

OTOLOGY

Musical training software for children with cochlear implants

Software di training musicale per bambini con impianto cocleare

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SUMMARY

Although the voice in a free field has an excellent recruitment by a cochlear implant (CI), the situation is different for music because it is a much more complex process, where perceiving the pitch discrimination becomes important to appreciate it. The aim of this study is to determine the music perception abilities among children with CIs and to verify the benefit of a training period for specific musical frequency discrimination. Our main goals were to prepare a computer tool for pitch discrimination training and to assess musical improvements. Ten children, aged between 5 and 12 years, with optimal phoneme recognition in quiet and with no disabilities associated with deafness, were selected to join the training. Each patient received, before training period, two types of exams: a pitch discrimination test, consisting of discovering if two notes were different or not; and a music test consisting of two identification tasks (melodic and full version) of one music-item among 5 popular childhood songs. After assessment, a music training software was designed and utilised individually at home for a period of six months. The results following complete training showed significantly higher performance in the task of frequency discrimination. After a proper musical training identification, frequency discrimination performance was significantly higher ($p < 0.001$). The same considerations can be made in the identification of the songs presented in their melodic ($p = 0.0151$) and full songs version ($p = 0.0071$). Cases where children did not reach the most difficult level may be due to insufficient time devoted to training (ideal time estimated at 2-3 hours per week). In conclusion, this study shows that it is possible to assess musical enhancement and to achieve improvements in frequency discrimination, following pitch discrimination training.

KEY WORDS: Cochlear implants • Music perception • Speech perception • Children • Music Test battery

RIASSUNTO

Gli attuali impianti cocleari forniscono buoni segnali temporali e grossolane indicazioni spettrali. In generale queste proprietà sono sufficienti per la percezione di un discorso in condizioni di quiete e per l'acquisizione del linguaggio nei bambini piccoli. Tuttavia esse risultano essere inadeguate per la trasmissione della moltitudine di pitch della musica. Lo studio si propone come obiettivi la determinazione delle abilità di percezione della musica nei bambini portatori di impianto cocleare e la verifica dei benefici di un periodo di training musicale specifico per la discriminazione frequenziale. In particolare abbiamo proposto un allenamento alla discriminazione delle note musicali, secondo un metodo da noi sviluppato attraverso un supporto computerizzato. Sono stati inclusi nello studio 10 bambini portatori di impianto cocleare di età compresa tra i 5 e i 12 anni senza disabilità associate alla sordità. Tutti i soggetti avevano un'ottima comprensione dei fonemi in ambiente silenzioso. Ogni paziente nel periodo precedente al Training è stato sottoposto a due tipi di esame: un test di discriminazione del pitch, che consiste nel riuscire ad identificare come differenti due note musicali pur in condizioni di crescente difficoltà (da 1 ottava ad 1 semitono), e un Music Test costituito da due prove di identificazione, Melodica e Strumentale completa. Il materiale del Music Test era costituito dai 5 canzoni popolari per l'infanzia, sintetizzate con il software Finale 2008™ (Makemusic Inc. Eden Prairie, MN). I brani, ciascuno della durata di 30 secondi, erano simili per il ritmo e venivano presentati in due modalità differenti: una versione melodica suonata al pianoforte senza accompagnamento orchestrale e parole cantate, ed una versione completa della canzone, che include l'accompagnamento dell'orchestra e le parole cantate. Il Training consisteva in un allenamento guidato da un programma che veniva fornito su supporto informatico ad ogni paziente, della durata di 6 mesi con allenamento almeno bisettimanale. I risultati ottenuti evidenziano che tutti i bambini sono migliorati nel training di discriminazione frequenziale ($p < 0,0001$). Per eliminare la possibilità che questo progresso potesse essere dovuto al caso o ad altri fattori si è applicata un'analisi statistica t-Student ad una coda per dati appaiati per verificarne la significatività. Le prestazioni al test di identificazione di item musicali sia nella versione melodica che in quella completa sono risultate significativamente superiori al livello casuale con un $p < 0,05$. I risultati ottenuti mostrano performance significativamente superiori nel compito di discriminazione frequenziale successivamente all'esecuzione del Training. Infatti prima del training 2 bambini si posizionavano al 1° livello (discriminazione frequenziale di 12 semitoni), 3 bambini al 2° livello (discriminazione frequenziale di 10 semitoni), 4 bambini al 3° livello (discriminazione frequenziale di 8 semitoni) e 1 bambino al 5° livello (discriminazione frequenziale di 4 semitoni), mentre dopo il training, 2 bambini si collocavano uno al 4° e uno al 5° livello, 5 bambini al 6° livello e i restanti 3 bambini al 7° ed ultimo livello. Dal nostro studio emerge quindi come sia possibile, in seguito ad un allenamento specifico con materiale dedicato, ottenere dei significativi miglioramenti nella discriminazione frequenziale permettendo anche ai soggetti impiantati di apprezzare meglio il mondo della musica.

