International Journal of Pediatric Otorhinolaryngology 76 (2012) 1392–1400

Contents lists available at SciVerse ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Review article

The music perception abilities of prelingually deaf children with cochlear implants

Katja Kladnik Stabej [a,*], Lojze Smid [a,1], Anton Gros [a,2], Miha Zargi [a,3], Andrej Kosir [b,4], Jagoda Vatovec [a,5]

[a] University Department of Otorhinolaryngology and Cervicofacial Surgery, The University Medical Centre Ljubljana, Zaloska 2, SI-1000 Ljubljana, Slovenia
[b] University of Ljubljana, Faculty of Electrical Engineering, Trzaska 25, SI-1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 6 March 2012
Received in revised form 27 June 2012
Accepted 1 July 2012
Available online 24 July 2012

Keywords:
Cochlear implant
Music perception

ABSTRACT

Objective: To investigate the music perception abilities of prelingually deaf children with cochlear implants, in comparison to a group of normal-hearing children, and to consider the factors that contribute to music perception.

Methods: The music perception abilities of 39 prelingually deaf children with unilateral cochlear implants were compared to the abilities of 39 normal hearing children. To assess the music listening abilities, the MuSIC perception test was adopted. The influence of the child's age, age at implantation, device experience and type of sound-processing strategy on the music perception were evaluated. The effects of auditory performance, nonverbal intellectual abilities, as well as the child's additional musical education on music perception were also considered.

Results: Children with cochlear implants and normal hearing children performed significantly differently with respect to rhythm discrimination (55% vs. 82%, $p < 0.001$), instrument identification (57% vs. 88%, $p < 0.001$) and emotion rating ($p = 0.022$). However we found no significant difference in terms of melody discrimination and dissonance rating between the two groups. There was a positive correlation between auditory performance and melody discrimination ($r = 0.27$; $p = 0.031$), between auditory performance and instrument identification ($r = 0.20$; $p = 0.059$) and between the child's grade (mark) in school music classes and melody discrimination ($r = 0.34$; $p = 0.030$). In children with cochlear implant only, the music perception ability assessed by the emotion rating test was negatively correlated to the child's age ($r_S = -0.38$; $p = 0.001$), age at implantation ($r_S = -0.34$; $p = 0.032$), and device experience ($r_S = -0.38$; $p = 0.019$). The child's grade in school music classes showed a positive correlation to music perception abilities assessed by rhythm discrimination test ($r_S = 0.46$; $p < 0.001$), melody discrimination test ($r_S = 0.28$; $p = 0.018$), and instrument identification test ($r_S = 0.23$; $p = 0.05$).

Conclusions: As expected, there was a marked difference in the music perception abilities of prelingually deaf children with cochlear implants in comparison to the group of normal hearing children, but not for all the tests of music perception. Additional multi-centre studies, including a larger number of participants and a broader spectrum of music subtests, considering as many as possible of the factors that may contribute to music perception, seem reasonable.

Contents

* Corresponding author. Tel.: +386 31853733; fax: +386 15224898.
E-mail addresses: katja.kladnik@kclj.si (K.K. Stabej), 1lojze.smid@mf.uni-lj.si (L. Smid), andrej.kosir@ldos.fe.uni-lj.si (A. Kosir).
[1] Tel.: +386 64110621; fax: +386 15224815.
[2] Tel.: +386 15222958; fax: +386 15224815.
[3] Tel.: +386 15224814; fax: +386 15224815.
[4] Tel.: +386 14768354.
[5] Tel.: +386 15223761; fax: +386 15224898.

0165-5876/$ – see front matter © 2012 Published by Elsevier Ireland Ltd.
http://dx.doi.org/10.1016/j.ijporl.2012.07.004

1. Introduction

The rapid developments in cochlear implant (CI) technology over recent decades mean that basic language perception is now routinely achieved in properly selected candidates. The audiologic criteria for cochlear implantation has been continuously relaxed from bilateral total deafness in the early 1980s, to severe hearing loss in the 1990s, and then to the current suprathreshold speech-based criteria [1]. Improvements in CI technology and concurrent improvements in speech perception outcomes have led to an expansion in the implantation criteria to include individuals with low-frequency residual hearing in one or both ears. The use of a hearing aid in the non-implanted ear of a CI user, known as bimodal stimulation, enables additional pitch cues provided via this low-frequency hearing [2]. The broadening CI selection criteria have resulted not only in more patients having implants, but also to higher expectations of CI performance [3].

The progress in CI technology is also of utmost importance in children using cochlear implants. Age at implantation has been found to be a significant factor where the development of speech perception and intelligibility in the young profoundly deaf is concerned. Therefore, the mean age at implantation is decreasing worldwide and in many places it is now at less than two years of age. With the advent of Newborn Hearing Screening and increased surgical experience, cochlear implantation is now feasible for profoundly deaf children below 12 months of age [4].

The efficacy of multi-channel CIs for children with profound hearing loss has been well established in terms of speech-perception benefit, language-acquisition rates and speech-production improvements. We are now able to define some variables leading to optimum speech perception and language outcomes for children using a CI, such as younger age at implantation, use of the most current speech-processor technology, a communication mode emphasising an aural/oral approach, the absence of developmental delay, a shorter duration of profound hearing loss and preimplant residual hearing [5].

Prelingually deaf children with CIs acquire good speech perception, competence in spoken language and improve their voice quality [6–8]. However, they still have problems with perceiving talker identity [9], speech in noise [10], pitch [2] and melody [11–16]. The environmental sound perception of CI children appears to be good; however, it is not perfect [17].

There are many studies concerning music perception in adult CI users, but the music perception of children with CIs is still an under-researched area. Children with CIs differ from adults in a number of important respects. Congenital deafness limits the amount of prior musical experiences and expectations, e.g., children with CIs tend not to mourn the loss of music [19]. On the other hand, greater cortical plasticity may enable them to achieve levels of musical enjoyment or skills that are impossible for adult implant users [15,18,19].

The first goal of our study was to compare the music perception abilities of prelingually deaf children with CIs with the abilities of normal hearing (NH) children. The second goal was to evaluate the role of some factors (age, age at implantation, device experience, type of sound-processing strategy, auditory performance and nonverbal intellectual abilities) that may contribute to the child's music perception. The influence of the child's additional musical education on music perception was also considered.

2. Methods

2.1. Participants

The music perception abilities of 39 prelingually deaf children with CI (90% of all the school-aged children with CIs in Slovenia) were compared with the music perception abilities of 39 NH children. All 78 children were native Slovene speakers.

Children with CIs received their implants at the University Department of Otorhinolaryngology and Cervicofacial surgery in Ljubljana, Slovenia. They were all recruited during a routine follow up visit at the hearing out-patients' clinic. NH children were recruited from one of Ljubljana's primary schools. The parents of the participants were asked to sign a statement of consent, and to complete a questionnaire about the child's grade for school music classes and the child's additional musical education.

