

23.9% of the participants had received singing and/or instrument lessons (in primary school: *M* = 3.6 y; in high school: *M* = 1.5 y). 12.9% had been a member of a band, choir, or an orchestra. Table 2 sums up the respondents' self-assessed knowledge and experience with music. In total, 77% were involved in music to a lesser or larger extent. This is in agreement with Gfeller *et al.* (2000) and considered representative of the general population.

Category	**Percentage**
No formal training and only limited knowledge about music	23 %
No formal training or knowledge about music, but informal listening experience	56 %
Autodidact musician	3 %
Some musical training and have basic knowledge of musical terms	12 %
Several years of musical training, knowledge about music, and involvement in music groups	4 %

Table 2: Self-assessment of musical experience.

Music listening habits

The participants indicated on a four-point Likert-scale to what degree they would consider themselves as a person who often chose to listen to music (i) before the hearing loss and (ii) after receiving their implant (from 1 point = strongly disagree to 4 point = strongly agree). Furthermore, they indicated how often they chose to listen to music before their hearing loss and after getting accustomed to their implant, respectively (from 1 point = 0-2 hours per week to 4 points = 9 hours or more per week). Summed and averaged, the scores were used as mean composite scores for pre- and post-music listening habits. The mean composite score for music listening habits prior to hearing loss was 4.96 (*SD* = 1.86). The mean composite score for listening habits post-implantation was lower, at 4.23 (*SD* = 1.76). A paired *t*-test showed that the difference was significant ($t = 3.6$, $p = 0.000$).

Quality of musical sound

Figure 1 shows the mean values for the seven adjective descriptors of music through the implant. The average quality rating across all descriptors was 56.1, indicating a positive trend.

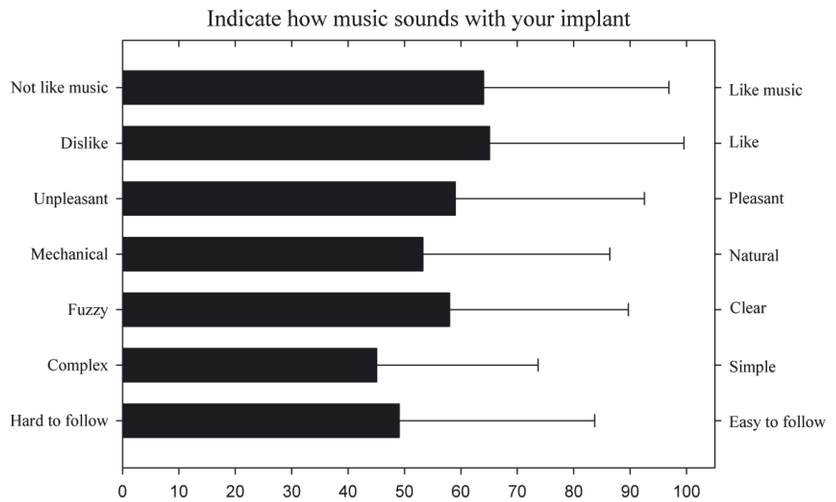

Fig. 1: Mean scores for adjective descriptors of music through the implant.

Music enjoyment

Figure 2 shows the respondents' evaluation of how their music enjoyment has changed after receiving their implant. The two rightmost categories (37%; 44%) indicate a range of music enjoyment. The left category (19%) indicates no music enjoyment.

Correlations

The ability to talk on the phone showed a weak positive correlation with both music listening habits (r = 0.233, p = 0.003), quality of musical sound (r = 0.361, p = 0.000), and enjoyment (r = 0.138, p = 0.013). Furthermore, age was negatively correlated with music listening habits (r = −0.264, p = 0.000), quality of musical sound (r = −0.245, p = 0.001), and enjoyment (r = −0.389, p = 0.000). No other demographic factors showed any significant correlation with any measures of music listening. The composite scores of the GBI questionnaire showed a significant correlation with music listening habits (r = 0.329, p = 0.000), quality of musical

sound (r = 0.408, p = 0.000), and enjoyment (r = 0.326, p = 0.000). Furthermore, the social functioning subscale of the SF 36 questionnaire data showed correlations of similar strength with the three music listening measurements.