PAROLE CHIAVE: Impianto cocleare • Percezione linguistica • Ascolto della musica • Bambini • Test musicale

Introduction

In recent years, advancements in cochlear implant (CI) technology has allowed the device to achieve its primary goal, that is to restore a near-normal speech understanding in profoundly deaf subjects, at least in favourable listening conditions^{1,2}. New signal processing strategies have brought benefits for CI users in terms of perception. Technological innovations in CI systems, enabled functional hearing, oral speech and language achievements in many children with pre-lingual severe-to-profound hearing impairment. Nonetheless, CIs still provide poorer auditory information than those conveyed through an intact natural cochlea.

One of the main weaknesses of the latest generation CIs appears to be the limited number of active channels, too low to allow an appropriate encoding of detailed spectral information, which is crucial to give perceptual accuracy of melody pitch patterns³ (Fig. 1a, b). Moreover, most of the current processing strategies remove fine temporal structure information from stimulus waveforms, therefore limiting the users' ability to extract pitch cues from temporal components of the signal⁴. In fact, CI encoding signal algorithms generally fail in reproducing higher order harmonics. Preservation of tonotopicity is crucial in CI-mediated music understanding, mainly because it

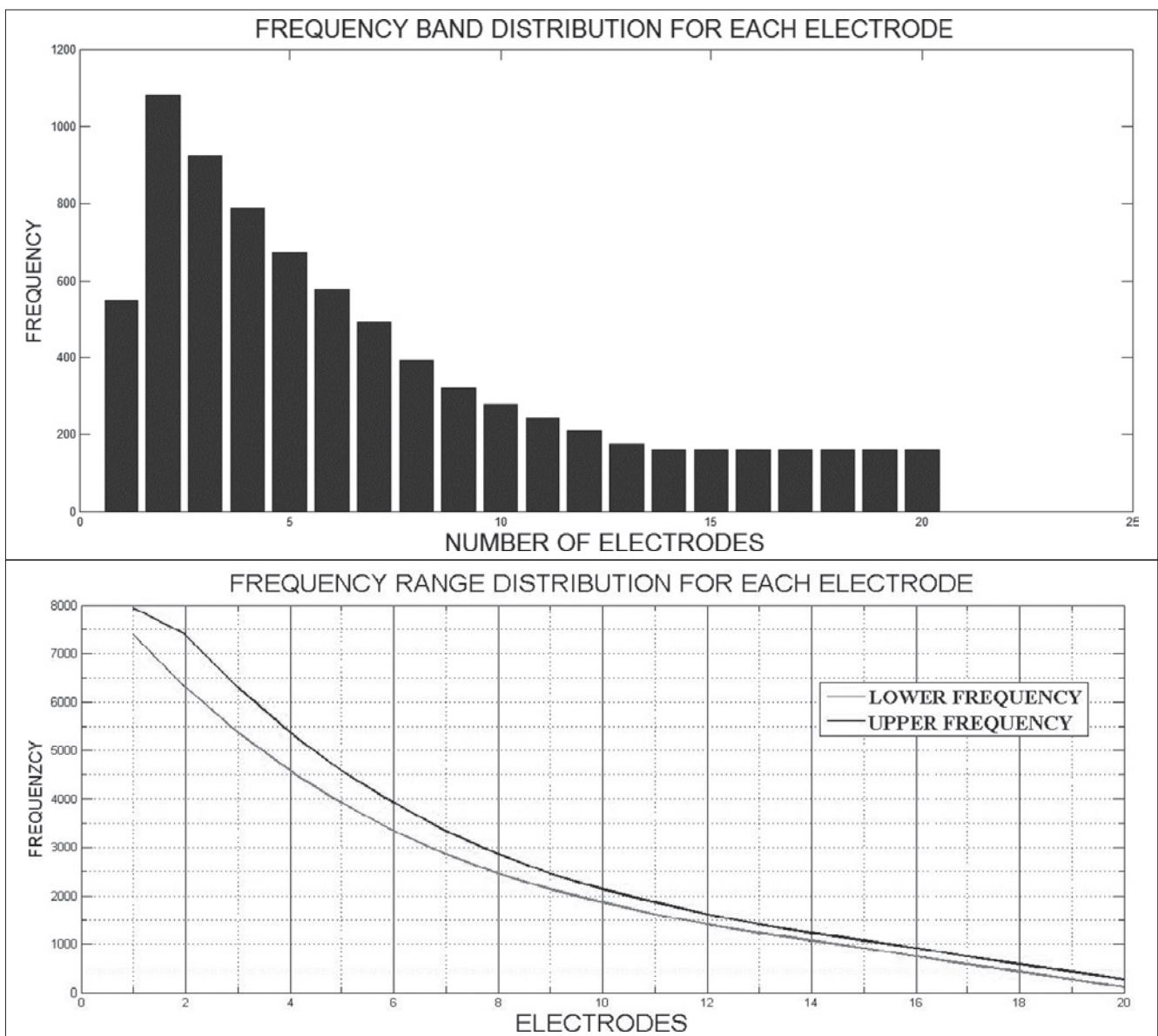


Fig. 1a-b. Distribution of frequency bands of the strategy encodes. Histogram shows the distribution of frequency bandwidths on each electrode, which is in proportion to the cochlear tonotopicity following the placement of the electrodes. The second curve represents the frequency range transduced by the implant according to the distribution of the bands set in the histogram. Data were extrapolated from the stimulation of the mapping software of the processor for each patient. In this case, it shows the frequency distribution of patient C1.

demands an absolute fidelity of signal transduction, while there is mounting evidence that the tonotopic representation of frequencies through the CI is often distorted due to a poor correspondence between the frequency bands allocated to the electrodes, according to the conventional frequency maps, and the pitch elicited by stimulation of the same electrodes. Thus, fundamental frequencies – and consequently harmonics – cannot be efficiently extracted and properly decoded, due to the mismatch between electrode-assigned frequencies and pitch⁵⁻⁷.

It is widely accepted that music and speech are the most complex sound features produced by the human species. These two processes have similar properties and central processing, albeit analysed in different human brain areas. The inter-hemispheric domains of music and speech allow psychosocial and cognitive skills development in communication⁸. The “musician effect” persists under degraded pitch condition of CI simulation and may offer advantages in pitch processing⁹. Studies with normal-hearing people showed that musical training can improve pitch recognition: musician children detect pitch variations in both music and language much more accurately¹⁰⁻¹² and rapidly¹³ than non-musician peers¹⁴. Although the voice in a free field has an excellent recruitment by the CI, the situation is different concerning musical sounds because it is a much more complex process, where perceiving