The basic demographic characteristics and information on implants for children with CIs are presented in Table 1. There were 20 (51%) females and 19 (49%) males, with a median (interquartile range (IQR)) age at examination of 135 (67) months (minimum–maximum, 76–187 months), and a median age at implantation of 30 (24) months (minimum–maximum, 13–98 months). The median (IQR) device experience time was 102 (47) months (minimum–maximum, 61–139 months). The majority of deaf children had a CI with ACE sound processing strategy (28/39, 72%), others had a CI with the FSP (8/39, 21%) or HDCIS (3/39, 8%) sound processing strategy. Of the 39 children with CIs, 37 were in the mainstream school system and two attended a school for deaf children. Children with CIs were enrolled regardless of their basic auditory/language skills. None of the children with CIs used

Table 1
Basic demographic and clinical characteristics of children with CIs.

Subject no.	Sex	Age at implantation (months)	Device experience (months)	Type of CI	CI sound processor	CI sound processing strategy
1	M	28	138	Nucleus 24	Freedom	ACE
2	F	46	128	Nucleus 24	Freedom	ACE
3	F	28	98	Nucleus 24	Freedom	ACE
4	F	41	127	Pulsar 100	Opus 2	HDCIS
5	M	19	76	Combi 40+	Opus 2	HDCIS
6	F	73	86	Nucleus 24	Freedom	ACE
7	F	32	107	Pulsar 100	Opus 2	FSP
8	M	27	71	Nucleus 24	Freedom	ACE
9	M	21	102	Nucleus 24	ESPrit 3G	ACE
10	M	26	139	Nucleus 24	Freedom	ACE
11	M	47	125	Nucleus 24	Freedom	ACE
12	F	13	83	Nucleus 24	Freedom	ACE
13	F	50	109	Nucleus 24	Freedom	ACE
14	M	76	83	Combi 40+	Opus 2	FSP
15	M	18	78	Nucleus 24	Freedom	ACE
16	F	43	67	Nucleus 24	Freedom	ACE
17	F	52	83	Nucleus 24	Freedom	ACE
18	F	34	131	Combi 40+	Opus 2	HDCIS
19	F	20	72	Nucleus 24	Freedom	ACE
20	M	19	77	Nucleus 24	Freedom	ACE
21	M	39	120	Combi 40+	Opus 2	FSP
22	F	20	76	Combi 40+	Opus 2	FSP
23	F	26	78	Nucleus 24	Freedom	ACE
24	M	29	103	Nucleus 24	Freedom	ACE
25	F	53	126	Combi 40+	Opus 2	FSP
26	F	31	83	Nucleus 24	Freedom	ACE
27	F	54	127	Combi 40+	Opus 2	FSP
28	F	29	112	Nucleus 24	Freedom	ACE
29	M	62	112	Nucleus 24	ESPrit 3G	ACE
30	F	17	77	Nucleus 24	Freedom	ACE
31	F	30	90	Nucleus 24	Freedom	ACE
32	M	24	64	Nucleus 24	Freedom	ACE
33	M	98	89	Combi 40+	Opus 2	FSP
34	F	36	126	Combi 40+	Opus 2	FSP
35	M	30	109	Nucleus 24	Freedom	ACE
36	M	33	102	Nucleus 24	Freedom	ACE
37	M	48	126	Nucleus 24	Freedom	ACE
38	M	15	61	Nucleus 24	Freedom	ACE
39	M	23	105	Nucleus 24	Freedom	ACE

CI, cochlear implant; F, female; M, male.

hearing aids in their unimplanted ear. They communicated exclusively orally.

The control group consisted of 39 NH children, who had hearing-threshold levels within normal limits. Of the 39 NH children, 21 (54%) were girls and 18 (46%) boys, which was comparable to the CI group (Pearson's chi-squared test, $p = 1$). In the NH group, the median age at examination was slightly lower than in the CI group (median (IQR) age at examination of 121 (40) months; minimum–maximum, 97–164 months), but the difference was not statistically significant (Mann–Whitney test, $p = 0.169$). In the NH children, their hearing age was of course identical to their age at examination, and in the median value it was significantly higher than the hearing age in the CI children (Mann–Whitney test, $p < 0.001$). As individual matching by age between the subjects and the controls was not feasible, the adjustment was undertaken in the statistical analysis for the variables age at examination and hearing age.

The study was approved by the National Medical Ethics Committee.

2.2. Auditory performance

The auditory performance of the CI children and NH children was assessed according to the Categories of Auditory Performance (CAP) scale [22]. This scale is used to rate the outcomes from paediatric cochlear implantation in everyday life. It is an 8-point scale, where the lowest level (0) describes no awareness of environmental sounds, and the highest level (7) is represented by the ability to use a telephone with a known speaker [21,22].

2.3. Non-verbal intellectual abilities

The Leiter R test or WISC-III test (for 3 children older than 6 years at the time of implantation) were conducted to evaluate the CI child's non-verbal intellectual abilities, before implantation at a median (IQR) age of 2.5 (2) years (minimum–maximum, 1.1–8.2 years). At the age of three years the Praper psychological test was also undertaken for both groups of children. This nonverbal screening test is used in Slovenia as a tool to determine the presence of the child's learning disability or a developmental delay, for all children at the age of three years [23]. It was not possible to apply the Leiter R or WISC-III tests retrospectively for children from the control group. Therefore with similar criteria for all three tests (additionally Praper personal communication), the psychologist defined the non-verbal intellectual abilities of CI and NH children as below average, normal and above average.

2.4. Education

The parents completed questionnaires about the child's grade (mark) in school music classes and her or his additional musical education (extra classes at a separate school for music). The grade for music classes in the mainstream school system or the school for deaf children was set from 1 to 5. We described the child's additional musical education as 1 if the child had no additional musical education and as 2 if the child had been or was attending a music school alongside regular music classes for at least one year.

2.5. Music perception abilities

The MuSIC (Musical Sounds in Cochlear Implants) test was developed to assess the music listening abilities of CI users [24]. This computerised test battery includes modules that assess several areas of music perception. The original CD version of the test was used. The stimuli were presented through a computer loudspeaker (HP Compaq NX 7000) at a sound level of 70 dB measured in the listener's ear with a sound level metre (Bruel & Kjaer 2250). All participants were tested individually. The testing took place in a double-walled sound-attenuating room. At the beginning of each subtest, comprehensive child adjusted explanations and instructions about the task were given to each participant, with an audiologist available throughout the test to provide further explanations, if requested. Before starting, a demonstration of each subtest, apart from instrument identification was provided. One repetition per item was allowed for all the subtests.

