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Investigating the Effects of Music-Based Training on Improving Hearing, Speech, and Language Comprehension in Cochlear Implant Users

Felicia Manole[a], Alexia Manole[a]*, Mădălin Bulzan[a], Gheorghe Szilagyi[a], Călin Tudor Hozan[a]

[a]*Faculty of Medicine and Pharmacy, University of Oradea, 410087 Oradea, Romania.*
manole.alexia03@gmail.com.

***Corresponding Author:** Alexia Manole,*
Faculty of Medicine and Pharmacy, University of Oradea, 410087 Oradea, Romania,
Email: manole.alexia03@gmail.com.

Abstract

Speech communication is the easiest way to exchange thoughts, and a systematic combination of consonants, vowels, and phonetic units is used to transmit speech information. People who use cochlear implants have difficulty understanding sound's spatiotemporal and spectral characteristics. On the other hand, the musician's better abilities compared to non-musicians in different fields have been validated by neurophysiological evidence. Since the functional overlapping and structural processing of music and speech at the cognitive and sensory level has been stated in studies, this study tries to do that. Investigating the music-based training effects on improving the language and speech comprehension in cochlear implant users. Music-based education use has attracted much attention in recent years to improve language and speech in children with normal hearing and communication disorders, including cochlear implant users. Different studies have applied methods that have emphasized one of the ascending and descending processes mentioned in the article. Studies reveal that music training can have a facilitating impact on different aspects of language and speech processing. Addressing cognitive abilities through music training along with abilities of low-level sensory seems essential to treating auditory perception. Because the long-term aim is to improve hearing-impaired communication, group playing and music in particular provide an attractive social situation and a useful tool for language development, especially the social aspects of language, such as language flexibility, turn-taking, role-playing or it's even a joke. These aspects have a significant effect on the life quality of the hearing impaired.

Keywords: Music-based training, Hearing, Speech, Cochlear implant.

Introduction

Speech communication is the easiest way to exchange thoughts, and a systematic combination of consonants, vowels, and phonetic units is used to transmit speech information (1-4). Speech understanding does not happen only with acoustic features, but it is the result of the interaction between downward linguistic projections and upward sensory signals (5, 6). Indeed, an encoded predictive framework minimizes the errors between the

predicted signal and the sensory input, which demonstrates how prior knowledge can fundamentally alter what we hear (7, 8). This view is useful in examining the potential benefits of music on language and speech abilities (1).
For the past century, language and music have been discussed as two distinct human domains (each with various neural functions), but the current view is rather different because to understand language and music, one must be able to distinguish between sounds (9, 10). Although sounds can be classified according to several spectral characteristics that are relevant in both the categories of musical and linguistic sounds, we usually perceive sounds in a complex sound context, which itself causes the formation of some kind of cognitive framework (11, 12). Regarding the sequence of time elements, they become sounds (13, 14). As a result of our previous experience with sounds, they have a strong influence on the way sounds are understood in the speech structure (1, 15). Such experiences produce internal patterns that allow us to make good predictions about future events. These predictions affect phonetic classification, semantic, syntactic, and prosody processing (1, 8, 16, 17).
The first cochlear prosthesis was implanted in 1961 by an American otologist named William House (18-20). This initial prosthesis consisted of an induction ring with five electrodes, and with its help, patients were able to distinguish basic frequencies and recognize words (21, 22). Physiological advances in the field of auditory pathways and technological advancement led to the construction and implantation of the first multi-channel cochlear implant prosthesis in 1964, and since then, the process of cochlear implantation in the fields of cochlear implant prosthesis components (23, 24). The surgical methods used, processing strategies (25), and post-implantation training (26-28) have made significant progress. The initial expectations of the cochlear implant prosthesis were small and limited to helping to improve lip reading in people with sensorineural hearing loss. - It was deep neural. Over the last 30 years, hearing with cochlear implants has advanced significantly, especially in the area of speech perception (25). Since the cochlear implant prosthesis transmits information about time-varying cues (29-31). Many cochlear implant users have no problem using the phone, understanding speech in silence, and also understanding the temporal aspects of music (i.e.: beat/rhythm, timbre/tempo, and tempo/meter). In terms of perception, they can reach the same performance as people with normal hearing (25). Nevertheless, cochlear implant users in understanding things such as speech prosody, speech in the presence of noise, emotional speech, tonal language, speaker identification, music assignments (32-34) including spectral characteristics (i.e., pitch, consonance/harmony, and tone/melody) and spectral-temporal characteristics such as resonance and enjoyment of music (25) are facing problems, because the cochlear implant prosthesis does not transmit the information related to the subtle spectral-temporal structures in the stimulus waveform, which leads to the weakness of broad spectral signals and reduced frequency resolution and maybe the main reason for these problems. Indeed, it is important to note that cochlear implant users depend on 22 electrodes (instead of 3,500 inner hair cells in normal-hearing individuals) to transmit tonotopic pitch information, which results in extensive and significant stimulation of the auditory nerve. It is electroded by HERA (33, 35, 36). In addition, factors such as limited insertion depth (lack of access to the apical regions of the cochlea) and the position of the electrodes compared to healthy neurons cause the tonotopic mismatch of the acoustic inputs with the stimulation location in the cochlea (25, 29). In addition to problems directly related to implant limitations in spectral resolution terms, CI user children suffer from hearing loss during the first months of life, possibly resulting in defects in structural connectivity and cortical reorganization (37, 38). Verbal communication usually happens in noisy and crowded environments and on the other hand, during the communication flow, an important part of the message is transmitted non-verbally (39), so the limitations and problems raised for users of Cochlear implants can have direct effects on social interactions and the quality of life of these people. Perhaps it is possible to help these people by using music-based education and music therapy. In this study, an attempt is made to study the impact of music-based education on improving the language and speech comprehension of cochlear implant users.