the higher order harmonics becomes important to appreciate it. Many studies have shown that some CI recipients are quite able to perceive features such as tempo and rhythm¹⁵, but the extent of this perception is variable¹⁶⁻¹⁷. Other papers have focused on pitch processing skills due to their immediate relevance to music perception¹⁸⁻²². In some of these studies, familiar melodies have been recognised from a closed set¹⁹⁻²³, whereas in others simple melodic contours have been discriminated²⁴. The results indicate that melody perception is generally poor in CI users, again considering a large inter-individual variability. Several studies have examined the accuracy of different devices and coding strategies on melody and speech in noise perception,

concluding that there are statistically significant correlations between pitch ranking and familiar melody recognition²⁵. Children with CIs have greater difficulties in recognising familiar songs when these melodies are without words²⁶. Recent research demonstrated that there is a correlation between music perception and phonological and reading process skills; the same authors hypothesised that some music characteristics (such as rhythm and pitch) are associated with some speech perception parameters²⁷. However, standardised methods for assessing music perception in patients with CI are lacking²⁸. Yucel et al.²⁹ found that musical training is an effective rehabilitation tool for auditory perception improvement. In particular, one of the most relevant points of this work is the ability to subject children to this training without requiring them any additional efforts, thanks to the possibility to perform the exercises at patient’s home, by themselves or with the help of a family member if the subjects were too young. The authors stated that submitting children to musical exercises – such as pitch discrimination test between two notes – leads to improvements in spoken language perception. Dastgheib proposed a new music training program based on language development to optimise speech and language skills³⁰. These findings show that the CI alone does not satisfy all patients’ needs, and that speech therapy and specific training may be proper and necessary in order to maximise CI benefits.

The purpose of the present investigation is to determine whether children with CIs can benefit from training on pitch and music perception in terms of pitch discrimination; moreover, if pitch perception can be trained, it could also lead to improvements in speech perception and in music enjoyment.

Materials and methods

Subjects

Ten children (6 boys and 4 girls), monaurally Nucleus™ CI users (Table I), who periodically came to our ENT

Table I. Background information of the study group. Age, age of deafness onset, and duration of CI usage variables are all expressed in the unit of “years”.

Subject	Background information					
	Age	Aetiology	Onset age	Duration of CI	Deafness	Side of CI
C 1	12	Idiopathic	4	8	Pre-verbal	Right
C 2	6	Idiopathic	2	4	Pre-verbal	Right
C 3	11	Waardenburg Syndrome	2	9	Pre-verbal	Left
C 4	8	Homozygous for connexin 26 mutation	3	5	Pre-verbal	Right
C 5	12	Idiopathic	3	9	Pre-verbal	Right
C 6	12	Idiopathic	4	8	Pre-verbal	Right
C 7	12	Idiopathic	6	6	Post-verbal	Right
C 8	11	Idiopathic	4	7	Pre-verbal	Right
C 9	5	Heterozygous for connexin 26 mutation	2	3	Pre-verbal	Right
C 10	6	Idiopathic	2	4	Pre-verbal	Right

Table II. Main features of speech processor settings.