2.5.1. Rhythm discrimination

During this test we assessed the child's ability to distinguish temporal rhythms. Three pairs of rhythms were recorded and for each pair the child had to decide whether the rhythms were the same or not. All rhythmic patterns contained a four-beat measure. They differed only in one note value per beat; first pair: (a) quarter note (crotchet), triplet eighth notes (quavers), half rest, (b) quarter note, triplet eighth notes, half note, second pair: (a) four eighth notes, half note, (b) two eighth notes, quarter note, half note and third pair: (a) quarter note, four sixtheenth notes (semi-quavers), two eighth notes, four sixteenth notes, (b) two eighth notes, four sixtheenth notes, two eighth notes, four sixteenth notes. The same rhythmic patterns were presented to the CI and the NH children. The sound files for this test consisted of one pair of rhythms recorded on a snare drum, one pair on bongos and one pair on timpani. The rhythm patterns were 4 s long. A 1.5 s interstimulus interval separated each member of the pair. The computer decided at random, which of the files in the pair was played first and whether the same file was played twice (rhythms the same) or the second file was to be played (rhythms differ). We added up the number of correct answers for three rhythm pairs (0, 1, 2, 3) for each individual child. On the basis of the obtained results the numbers were changed in the percentage of correct answers.

2.5.2. Melody discrimination

This test determines the ability to detect melodic differences between two short phrases, with the same rhythmic pattern. To explain the purpose and the concept of the test, before the beginning of testing the child had to listen to two identical melodies that differed only in volume level, then two identical melodies that differed in timbre and finally two melodies that differed in pitch. It was explained to the child that we were interested in the third task – a decision made on the factor of pitch. During the test, three pairs of melodies were recorded and for each pair the child had to decide whether the melodies were the same or not. The melodies were presented at the same volume level and with the same sound quality. One pair of melodies was recorded on a piano in stereo, one on a violin and one on a flute in mono. The pairs that were different differed considerably in pitch (up to nine tones) and their melodic conture. The melodies were 5 s long. A 1.5 s interstimulus interval separated each member of the pair. The computer decided at random that which of the files in the pair was played first, and whether the same file was played twice (melody the same) or the second file was played (melodies differ). The same melodic patterns were presented to the CI and NH children. We added up the number of correct answers for three melody pairs (0, 1, 2, 3) for each individual child. On the basis of the obtained results the numbers were changed in the percentage of correct answers.

2.5.3. Instrument/voice identification

This test determines the ability of the child to identify the instrument, which he or she is hearing. Before this test, during music classes at school, the child had to listen and to recognise many times all the instruments that were also presented in the test (flute, guitar, piano, violin). For each individual child, the teacher confirmed that the child was familiar with the instruments chosen in the test. To avoid the need for the child to know the names of the instruments that were in the test, the responses were given by clicking on a picture of the instrument on a screen. In this closed-set test, five pictures were presented on the screen and after hearing the music the child had to decide between flute, guitar, piano, violin and a male-voice singing tenor. The computer decided at random which of the files in the pair was used. One recording of music was presented for each instrument. The same pieces of music were presented to both groups of children. For all the instruments there were sound files on an ascending and a descending scale followed by a song. For each instrument the typical piece of music lasted 22 s. These pieces were from the Western classical music repertoire and chosen by the artist playing the respective instrument. We added up the number of correct answers for all four instruments (0, 1, 2, 3, 4) for an individual child. On the basis of the obtained results the numbers were changed in the percentage of correct answers.

2.5.4. Emotion rating

In this subjective test we assessed the emotional impressions and responses of the individual child to a piece of music. After hearing a short piece of music the child positioned her or his impression on a happy-to-sad scale (a visual scale with discrete numbers between the picture of a sad face at the beginning and a happy face at the end of the scale), where 1 was the saddest piece of music she/he could imagine and 10 was the happiest. The same piece of music, rated as 10 by normal adult hearers, was presented to the children from both groups. The piece of music presented was 15 s long.

2.5.5. Dissonance rating

In this subjective test, the children were asked to rate individual chords on a visual scale with discrete numbers from 1 to 10. At the beginning of the scale there was a picture with sharp denticles (dissonance) and at the end there was a picture with fine waves (consonance). Level 1 was the harshest possible sound they could imagine and level 10 was the most melodious, pleasant sound. The same chord was presented to children with CIs and NH children.

2.5.6. Statistical analysis

Numerical variables were presented as median values and IQR or the 1st and 3rd quartile, whilst categorical variables were expressed as proportions. As data were distributed asymmetrically, the nonparametric Mann–Whitney test was used for comparisons between the study groups. Categorical variables were compared between the CI and NH groups by Pearson's chi-square test or Fisher's exact test, as appropriate. In the CI group, the relationship between factors that could contribute to auditory performance (i.e., age, age at implantation, hearing age, device experience, and grade for school music classes) and auditory performance was tested by Spearman correlation. Moreover, differences in auditory performance between CI children with additional musical education and CI children without it were analysed using Mann–Whitney test, whilst differences in auditory performance between sound processing strategy categories (ACE, FSP, HDCIS) and also between categories according to nonverbal intellectual abilities were analysed by the Kruskal–Wallis test. In multiple paired comparisons, the Keppel modification of the Bonferroni correction of type I error was used. The Spearman correlation was also used in testing for the relationship between age at implantation or device experience and MuSIC tests in CI children. Again, the Kruskal–Wallis test was used to test for differences in MuSIC tests results between the sound-processing strategy categories.

As the regression residuals were normally distributed, the linear regression model was applied for evaluating the impact of each possible predictor (auditory performance, nonverbal intellectual abilities, additional musical education, grade for school music classes) on music perception abilities, if the outcome variable was numerical or ordinal (i.e., rhythm discrimination, melody discrimination, instrument identification, dissonance rating, emotion rating), whilst the logistic regression was applied if the outcome variable was binary (i.e., tenor-, guitar-, piano-, flute-, violin-identification). The predictor variable "nonverbal intellectual abilities" was first dichotomised and than included in the regression model. Results were presented as correlation coefficients adjusted for age, hearing age and study group. The level of significance was set at $\alpha = 0.05$. Statistical analysis was performed using the R language for statistical computing (R Development Core Team 2008).

3. Results

3.1. The children's characteristics

A comparison of the children's characteristics as possible predictors for their music perception abilities between the CI and NH group is presented in Table 2. The auditory performance, nonverbal intellectual abilities and the child's grade for school music classes were significantly lower in CI children in comparison to NH children ($p = 0.006$, $p = 0.005$, $p < 0.001$, respectively). In the CI group, significantly more children had below average nonverbal intellectual abilities (22%) than NH children (3%, $p = 0.028$), and significantly less CI children were of average nonverbal intellectual abilities than NH children (65% vs. 95%, $p = 0.003$), whilst there was no significant difference in children with nonverbal intellectual abilities above average between the groups ($p = 0.199$).

Table 2
Possible predictors for music perception abilities in CI and NH group.