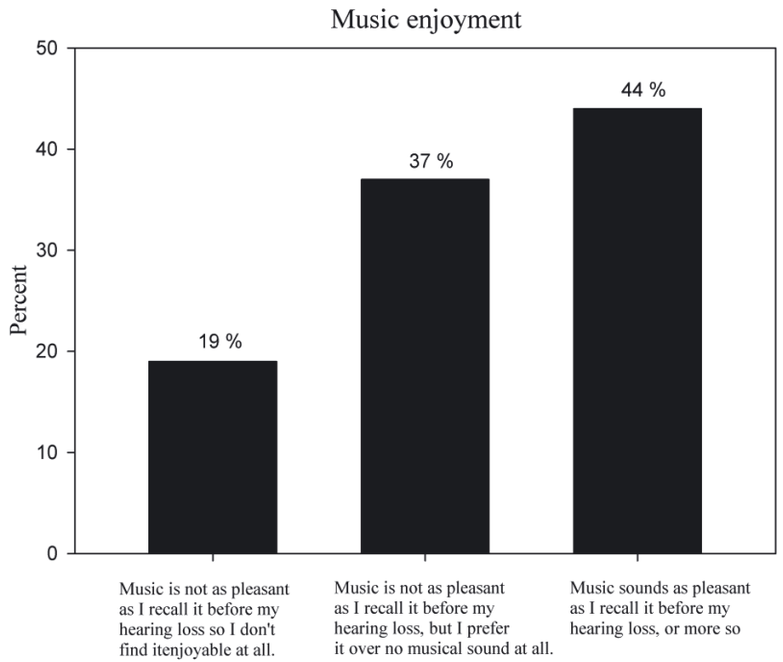

Fig. 2: Music enjoyment after implantation.

DISCUSSION

In line with findings by Gfeller *et al*. (2000), this study shows that in general adult CI users enjoy music less post-implantation than prior to hearing loss. In addition, the findings show a wide range of success with music. Interestingly, a large majority of CI listeners seem to listen to and enjoy music ranging from modest satisfaction to great enthusiasm, despite the technical disadvantages of the CI's music presentation. Furthermore, on average, the respondents describe their appreciation of different aspects of music slightly more positively than those in the Gfeller *et al.* (2000) study. This difference may suggest a benefit from the technical improvements achieved in the last decade. Interestingly, our findings indicate that solely the ability to talk on the phone is associated with success in all aspects of music listening. Previous studies found that both use of contralateral hearing aid and duration of

deafness were predictive for music perception with a CI (Looi *et al.*, 2008). However, no such correlations were found in the present study. In accordance with Lassaletta *et al*. (2007) our findings suggest an association between QOL and success in music listening. Although the causes for this association may be manifold, this suggests that music exposure or training could be beneficial not only for CI users' perception of music, but also for their QOL.

ACKNOWLEDGMENTS

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Addendum to the proceedings of ISAAR 2011:

Speech Perception and Auditory Disorders

Jont B. Allen and Woojae Han

"Sources of decoding errors of the perceptual cues, in normal and hearing impaired ears"

pp. 495-510

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Sources of decoding errors of the perceptual cues, in normal and hearing impaired ears[a]

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After many decades of work it is not understood how the average normal-hearing (NH) ears, or significantly hearing-impaired (HI) ears, decode consonants. We wish to discover the strategy HI persons use to recognize consonants in a consonant-vowel (CV) context. To understand how NH ears decode consonants, we have repeated the classic consonant perception experiments of Fletcher, French and Steinberg, G.A. Miller, Furui, and others. This has given us access to the raw data (e.g., to allow for ANOVA testing) and the ability to verify many widely held (typically *wrong*) assumptions. The first lesson of this research is the *sin* of averaging: While audiology is built on average measures, most of the interesting information is lost in these averages. It has been shown, for example, that averaging across consonants is a grievous error, as is averaging across talkers for a given consonant. It will be shown how an average entropy measure (a measure of dispersion in probability) has higher utility than the average error.

INTRODUCTION

A fundamental problem in auditory science is the perceptual basis of speech, that is, phoneme decoding. How the ear decodes basic speech sounds is important for both hearing-aid and cochlear-implant signal processing, both in quiet and in noise. The object of our studies are three-fold (We are at the out-set of objective 3, objectives 1 and 2 being mostly complete):

1. We have isolated the acoustic cues in $>$100 consonant-vowel (CV) utterances.
2. We have measured the full-rank confusions in $\approx$50 hearing-impaired (HI) ears.
3. We are attempting to relate the measured HI confusions to the NH cues.

Objective 1): An *acoustic cue* is defined as the time-frequency features of the acoustic signal which are decoded by the auditory system for representing the consonant-vowel (CV) combination (Cole and Scott, 1974). The acoustic cues used by the average normal-hearing (ANH) ear are made up of at least four different cues (Li and Allen, 2009): a) onset bursts, b) low-frequency "edges," c) durations, and d) F0 modulation.

[a] Page numbers starting with A refer to the ISAAR 2011 proceedings numbering.

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