Subject	Processor	Implant	Device- features				
			Maxima	Channel stimulation rate	Strategy	Pulse width	Total frequency
C 1	Freedom SP	CI24R (CS)	8	900	ACE	25	7200
C 2	Freedom SP	CI24RE (CA)	10	2400	ACE (RE)	12	24000
C 3	Freedom SP	CI24R (CS)	8	250	SPEAK	25	2000
C 4	Freedom SP	CI24RE(CA)	8	900	ACE	25	7200
C 5	Freedom SP	CI24R (CS)	8	900	ACE	25	7200
C 6	ESPrIt 3G	CI24R (CS)	8	900	ACE	25	7200
C 7	Freedom SP	CI24RE (CA)	10	2400	ACE (RE)	12	24000
C 8	ESPrIt 3G	CI24R (CS)	8	900	ACE	25	7200
C 9	Freedom SP	CI24RE (CA)	8	900	ACE	25	7200
C 10	Freedom SP	CI24RE (CA)	10	2400	ACE (RE)	12	7200

clinic to perform speech processor fitting, were recruited. Children were aged between 5 and 12 years and had no disability associated with deafness. Mean chronological age was 117 ± 36 months, while mean hearing age (i.e. months of CI use) was 77 ± 26 months. These subjects had bilateral hearing loss and regularly used conventional hearing aids until CI implantation. All these patients had been using a Nucleus™ CI device for at least 6 months: 5 had a perimodiolar electrode (CI24RE-CA) and 5 had a straight, non-perimodiolar electrode (CI24R-S). At the time the study took place, 8 of the 10 Nucleus™ CI recipients were using a Freedom™ speech processor and 2 were fitted with an ESPrIt 3G™ speech processor. Six had been using an ACE™ strategy with a 900 pps stimulation rate and 25 μ s pulse width, 3 patients had been using an ACE™ (RE) strategy with a 2400 pps stimulation rate and 12 μ s pulse width and the last one using SPEAK strategy with a 250 pps and 25 μ s (Table II). During the month preceding the test session, all speech processors were fitted so that all patients could receive comfortable stimulation. Impedance measurement and neural response telemetry (NRT™ for Nucleus™ recipients) were performed for all electrodes in each subject. As soon as it was possible, all subjects were enrolled in the auditory-musical training program of the Catholic University of Sacred Heart in Rome. None of the patients had been attending music classes at school, nor they had been taking part in any formal music training activity, so that they belonged to musical experience level “1” according to Looi³¹. Before introducing our test battery to CI subjects, we checked its validity on 10 normal hearing patients, all of them scoring between 95 and 100% in the Music Training Program based on Musical Pitch Discrimination (MPD) test.

Music test battery

A music test battery was designed in order to assess CI-mediated perception of music. It included a *Music Training Software* based on MPD, and a *Music Test*. In the pitch

discrimination test, stimuli consisted in pairs of notes played by a piano and distanced by at least one semitone (approximately 6% F0 difference), being the semitone the smallest interval size in traditional Western music. The notes were distributed within the three central octaves (C4, C5, C6, each matching with the following frequency bands: 262 Hz-523 Hz, 523 Hz-1046 Hz and 1046 Hz-1976 Hz), used for most of the songs, for a total of 36 notes. After listening to each pair of notes, the patient was asked to indicate which one was higher in pitch.

- *Music training software.* This software is designed to reproduce the melodic exercises of musical pitch discrimination: patients can perform exercises at home as shown in the present study. The Home-Learning Program is composed of several interfaces and levels of increasing difficulty. According to the test, subjects listen to 2 musical notes, and then say if the pair is made of the same or different sounds. The notes were played by a piano and, as in the previous test, lay between the 4th and 6th octave. Each pair was then recorded (sampling at 40 KHz), reproduced from the Home-Learning Program and delivered to the listener, sitting one meter away from a loudspeaker, sending a stimulus at 70 dB nHL. The software Home-Learning Program was installed on an IBM™ computer, which was routinely used to fit patients' maps in routine fitting sessions. The levels were 7, with increasing difficulty, determined by reducing the distance between notes: the 1st level comprised pairs of notes 12-semitones apart (easiest task), while the 7th level included notes one semitone apart (most difficult task; Table III). The test aimed to assess children's frequency discrimination in the frequency domain 262-1976 Hz. For each level, one pair of musical notes was administered: children had to say if the two tones were different or the same. Each level is further divided into two tests:
 - TEST A: composed of two parts (each of 10 questions) in which the subject had to choose between 2 notes belonging to the 5th and 6th musical octave (523-1976 Hz).

Table III. The levels are divided into 7 categories of increasing difficulty. The difficulty is determined by the distance in frequency between notes played.