Predictor	CI group	NH group	*p*-Value[a]
Auditory performance	8 [8,8] (6–8)	8 [8,8] (8–8)	0.006
Nonverbal intellectual abilities, *n* (%)			0.005
Above average	5/37 (13)	1/37 (3)	0.199
Average	24/37 (65)	35/37 (95)	0.003
Below average	8/37 (22)	1/37 (3)	0.028
MSG[b]	3 [3,4] (2–5)	5 [4,5] (3–5)	<0.001
Additional musical education, *n* (%)	4/37 (11)	9 (23)	0.156

Data are median [1st, 3rd quartile], (minimum–maximum), unless otherwise specified. CI, cochlear implant; MSG, school grade at the class of musical education in the mainstream school system; NH, normal-hearing.
[a] Mann–Whitney test if the variable was ordinal, and Pearson's chi-square test or Fisher's exact test if the variable was categorical.
[b] Missing data in five CI children and one NH child.

3.2. The music test battery

The testing time for the CI group was 60–98 min (mean 82 min), whilst for the NH participants it took 44–77 (mean 65 min) min to complete all the subtests. The median values of the MuSIC test battery results are presented in Table 3, whilst Fig. 1 presents the percentage of correct answers for those MuSIC tests results where percentages could be calculated. The comparisons of the individual MuSIC tests between study groups are explained below.

3.2.1. Rhythm discrimination

In the test for rhythm discrimination, the group of children with CIs was not as successful (median test value = 2, 55% correct answers on average) as their NH peers (median test value = 3, 82% correct answers on average). There was a statistical difference ($p < 0.001$) between the groups.

3.2.2. Melody discrimination

According to the mean percentage of correct answers, in the melody discrimination test, the NH children performed slightly better (78%) in comparison to the CI group (mean 70%), but the difference was not statistically significant ($p = 0.242$).

3.2.3. Instrument/voice identification

The NH children recognised the tested instruments better than the children with CI (57% vs. 88%, $p < 0.001$): piano (97% vs. 44%, $p = 0.008$), flute (92% vs. 44%, $p < 0.001$) and violin (97% vs. 46%, $p < 0.001$). The children from both groups were almost equally successful at recognising the guitar (63% vs. 64%) and the male-voice singing tenor (100% vs. 97%) ($p = 0.932$, $p = 0.324$, respectively).

3.2.4. Dissonance rating

The median rating of chord dissonance was the same for the children from both groups (median, 3; $p = 0.984$).

3.2.5. Emotion rating

The children with CIs determined the same selection of music as being more sad (median, 7) than their NH peers (median, 8), the difference being statistically significant ($p = 0.022$).

Table 3
Median values of the MuSIC test battery results for CI and NH group.

Subtest	CI group		NH group		*p*-Value[a]
	Median	[1st, 3rd quartile], (min–max)	Median	1st, 3rd quartile, (min–max)	
Rhythm discrimination	2	[1,2], (0–3)	3	[2,3], (1–3)	<0.001
Melody discrimination	2	[2,3], (0–3)	2	[2,3], (0–3)	0.242
Instrument identification[b]	2	[2,4], (0–4)	4[c]	[3,4], (2–4)	<0.001
Dissonance rating	3	[1,5], (1–10)	3	[1,5], (1–10)	0.984
Emotion rating	7	[5,9], (3–10)	8	[7,9], (3–10)	0.022

CI, cochlear implant; MSG, school grade at the class of musical education in the mainstream school system; MuSIC, musical sounds in cochlear implants; NH, normal-hearing.
[a] Mann–Whitney tests.
[b] All four instruments are included (guitar, piano, flute, violin).
[c] Missing data in one child.

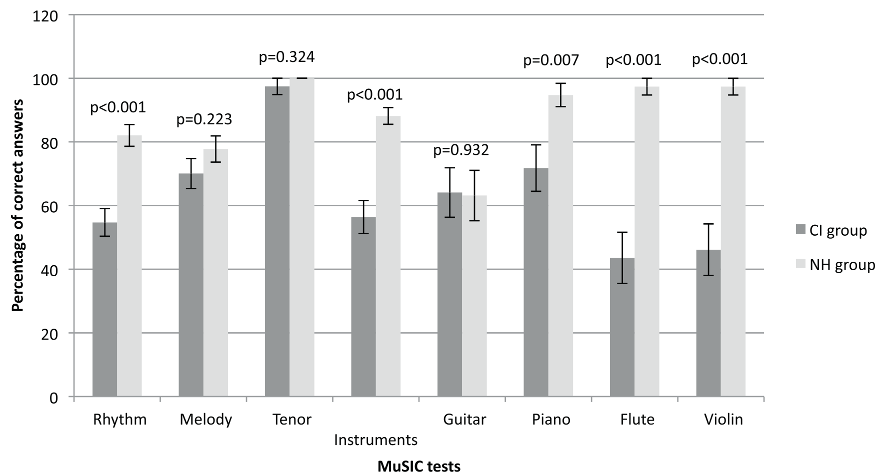

Fig. 1. The percentage of correct answers for some MuSIC tests. Error bars represent standard errors, *p*-values correspond to Mann–Whitney tests between CI and NH group for each MuSIC test separately. Category 'Instruments' include all four instruments (guitar, piano, flute, violin). CI, cochlear implant; MuSIC, musical sounds in cochlear implants; NH, normal-hearing.

3.3. Possible predictors of music perception

The results of testing the importance of each possible predictor of music perception in the linear regression model, adjusted for age, hearing age and study group, are presented in Table 4. They show that there was a positive correlation between auditory performance and melody discrimination ($r = 0.27$; $p = 0.031$), between auditory performance and instrument identification ($r = 0.20$; $p = 0.059$; the *p*-value was above but still near the significance level of 0.05), and between the child's grade (mark) in school music classes and melody discrimination ($r = 0.34$; $p = 0.030$).

The impact of possible predictors on the results of separate instrument/vocal identification testing in the logistic regression model, adjusted for age, hearing age and study group, could not be confirmed ($p > 0.05$).

In the CI children only, the music perception ability assessed by emotional rating was negatively correlated to the child's age ($r_S = -0.38$; $p = 0.001$), age at implantation ($r_S = -0.34$; $p = 0.032$), hearing age ($r_S = -0.41$; $p = 0.010$), and device experience ($r_S = -0.38$; $p = 0.019$). The child's grade in school music classes showed a positive correlation to music perception abilities assessed by the rhythm discrimination ($r_S = 0.46$; $p < 0.001$), the melody discrimination ($r_S = 0.28$; $p = 0.018$), and the instrument identification ($r_S = 0.23$; $p = 0.05$). Other correlations between noted possible predictors and music perception abilities, assessed numerically or ordinally, could not be confirmed ($p > 0.05$).

