Reestablishing Speech Understanding through Musical Ear Training after Cochlear Implantation
A Study of the Potential Cortical Plasticity in the Brain

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Cochlear implants (CIs) provide impressive speech perception for persons with severe hearing loss, but many CI recipients fail in perceiving speech prosody and music. Successful rehabilitation depends on cortical plasticity in the brain and postoperative measures. The present study evaluates the behavioral and neurologic effects of musical ear training on CI users’ speech and music perception. The goal is to find and work out musical methods to improve CI users’ auditory capabilities and, in a longer perspective, provide an efficient strategy for improving speech understanding for both adults and children with CIs.

Key words: cochlear implants; music training; music test; pitch perception; PET scanning

Introduction

Cochlear implantation is a surgical treatment that helps deaf people to regain hearing abilities. The success of the rehabilitation, however, is highly dependent on both the brain’s ability to adjust to the electric stimulation from the implant and the postoperative efforts implemented.1 Many cochlear implant (CI) users achieve good speech understanding in quiet listening conditions. But they often fail in perceiving complex auditory information, such as music, and subtle nuances in speech, such as prosody, and therefore suffer from impaired social communication. Music and prosody perception is highly dependent on subjects’ capabilities to encode pitch information, which in CI users is poor.2 So far, no data are at hand concerning the effects of specific musical ear training, focusing on musical features, such as rhythm, pitch, timbre, and music enjoyment, in CI users, although it is recognized that musical training positively affects cognitive processing of prosody and verbal memory in normal hearing subjects.3,4

Rhythm and pitch are the two primary and distinct components of music.5 The aptitude and success of processing spectral features (pitch) is crucial for the perception of speech prosody. The acoustic correlates of prosody
are frequency, duration, intensity, and spectral complexity. The aptitude for temporal discrimination and gap detection is crucial for general speech understanding and perception of fine temporal structures. Thus it seems plausible that musical ear training could improve auditory processing for spectral (≈pitch) as well as for temporal (≈rhythm) material in CI users.

**Aim of the Study**

We aim at:

- studying the behavioral and neural effects of specific musical ear training in an interventional study on music and affective speech perception;
- finding an efficient method to improve CI users’ auditory capabilities in the spectral and temporal domain;
- improving CI users’ perception of spoken language;
- improving CI users’ ability to perceive and appreciate music; and
- investigating brain areas responsible for the analysis of complex sounds in speech and music.

**Design of the Study**

We have designed the study as a case–control crossover trial including three groups of CI recipients. The groups are matched according to age, duration of deafness, and test results. Just after the switch-on procedure, subjects are scanned using positron emission tomography (PET) and tested for speech and music perception. Subsequently the subjects receive either pitch training (Group A), rhythm training (Group B), or postponed training (Group C). Scan and test procedures are repeated after 3 and 6 months, respectively. After 3 months, groups A and B alternate training strategies. With this design we expect to be able to assess not only the differences between training and no training, but also possible differences between a rhythmic and a melodic strategy.

**Material and Methods**

**Musical Ear Training**

Participants receive basic musical ear training in three different disciplines:

1. **Playing**: To establish a sense of pitch direction and melodic contour, those who train pitch are provided with an electronic keyboard for home practicing. The musical material chosen for playing consists of well-known folk and children songs with a limited range of notes [c4 (261.6 Hz) to g4 (392 Hz)]. As part of the training routine, subjects imitate simple phrases on the keyboard as well.
2. **Singing**: Subjects are encouraged to sing. Danish tunes of their preference are used, whereby intonation and articulation is trained. Although extremely challenging for persons hearing with the help of a CI, singing performance may improve through training.
3. **Listening**: Accompanied by a booklet with printed versions of the tunes, a CD featuring Danish songs is distributed with instructions on practicing lyric comprehension and learning the melodic contours of chosen songs. Additionally the Danish ear training software, Earmaster, is installed on the subjects’ private computers, giving them an opportunity to perform specific training tasks, such as discrimination of pitch distance and major/minor mode. Timbre recognition is trained by computer presentations of different musical instruments playing short melodies.

Main outcome measures include:

Speech perception outcome as assessed by two different tests:

1. The Hagerman speech perception test, which is used widely in Scandinavia. The test presents sentences with five words like “Peter buys five red flowers.” The subject is placed in a sound-proof booth and
sound is played back at 65 dB. Scores are registered as number of correctly repeated words.

2. An emotional speech test presenting words and sentences expressing a “sad” or “happy” mood. Subjects are asked to state which of the two emotions is expressed.

Music perception is tested using four specific tests worked out for this particular purpose:

1. Perception of melody and rhythm is tested in a “same” or “different” paradigm by comparing pairs of short patterns (Fig. 1).
2. Perception of pitch is tested by a pitch-ranking test in which the subject is asked to name which one of two notes is the higher.
3. Timbre recognition is tested by tests that present melodic phrases played by different musical instruments.

**Stimuli**

The melodic and the rhythmic tests are comprised by pairs of 1-bar phrases of increasing complexity, thus avoiding floor/ceiling effects. Melodies are presented by pure tones [174.6 Hz (f3) to 523.3 Hz (c5)] produced in Audacity, recorded as MIDI-notes in Cubase 4.1 (Steinberg Media Technologies GmbH, Hamburg, Germany) and played back by the software sampler Halion 2.0 (Steinberg). Rhythm patterns have been produced similarly using the sampled sound of a cowbell for the “call” and the sound of a woodblock for the “response.”

Tests are presented in the computerized test environment MACarena, developed by Waikong Lai at the Zürich University Hospital. Preprogrammed scripts present stimuli in random order and MACarena summarizes subjects’ responses thus facilitating test result analysis.

**PET Scanning**

We use PET as a method to detect regional cerebral blood flow (rCBF) in auditory brain areas with relation to music and speech. The PET scans are co-registered with MR images for anatomic localization of possible relative changes in rCBF. Four water scans are run at each of the three sessions and either multi-talker babble (ICRA) or running speech is played back in random order through the external input of the speech processor (Fig. 2).

**Perspectives**

Providing auditory capabilities to thousands of deaf children and adults, CIs have proven to be a colossal medical and technological achievement. However, educational measures supporting patients’ adjustment to the implant are still to be elaborated and explored further. Previous studies have shown positive correlations between CI users’ perception of spoken language and their ability to perceive music. In addition, research shows that musical training of children leads to enhanced neural processing of speech prosody. We expect to find behavioral and neural effects that support this and our presumption that specific musical ear training can be a valuable aid in improving CI listeners’ perception of language and music.

This study may add to our understanding of restoring speech comprehension and music enjoyment for CI users, and can be of great value to CI patients and the society as a whole.
Moreover, the implications of our study may be of value to language and music education in general and to CI children in particular. Furthermore, the project will contribute to the mapping of the human brain, especially concerning the relationship between neural processing of music and language. From a cognitive perspective, CI provides the possibility of pursuing the plastic processes underlying everyday learning that implant users undergo, as well as the potential production of tutorial material, not only for CI users but for musical ear training on a neurobiologic basis. If successful, the musical ear training can be particularly valuable in both improving CI users’ general quality of life, and in a long-term perspective propose an efficient strategy for improving speech understanding for children with CI.

**Conflicts of Interest**

The authors declare no conflicts of interest.

**References**