Level	Degree of difficulty
Level 1	12 semitones
Level 2	10 semitones
Level 3	8 semitones
Level 4	6 semitones
Level 5	4 semitones
Level 6	2 semitones
Level 7	1 semitone

- **TEST B:** consists of two parts (each of 10 questions) in which the subject had to choose between 2 notes belonging to the 4th and 5th musical octave (262- 988 Hz). In the last 2 levels (6th and 7th level) there are 20 more questions test that investigate discrimination on mid-range (linked to the 5th octave). The software was programmed to go to the next, harder level once 8 correct answers of 10 were obtained. The threshold of 8 correct answers was planned conforming to the Theorem Bernoulli Trials. The Home-Learning Program was given to study members' families; they were asked to set aside time (at least 2 hours weekly) to practice at home for a 6-month period. Parents had to teach children how to use the software.
- **Music Test.** The music test aims to assess children's identification skills in a closed set of music items. It is composed of 5 childhood songs in digital recording, synthesised with Finale™ 2008 (MakeMusic Inc., Eden Prairie, MN). The tunes were presented at 70 dB-nHL, coming from two frontal loudspeakers one metre apart from the CI recipient. Prior to test execution, subjects were conditioned to look at a specific cartoon movie linked to each song from an IBM laptop® (IBM, Armonk, USA). Each song is presented twice, for a total of 10 items. During testing, children sat in front of a screen showing the most representative characters for each of the previously seen cartoons. The music test is divided in two sessions: in session 1, full version songs (instrumental plus vocal), as those presented in the preliminary training, were played twice randomly, for a total of 10 items. Children had to indicate the distinctive character on the screen for each song. In session 2, children were exposed to the melodic version songs, presented twice in a random order for a total of 10 musical items. An overall score was calculated on the basis of the items correctly identified.

All children carried out an initial test to define the baseline music performances (musical pitch discrimination + music test). They then followed the specific musical training program, and eventually performed a final test with the same initial workup to evaluate possible improvement due to training.

Statistical analysis

We used a Kolmogorov-Smirnov test (K-S test) to compare a sample with a reference probability distribution, a paired t-Student statistic test to determine whether there were differences between two means or between a target value and a calculated mean, and used the Mann-Whitney U test, a non-parametric statistical test, when the distribution of samples did not respect of K-S test condition. A linear regression model according to Spearman's rank and Pearson's coefficient was used for correlations. Significance was set at $p < 0.05$.

Results

Training is based on a frequency discrimination task. Results were obtained comparing performances on MPD and music tests before and after the 6-month training period.

MPD results

Scores achieved after musical training showed significantly higher performance in frequency discrimination tasks than before training. At the baseline assessment, 2 children reached level 1 (frequency discrimination threshold of 12 semitones), 3 children reached level 2 (frequency discrimination threshold of 10 semitones), 4 children level 3 (frequency discrimination threshold of 8 semitones) and 1 child got to level 5 (frequency discrimination threshold of 4 semitones). Conversely, at the final assessment, 1 children came up to level 4, 1 to level 5, 5 children to level 6 (frequency discrimination threshold of 2 semitones) and the remaining 3 children got to the 7th and final level (frequency discrimination threshold of 1 semitone). Patients who reached last and hardest discrimination level (P3, P5 and P6) showed a proportional improvement in melody test scores (Figure 2): this suggests that these patients have higher frequency resolution than other CI children, but not comparable to that of normal hearing peers. In fact, children in the control group performed the MPD test without committing any error. The results showed that all children improved after training, each having reached more advanced level (almost up to the highest level). Statistical analysis was performed to rule out bias such as chance level; the Box-Plot and histogram show the significant difference in performances ($p < 0.0001$) obtained before and after training (Figs. 3, 4).

Music test results

There was an improvement in performances in both the melodic (Fig. 5a-b) and full (Fig. 6a-b) versions of the test comparing pre- and post-training assessments. In both cases, we found a significant difference between pre- and post-training scores $p = 0.0151$ for the melodic version and $p = 0.0071$ for the full song version).

On the other hand, there was no significant correlation between melodic and full version identification skill improve-