Another factor that could have an impact on music perception abilities in the CI children, the sound processing strategy, showed a significant relationship to child's melody perception (Kruskal–Wallis test, $p = 0.005$), and a potentially important relationship to the child's rhythm perception (Kruskal–Wallis test, $p = 0.091$). To find out between which particular types of sound processing strategy a significant difference in the melody and rhythm perception exists, multiple paired comparisons were made, using the Mann–Whitney tests. As for the rhythm perception so for the melody perception the only significant difference was found between ACE and FSP sound processing strategy types ($p = 0.036$ and $p = 0.001$ for rhythm and melody perception, respectively), whilst the difference was not significant for ACE vs. HDCIS and FSP vs. HDCIS comparisons ($p > 0.05$). Possibly, there were too few subjects with the FSP type (8 subjects) and the HDCIS type (3 subjects) to prove any significant difference at all.

3.4. Factors that contribute to the auditory performance in CI children

The relation of the following factors that could contribute to the auditory performance: age, age at implantation, hearing age, device experience, grade in the school music class, to the auditory performance was proved only for the child's age and was negative ($r_S = -0.32$; $p = 0.049$). A comparison of auditory performance between children with additional musical education and those without it showed no significant difference (Mann–Whitney test, $p = 0.359$). The same was true for the comparison of auditory performance between the sound-processing strategy types (Kruskal–Wallis test, $p = 0.154$). However, the auditory performance differed in CI children in respect to their nonverbal intellectual abilities (Kruskal–Wallis test, $p = 0.030$). Paired comparisons

Table 4
Possible predictors for music perception abilities (MuSIC test battery), analysed in multiple linear regression model adjusted for children's age and study group.

MuSIC test	Auditory performance		Nonverbal intellectual abilities[a]		Additional musical education		MSG	
	Correlation coefficient	*p*-Value	*p*-Value below/other	*p*-Value above/other	Correlation coefficient	*p*-Value	Correlation coefficient	*p*-Value
Rhythm discrimination	0.076	0.490	0.425	0.966	−0.070	0.502	0.210	0.126
Melody discrimination	0.270	0.027	0.139	0.367	0.075	0.515	0.336	0.031
Instrument identification[b]	0.207	0.052	0.954	0.707	−0.018	0.858	−0.181	0.172
Dissonance rating	0.037	0.768	0.461	0.603	−0.150	0.208	−0.092	0.566
Emotion rating	0.021	0.852	0.590	0.345	0.005	0.960	0.092	0.522

CI, cochlear implant; MSG, school grade at the class of musical education in the mainstream school system; MuSIC, musical sounds in cochlear implants; NH, normal-hearing.
[a] Variable was dichotomised before inclusion into the model: below/other = below average vs. average or above average; above/other = above average vs. below average or average.
[b] All four instruments are included (guitar, piano, flute, violin).

showed that children with average nonverbal intellectual abilities had higher auditory performance than children with below average nonverbal intellectual abilities (Mann–Whitney test, $p = 0.023$) and furthermore, children with above average nonverbal intellectual abilities seemed to have higher auditory performance than children with below average nonverbal intellectual abilities (Mann–Whitney test, $p = 0.071$). Differences in auditory performance between children with above average nonverbal intellectual abilities and those with average nonverbal intellectual abilities could not be confirmed (Mann–Whitney test, $p = 0.412$).

4. Discussion

The literature on paediatric musical perception in children with CIs is very scarce. There are only a few published reports that deal with melody recognition and/or appraisal in paediatric CI users. Stordahl et al., who compared song recognition in 15 children with implants and 32 normal hearing children, found that CI recipients performed significantly less well than the normal-hearing (NH) children [25]. In another two studies of 13 and 17 congenitally deaf Japanese children with CIs, the children were only successful in identifying the original versions (vocal and instrumental) of songs that they heard regularly on popular television programmes [15,16]. When the words were absent or when a solo flute played the melody, they were unable to recognise the music [15]. Vongpaisal et al. studied 10 prelingually deaf children and 10 NH children. The CI users succeeded in identifying the original (vocal and instrumental) and instrumental versions of familiar recorded songs, but they could not identify the melody versions that were available in the original recordings. However, unlike NH listeners, they were unable to identify simple piano renditions of the melody, even though these renditions preserved the original timing cues [11,26]. In another study by Olszweski et al. on familiar-melody recognition, adult implant users were found to be considerably more accurate at identifying instrumental renditions of well-known songs in a four-alternative forced-choice task than postlingually deaf children who, in turn, were more accurate than prelingually deaf children. Unlike the child implant users, their adult counterparts showed substantial benefit from the availability of distinctive rhythmic cues [14]. In a third study by Vongpaisal et al. using a closed-set task, prelingually deaf children with CIs and NH children were required to identify three renditions of the theme music from their favourite TV programmes. The deaf children with CIs were much worse than young hearing children at recognising TV theme songs. Nevertheless, they performed significantly above chance levels with monophonic versions (i.e., sequences of single notes) of the main melodies and on instrumental versions of the theme songs that retained all the original cues, except for the vocals [12].

Adult CI users generally *perceive musical rhythm* approximately as well as listeners with normal hearing [27–29]. Similarly, in a recent study by Looi et al. regarding rhythm tests performed on a group of adult CI users and a group of subjects with hearing aids, there was no statistically significant difference between the two groups [30]. However, when the rhythmic pattern becomes more complicated, implant users tend to score slightly worse than NH subjects, possibly reflecting a reduced capacity in working memory in the CI subjects [1,29,31,32]. To our knowledge, there are no published data on rhythm perception in children with CI. In the present study, a statistical difference was observed in rhythm discrimination between the CI and NH groups of children. We anticipate that a minimum difference of only one note value between the presented rhythm pairs, with the same tempo and measure, was the reason for the worse score achieved in both groups of children compared to those reported in the adult population. It is possible that the minor differences between rhythm pairs were for an unknown reason more easily detected by NH children than by CI users, which might explain the difference between the groups. However, this is not in accordance with the results of several studies on rhythm perception in the adult CI population [27–33].

In adult implant users, *recognition of melodies*, especially without rhythmic or verbal cues, is poor [33]. Already initial studies by Schulz and Kerber found that implant users recognise melodies that have a distinctive rhythmic pattern more readily than melodies that are less rhythmic [27]. The "real-world" melodies, lyrics and rhythms can help implant users to identify melodies [34]. Gfeller et al. found that implant users were not as good as NH listeners at identifying real-world melodies [35]. Kong et al. presented 12 familiar melodies with and without rhythm to six CI listeners. With rhythm, the performance averaged from 50% to 60%, but without rhythm it averaged from 10% to 15% [29]. The tests of melody recognition reflected the difficulty experienced by CI users in accurately perceiving pitch, regardless of whether both rhythm and pitch cues were left intact, or whether only the pitch cues were preserved [36,37]. In a closed-set study by Looi, where melodies were presented without verbal cues or accompaniment, the implant users correctly recognised only about half the tunes, whereas NH listeners who performed the same task achieved nearly 100% correct answers [38]. We already mentioned that there are only a few studies on the recognition of melodies in children with CIs. These studies indicate that CI children's recognition of melodies is poor, especially without rhythmic or verbal cues, as in studies of adult implant users. There are differences between children with implants and adults and one cannot presume how similar their music perception and enjoyment will be. Congenitally deaf children had no exposure to normal representation of pitch prior to implantation. Furthermore, prelingually deafened children are less likely to have specific expectations of what music should 'sound' like, and so they may develop their own effective mental schema of musical sounds in response to music instructions or listening experiences [14]. In another study by Looi, the speech recognition and pitch ranking abilities of NH children were compared to prelingually deafened children using a CI alone, bilateral hearing aids or bimodal stimulation. As expected, the NH group ranked pitch significantly more accurately than the CI-only group. Contrary to findings in postlingually deafened adults they found no significant bimodal advantage for pitch perception for prelingually deafened children. However, the performance of children using electrical stimulation was significantly poorer than children using only acoustic stimulation [2]. In the present study, during the melody discrimination test, the NH children performed insignificantly better (78%) in comparison to the CI group (70%). It is possible that a prominent difference in pitch change and a fundamentally different melodic pattern between the pairs of melodies in the melody discrimination test contributed to the relatively high score in the group of children with CIs. An alternative explanation of the good results by the CI children was the higher cortical plasticity of child CI recipients compared to studies of adult CI users. Another reason may be related to differences in the distribution of spiral ganglion neurons in congenitally deafened children and postlingually deafened adults. Looi et al. already predicted in their study that a larger, more evenly distributed spiral ganglion neuron population may have allowed the child CI users to more accurately discriminate directional changes in the pattern of electrode activation across the array, improving the accuracy of pitch ranking judgements relative to their adult counterparts [2]. Some studies have shown that the concept of pitch is fully matured in a normal hearing child after the age seven. This would be different for a hearing impaired child. The mean age range of the tested children with CI in the present study was 11.25 years (only one child with CI was younger than seven years). The reason for the relatively poor performance of the children in the NH group in this test remains unclear to us.

There are several studies on the ability to *discriminate between the timbres of different musical instruments* in adult CI users; however no reports exist on this subject in the paediatric CI population. Adult CI recipients have a great deal of difficulty identifying timbres associated with different musical instruments [39,40]. Whilst NH subjects most often mistake one instrument for another in the same instrument family (e.g., a trumpet for a trombone), implant users consistently show more diffuse error pattern [30,35,40]. CI users show a greater ability to identify percussive instruments, such as the piano, in comparison to woodwind or brass instruments [35,40–42]. Our findings for instrument identification were largely consistent with the results of studies concerning adult CI users. The NH children were able to recognise the tested instruments significantly better than the children with CIs. According to our study, children with cochlear implants most often recognised the male-voice singing tenor, whilst the identification of the piano, violin, flute and guitar was less successful.

In existing research, not only music perception but also appreciation was assessed by applying various methods. It is a widely held view that happiness and sadness in music are associated with two structural properties: tempo (i.e., the number of beats per minute) and mode (i.e., the specific arrangement of the intervals amongst the subset of pitches used to write a given musical excerpt) [43–46]. In general, the emotion evoked by music depends on personal, cultural and structural aspects [24]. In a study of adult CI users, Gfeller showed that music habits and appreciation vary greatly and are influenced by the structural characteristics of the music, individual user differences and technical features of the device or processing scheme [47]. In a study by Mirza et al., only 16 out of 35 adult CI users (46%) listened to music after implantation. Enjoyment of music on a self-assessment scale was graded with a mean of 8.7/10 before deafness, but only 2.6/10 after implantation. Listening to music after implantation was more likely in younger patients, those with higher speech perception scores and those with a shorter duration of deafness, but was not found to be related to gender, type of implant, sound processing strategy, device experience or music enjoyment before becoming deaf [48]. In another study by Gfeller et al. multivariate predictors of music perception and appraisal by adult CI users were examined [49]. Their music listening background, residual hearing, cognitive factors, and some demographic factors predicted several indices of perceptual accuracy or appraisal of music. Importantly, neither device type nor processing strategy predicted music perception or music appraisal. Speech recognition performance was not a strong predictor of music perception. Good music perception skills might be necessary, but are not sufficient or required for good music appraisal. The child implant users who were born deaf typically find music interesting and enjoyable. Within months after receiving their implant, they prefer singing to silence [50]. On the other hand the comparatively poor music appreciation in patients with cochlear implants might be ascribed to inadequate exposure to music. Recent studies have shown the importance of musical training for the improvement of pitch perception. These studies included prelingually deaf children with CI's who lack a great deal of prior music experience and, rather than finding music disconcerting, tend to find it enjoyable and interesting, whilst also showing improvements over time [50–52]. In our study, a significant difference was confirmed in the average emotional rating of a selected piece of music between the CI and NH groups of children. It is possible that better music perception skills contributed to more apparent music appraisal by the NH children. We also found that younger children with cochlear implants assessed the same selection of music as being happier on the happy-to-sad-scale than older children did. The difference was statistically significant. These results could apply to the assumptions of other studies that structured training programmes for music perception would be beneficial early in life and as part of the postoperative rehabilitation programme for prelingually deafened children with cochlear implants. An important task of future research is to ascertain the relative contributions of perceptual and motivational factors to the apparent differences between child and adult implant users.

Musical psychology differentiates between musical harmony or consonance and dissonance [53]. The impression of stability and repose (consonance) in relation to the impression of tension or clash (dissonance) in music is experienced by a listener when certain combinations of tones or notes are sounded together. Until now, only Brockmeier et al. have reported on the consonance–dissonance perception in adult CI users [24]. Our study confirmed their results also for children, in whom no differences in chord-dissonance perception between the NH and the CI groups of children were detected.

In our study, nonverbal intellectual abilities were significantly lower in CI children in comparison to NH children. On the contrary Che-Ming Wu et al. demonstrated in their study that the performance IQ for children using cochlear implants did not differ from their counterparts with normal hearing [54]. The higher nonverbal IQ of children with CIs correlated with better auditory performance [55] and reading abilities [56].

In our study auditory performance negatively correlated with age at testing. It is possible that the reason for the better AP score on the CAP scale in younger children was their lower age at implantation, compared to the worse AP score in those, who were implanted at a higher age. From our study we have learned that auditory performance and the child's grade in school music classes were the main factors that correlated with music perception. The auditory performance correlated with melody discrimination and instrument identification. The child's grade in school music classes showed a positive correlation to music perception abilities assessed by the rhythm discrimination test, the melody discrimination test, and the instrument identification test. Another factor that could have an impact on music perception abilities in CI children was the sound processing strategy. It showed a significant relation to the child's melody perception and a potentially important relationship to the child's rhythm perception. According to our study, the child's age, the age at implantation and the device experience negatively correlated with the emotional perception of the music.