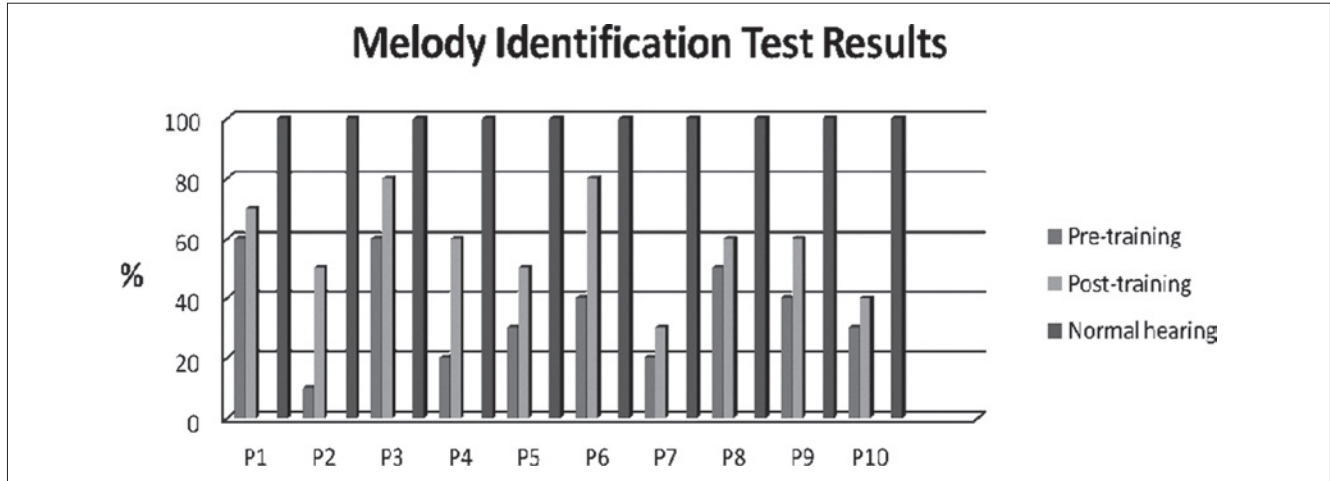


Fig. 2. Comparison between overall scores before and after musical training in the music test. We checked the validity of the melody and full version test, on 10 normal hearing patients, all of whom scored between 95 and 100%.

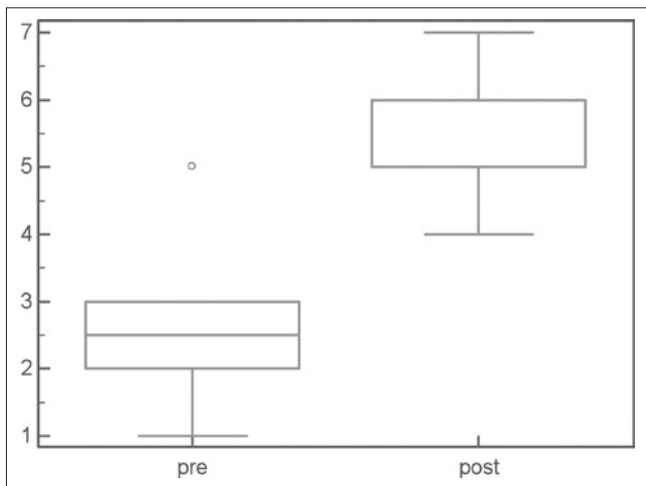


Fig. 3. Box plot of results: The box-plot represents the distribution of levels, of the MPD test, achieved by patient, before and after musical training ($p < 0.0001$).

ments and stimulation strategy parameters, such as pulse width ($r^2 = 0.33$, $p = 0.102$) and maxima ($r^2 = 0.36$, $p = 0.10$).

Discussion

Music is a challenging task that is generally more difficult than conventional speech. Music is also a powerful tool in auditory training in children with CIs because it is an integral part of human natural environment. Music perception by CI recipients is hard because most common signal-processing strategies fail in transmitting effective pitch information³². The underlying causes may be several: current CI processing strategies, which are more operative in preserving envelope cues but do not convey fine structure cues associated with good pitch perception; neural damage, that can limit the discrimination rate in some CI recipients; the limited electrode number; the abnormal frequency-coding