Since music is a prevalent art form and social activity, a better understanding of musical perception by CI users may address issues of user satisfaction in daily functioning [28]. In terms of social benefit after implantation, listening to music could be considered a benchmark of success [57].

The present study investigated several different aspects of music perception for prelingually deafened children with CIs. We are aware that our study is deficient in terms of tests on rhythm and melody perception because it could involve a higher number of different pairs of rhythms or melody pairs that would contain different difficulty levels. For prelingually deafened children who have never heard music through a normal hearing mechanism and have learned to hear using electrically stimulated hearing, which provides a completely different perception of sound, auditory terms and concepts such as pitch, dissonance or even rhythm may have no or a completely different meaning to what we assume. Therefore, correct interpretation of our results can be somehow questionable. In the future, further studies on this subject with a larger number of participants and a broader spectrum of music subtests will be needed. It is important to assess as many factors as possible that may contribute to the music perception of children with CI so they are able to enjoy music like their NH peers.

Conflicts of interest

The authors declare that they have not received any financial support and that there are no conflicts of interest. All authors declare to have participated in the study and have seen and approved the final version.

References

[1] F.G. Zeng, Trends in cochlear implants, Trends Amplif. 8 (2004) 1–34.
[2] V. Looi, C.J. Radford, A comparison of the speech recognition and pitch ranking abilities of children using a unilateral cochlear implant, bimodal stimulation or bilateral hearing aids, Int. J. Pediatr. Otorhinolaryngol. 75 (2011) 472–482.
[3] V. Looi, H. McDermott, C. McKey, L. Hickson, Comparison of quality ratings for music by cochlear implant and hearing aid users, Ear Hear. 28 (Suppl. 2) (2007) 59–61.
[4] M. Tait, L. De Raeve, T.P. Nikolopoulos, Deaf children with cochlear implants before the age of 1 year: comparison of preverbal communication with normally hearing children, Int. J. Pediatr. Otorhinolaryngol. 71 (2007) 1605–1611.
[5] S.J. Dettman, W.A. D'Costa, R.C. Dowell, E.J. Winton, K.L. Hill, S.S. Williams, Cochlear implants for children with significant residual hearing, Arch. Otolaryngol. Head Neck Surg. 130 (2004) 612–618.
[6] M.A. Svirsky, A.M. Robbins, K.I. Kirk, D.B. Pisoni, R.T. Miyamoto, Language development in profoundly deaf children with cochlear implants, Psychol. Sci. 11 (2000) 153–158.
[7] A.E. Geers, Spoken language in children with cochlear implants, in: P.E. Spencer, M. Marschark (Eds.), Advances in the Spoken Language Developement of Deaf and Hard-of-Hearing Children. Perspectives on Deafness, Oxford University Press, New York, 2006, pp. 244–270.
[8] I. Hocevar-Boltezar, Z. Radsel, J. Vatovec, B. Getczy, S. Cernelc, A. Gros, et al., Change of phonation control after cochlear implantation, Otol. Neurotol. 27 (2006) 499–503.
[9] M. Cleary, D.B. Pisoni, Talker discrimination by prelingually deaf children with cochlear implants: preliminary results, Ann. Otol. Rhinol. Laryngol. 111 (2002) 113–118.
[10] E.C. Schafer, L.M. Thibodeau, Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements, Am. J. Audiol. 15 (2006) 114–126.
[11] T. Vongpaisal, S.E. Trehub, E.G. Schellenberg, Song recognition by children and adolescents with cochlear implants, J. Speech Lang. Hear. Res. 49 (2006) 1091–1103.
[12] T. Vongpaisal, S.E. Trehub, E.G. Schellenberg, Identification of TV tunes by children with cochlear implants, Music Percept. 27 (2009) 17–24.
[13] T. Vongpaisal, S.E. Trehub, E.G. Schellenberg, P. van Lieshout, B.C. Papsin, Children with cochlear implants recognize their mother's voice, Ear Hear. 3 (2010) 555–565.
[14] C. Olszweski, K. Gfeller, R. Froman, J. Stordahl, B. Tomblin, Familiar melody recognition by children and adults using cochlear implants and normal hearing children, Cochlear Implants Int. 6 (2005) 123–140.
[15] T. Nakata, S.E. Trehub, C. Mitani, Y. Kanda, A. Shibasaki, E.G. Schellenberg, Music recognition by Japanese children with cochlear implants, J. Physiol. Anthropol. Appl. Human Sci. 24 (2005) 29–32.
[16] C. Mitani, T. Nakata, S.E. Trehub, Y. Kanda, H. Kumagami, K. Takasaki, et al., Music recognition, music listening and word recognition by deaf children with cochlear implants, Ear Hear. 28 (Suppl. 2) (2007) 29–33.
[17] K. Kaga, A. Yusuke, Environmental sound perception in patients with cochlear implants compared with that in patients with auditory nerve diseases (auditory neuropathy) and cortical deafness, in: K. Kaga, A. Starr (Eds.), Neuropathies of the Auditory and Vestibular Eight Cranial Nerves, Springer, Tokyo, 2009, pp. 53–59.
[18] E. Bates, J. Reilly, B. Wulfeck, N. Dronkers, M. Opie, J. Fenson, et al., Differential effects of unilateral lesions on language production in children and adults, Brain Lang. 79 (2001) 223–265.
[19] L. Scattergood, C.J. Limb, Music perception in children with cochlear implants, Perspect. Hear. Hear. Disord. Child. 20 (2010) 32–37.
[21] S. Archbold, M.E. Lutman, T. Nikolopoulos, Categories of auditory performance: inter-user reliability, Br. J. Audiol. 32 (1998) 7–12.
[22] P.J. Govaerts, C.D. Beukelaer, K. Daemers, G. De Ceulaer, M. Yperman, T. Somers, et al., Outcome of cochlear implantation at different ages from 0 to 6 years, Otol. Neurotol. 23 (2002) 885–890.
[23] P. Praper, Sistematični psihološki pregled triletnega otroka SPP-3: priročnik, Zavod SR Slovenije za produktivnost dela, Center za psihodiagnostična sredstva, Ljubljana, 1980.
[24] S.J. Brockmeier, D. Fitzgerald, O. Searle, H. Fitzgerald, M. Grasmeder, S. Hilbig, et al., The MuSIC perception test. A novel battery for testing music perception of cochlear implant users, Cochlear Implants Int. 12 (2011) 10–20.
[25] J. Stordal, Song recognition and appraisal: a comparison of children who use cochlear implants and normally hearing children, J. Music Ther. 39 (2002) 2–19.
[26] T. Vongpaisal, S.E. Trehub, E.G. Schellenberg, B. Papsin, Music recognition by children with cochlear implants, Int. Congr. Ser. 1273 (2004) 193–196.
[27] E. Schulz, M. Kerber, Music perception with the MED-EL implants, in: I.J. Hochmair-Desoyer, E.S. Hochmair (Eds.), Advances in Cochlear Implants, Manz, Vienna, 1994, pp. 326–332.
[28] K. Gfeller, C.R. Lansing, Melodic, rhythmic, and timbral perception of adult cochlear implant users, J. Speech Hear. Res. 34 (1991) 916–920.
[29] Y.Y. Kong, R. Cruz, J.A. Jones, F.G. Zeng, Music perception with temporal cues in acoustic and electric hearing, Ear Hear. 25 (2) (2004) 173–185.
[30] V. Looi, H. McDermott, C. McKey, L. Hickson, Music perception of cochlear implant users compared with that of hearing aid users, Ear Hear. 29 (2008) 421–434.
[31] L.M. Collins, G.H. Wakefield, G.R. Feinman, Temporal pattern discrimination and speech recognition under electrical stimulation, J. Acoust. Soc. Am. 96 (1994) 2731–2737.
[32] K. Gfeller, G. Woodworth, D.A. Robin, S. Witt, J.F. Knutson, Perception of rhythmic and sequential pitch patterns by normally hearing adults and adult cochlear implant users, Ear Hear. 18 (1997) 252–260.
[33] H.J. Mc Dermott, Music perception with cochlear implants: a review, Trends Amplif. 8 (2004) 49–82.
[34] W.R. Drennan, J.T. Rubinstein, Music perception in cochlear implant users and its relationship with psychophysical capabilities, J. Rehabil. R. D. 45 (2008) 779–790.
[35] K. Gfeller, C. Olszewski, M. Rychener, K. Sena, J.F. Knutson, S. Witt, et al., Recognition of "real-world" musical excerpts by cochlear implant recipients and normal-hearing adults, Ear Hear. 26 (2005) 237–250.
[36] J.J. Galvin III, Q.J. Fu, G. Nogaki, Melodic contour identification by cochlear implant listeners, Ear Hear. 28 (2007) 302–319.
[37] K. Gfeller, C. Turner, M. Mehr, G. Woodworth, R. Fearn, J. Knutson, et al., Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults, Cochlear Implants Int. 3 (2002) 29–53.
[38] V. Looi, H. McDermott, C. McKay, L. Hickson, Pitch discrimination and melody recognition by cochlear implant users, Int. Congr. Ser. 1273 (2004) 197–200.
[39] J. Galvin, F.G. Zeng, Musical instrument perception in cochlear implant listners, in: Processing of 16th International Congress Acoust and 135th Meet Acoust. Soc. Am., vol. 3, 1998, 2219–2220.
[40] K. Gfeller, J.F. Knutson, G. Woodworth, S. Witt, B. DeBus, Timbral recognition and appraisal by adult cochlear implant users and normal-hearing adults, J. Am. Acad. Audiol. 9 (1998) 1–19.
[41] K. Gfeller, S. Witt, M. Adamek, M. Mehr, J. Rogers, J. Stordahl, et al., Effects of training on timbre recognition and appraisal by postlingually deafened cochlear implant recipients, J. Am. Acad. Audiol. 13 (2002) 132–145.
[42] P.J. Donnelly, C.J. Limb, Music perception in cochlear implant users, in: J.K. Niparko (Ed.), Cochlear Implants: Principles and Practices, 2nd ed., Williams & Wilkins, Philadelphia: Lippincott, 2009, pp. 223–228.
[43] S.J. Brockmeier, M. Grasmeder, S. Passow, D. Mawmann, M. Vischer, A. Jappel, et al., Comparison of musical activities of cochlear implant users with different speech-coding strategies, Ear Hear. 28 (Suppl. 2) (2007) 49–51.
[44] K. Veekmans, L. Ressel, J. Mueller, M. Vischer, S.J. Brockmeier, Comparison of music perception in bilateral and unilateral cochlear implant users and normal-hearing subjects, Audiol. Neurotol. 14 (2009) 315–326.
[45] S. Dalla Bella, I. Peretz, L. Rousseau, N. Gosselin, J. Ayotte, A. Lavoie, Children and emotions. Development of the happy-sad distinction in music appreciation. Does tempo emerge earlier than mode, Ann. N. Y. Acad. Sci. 930 (2001) 436–438.
[46] L. Gagnon, I. Peretz, Mode and tempo relative contributions to "happy-sad" judgements in equitone melodies, Cogn. Emot. 17 (2003) 25–40.
[47] K. Gfeller, A. Chris, J. Knutson, S. Witt, K. Murray, R. Tyler, Musical backgrounds, listening habits and aesthetic enjoyment of adult cochlear implant recipients, J. Am. Acad. Audiol. 11 (2000) 390–406.
[48] S. Mirza, S.A. Douglas, P. Lindsey, T. Hildreth, M. Hawthorne, Appreciation of music in adult patients with cochlear implants: a patient questionnaire, Cochlear Implants Int. 4 (2003) 85–95.
[49] K. Gfeller, J. Oleson, J. Knutson, P. Breheny, V. Driscoll, C. Olszewski, Multivariate predictors of music perception and appraisal by adult cochlear implant users, J. Am. Acad. Audiol. 19 (2008) 120–134.
[50] S.E. Trehub, T. Vongpaisal, T. Nakata, Music in the lives of deaf children with cochlear implants, Ann. N. Y. Acad. Sci. 1169 (2009) 534–542.
[51] J.K. Chen, A.Y. Chuang, C. McMahon, J.C. Hsieh, T.H. Tung, L.P. Li, Music training improves pitch perception in prelingually deafened children with cochlear implants, Pediatrics 125 (2010) 793–800.
[52] C. Limb, J.T. Rubinstein, Current research on music perception in cochlear implant users, Otolaryngol. Clin. N. Am. 45 (2012) 129–140.
[53] C.L. Krumhansl, Music psychology: tonal structures in perception and memory, Annu. Rev. Psychol. 42 (1991) 277–303.
[54] C.M. Wu, H.L. Lee, J.H. Hwang, Y.S. Sun, T.C. Liu, Intellectual ability of Mandarin-speaking children using cochlear implants, Audiol. Neurotol. 13 (2008) 302–308.
[55] H.M. Yang, C.Y. Lin, Y.J. Chen, J.L. Wu, The auditory performance in children using cochlear implants: effects of mental function, Int. J. Pediatr. Otorhinolaryngol. 68 (2004) 1185–1188.
[56] A.E. Geers, Predictors of reading skill development in children with early cochlear implantation, Ear Hear. 24 (Suppl. 1) (2003) 59–68.
[57] M.C. Leal, Y.J. Shin, M.L. Laborde, M.N. Calmels, S. Verges, S. Lugardon, et al., Music perception in adult cochlear implant recipients, Acta Otolaryngol. 123 (2003) 826–835.