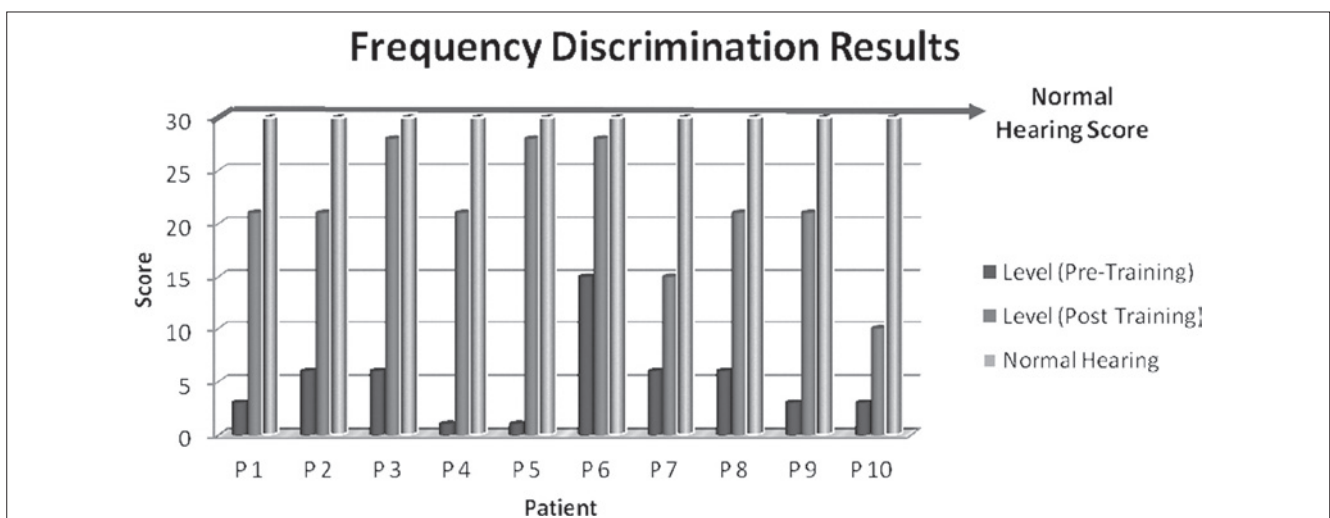


Fig. 4. Comparison between scores before and after musical training in the MPD test. We checked the validity of music training program, based on the MPD test, on 10 normal hearing patients, all of whom achieved the 7th level without any problem.

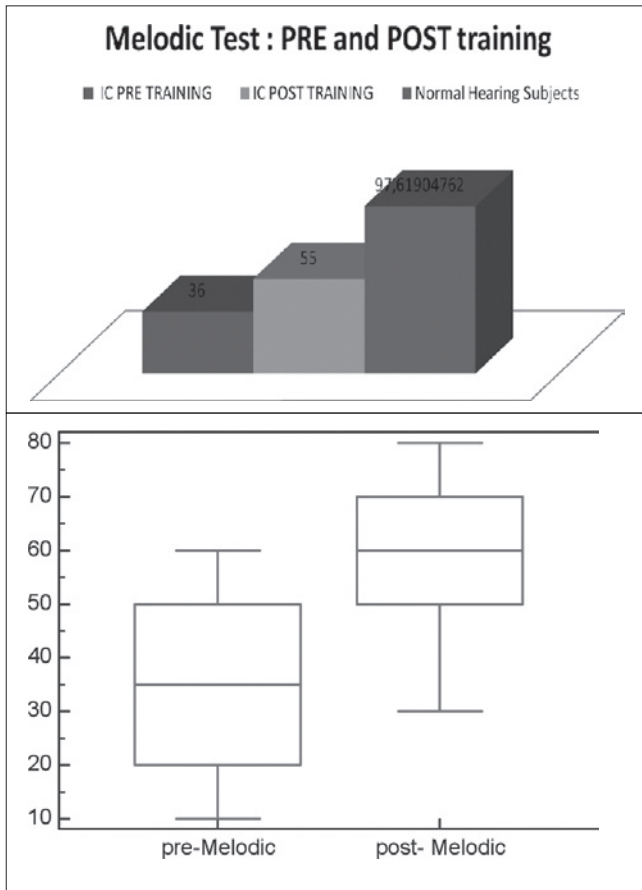


Fig. 5a-b. Music Test – Melodic version: representation of pre- and post-training score mean, in comparison with normal hearing subjects. The box-plot shows the distribution of score ($p = 0.0151$).

resolution resulting from the tonotopicity destructuring in the auditory cortices of prelingually deafened children; another is due mismatch, or rather, misalignment between the conventional frequency band allocation to the electrodes of the array (frequency-place function) and the distribution of pitch percepts generated by electrode stimulation along the array (electrode-pitch function)³²⁻³⁴.

We provided the children with a compact disc (CD) containing frequency discrimination exercises divided into increasing difficulty levels and assessed their performances before and after training.

Melody Identification Test. Comparison between normal hearing and implanted children revealed a significantly lower performance of the latter. These findings are consistent with known CI users' pitch perception problems due to:

- A limited number of intracochlear electrodes, which seem to be enough to convey speech information, but inadequate to distinguish two notes one semitone apart. Theoretically, 88 different electrodes would be required to provide a complete representation of the entire piano keyboard; currently, this is not possible because of physical limitations imposed by electrical interferences

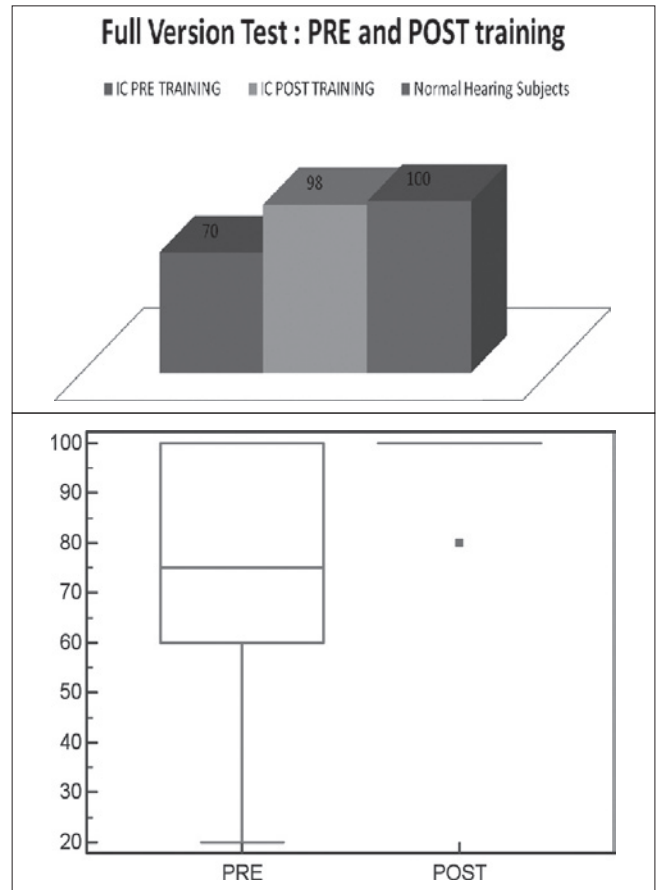


Fig. 6a-b. Music Test – Full songs version: representation of pre- and post-training score mean, in comparison with normal hearing subjects. The box-plot shows the distribution of score. ($p = 0.0071$).

among electrodes. This problem could be partly overcome by “virtual electrodes” that create intermediate pitch sensations³⁵; of course they should be made active, not all randomly, but only the virtual channels can determine pitch sensation effective and distinct from other, in order to avoid interference and confusion in listening.

- Misalignment phenomena between the conventional frequency bands located on the array and the perceived pitch³⁶. A recent study³³ showed that the mismatch correction can lead to improvement in melodic identification skills in adult CI patients.

After specific musical training, the identification abilities of CI patients became higher even if not comparable to those of normal hearing children. This is consistent with the work of Gantz et al.³⁷ where they demonstrated that musical abilities in children with CIs can improve after perception training.

Full songs Identification Test. The results suggest the same considerations made for melody identification. In this case, children performed better during the baseline assessment. This seems to be consistent with previous papers reporting best musical skills through the use of ly-

ics: in fact, in the complete songs identification test, the CI group performed quite similar to the control group. Frequency Discrimination. The strength of this study was to give the chance to perform the MPD test directly at the patients' home. From this experience, we highlight several important issues:

- objective improvement of music perception in CI children (melodic and full songs identification test);
- subjective improvement (parents referred to clinicians that their children were more comfortable listening to music than in the past);
- the possibility of self-training (which allows the child to perform the training in a comfortable environment and to correct his mistakes by himself);
- the chance to train with family and to be assisted in performing the test where needed.

Higher scores in pitch perception test positively correlated with a longer duration of musical training in implanted children. Our finding is consistent with a previous study, in which structured training was suggested to obtain positive correlation with recognition and appraisal of musical pitch discrimination by postlingually deafened cochlear implant recipients³³. After six months of training, our CI recipients showed significant improvements in pitch recognition and appraisal compared to the control group. Some mechanisms underlying the enhanced performance of pitch perception after musical training in the prelingually deafened CI children may be proposed. One explanation is the modification of disorganised tonotopy through the effect of auditory plasticity in the central auditory pathway of our subjects. The reinstatement of afferent input via cochlear implantation could consequently launch a cascade of plastic changes in the auditory system. Such reorganisation, probably coupled with essential changes in neurotransmission or neuromodulation, might lead to reduction of further deterioration in the central nervous system resulting from the interruption of electrical and nutritional input due to cochlear damages^{38,39}. This might reverse the disrupted tonotopic maps toward a relatively normal organisation⁴⁰. In normal hearing children, improved music perception via music education has been demonstrated by increased auditory evoked fields, possibly due to a greater number and/or synchronous activity of neurons⁴¹. With the intervention of musical training, it seems likely that the modified tonotopy organisation of our prelingually deafened children could be further optimised for a more precise resolution of frequency spectrum, as is indexed by a better performance of pitch perception.

Conclusions

At present, however, no one can truly know how CI users with preverbal deafness perceive the musical melody. There is no doubt that as long as we do not find an effective solution to the lack of frequency discrimination and mismatch, these patients may not appreciate the beauty of

music, even if they are able to recognise different songs. Nowadays, no codified procedure for a standardised music assessment nor specific musical training is available, especially for hearing impaired children.

In this paper, we present a completely new tool to train CI children in pitch discrimination and melody identification tasks. We found a significant difference between pre- and post-training scores in the full version test ($p = 0.0071$), melodic test ($p = 0.0151$) and frequency discrimination test (0.0001). In the light of our findings, we can conclude that it is possible to achieve improvements in frequency discrimination and song recognition following specific perceptual training in prelingually deafened CI children.

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