The Impact of Music on Language, Speech, and Hearing
The first goal of hearing rehabilitation in hearing-impaired people is the optimal use of residual hearing. This includes increasing the benefit of hearing aids and cochlear implant users from defective sound stimuli (26). In several studies, the effectiveness of hearing rehabilitation in improving speech comprehension with music in cochlear implant users has been shown (27, 29, 32).
Researchers' findings in the field of neural constructability as a key factor in hearing rehabilitation (26) and learning capacity have led researchers to be interested in the field of formal hearing training (40). The use of music-based education has attracted much attention in recent years to improve language and speech in children with normal hearing and communication disorders, including cochlear implant users (29, 32).
The acoustic features of music and speech are represented by hierarchical auditory networks. The regions of low-level (i.e. brainstem and primary auditory cortex (A1)) encode simple acoustic features such as pitch and stimulus onset, and high-level regions (non-primary auditory cortex) encode more complex stimulus features,

such as transmitting time spectral information. Research has provided evidence about specialized neural networks for processing music or speech at the auditory cortex level and beyond (41). However, there is structural and functional overlap for speech and music processing at the sensory and cognitive levels (41). In this regard, the panel put forward the opera hypothesis, which proposes the occurrence of five basic conditions in justifying the occurrence of plasticity resulting from music in speech processing networks: these items consist of (1) Overlap: Overlap of brain networks that process speech and language, (2) Accuracy: Music makes more demands than speech in these shared networks. This is especially evident during auditory scene analysis, temporal processing, and pitch processing, (3) Affection: Musical activities involving the network evoke many positive emotions, (4) Repetition: musical activities involving this network are repeated many times, (5) Attention: musical activities involving this network are related to the focused attention (42).

Music composition requires a high temporal level and spectral prediction using adopting a predictive perspective. Music-making needs very precise levels of temporal coordination (1). These findings indicate the benefit of music education at various levels of language and speech processing, which is confirmed by the various dynamics and neural structures between musicians and non-musicians (43). In the following, these differences (the effects of music on the nervous system) are mentioned at the levels of the brain stem and cerebral cortex.

The better abilities of musicians in pitch discrimination compared to non-musicians have been confirmed by neurophysiological evidence (41). In a study, Wang *et al*. showed that the encoding of the pitch of speech sounds in musicians is more accurate at the level of the brain stem under passive hearing conditions (44).

Numerous studies have stated that musicians can better timing. They achieve better gap thresholds and better time interval discrimination. These perceptual advantages also extend to speech-related abilities, to the extent that musicians are also better at distinguishing late syllables (45). In general, musicians have better performance in understanding rhythm, producing rhythm, and auditory-motor coordination in simple and complex rhythms (1).

Musicians also have a better perception of resonance from musical instruments and sound. Their brainstem responses to the resonances of different instruments have been more accurate and this advantage is also extended to vowels (46). Evidence shows that musicians have better verbal and non-verbal working memory and perform better in understanding and encoding speech in hard listening conditions so that F1 and F0 of a vowel are better distinguished and encoded in severe open phonetic conditions. They also encode speech in noise more accurately in the response of the brain stem (47) and this coding advantage extends to understanding speech in the presence of noise (48). In addition, studies conducted on elderly musicians who have been dealing with music throughout their lives have shown improvement in speech understanding of noise (48, 49) and auditory scene analysis (50). Musicians have also performed better in differentiating and identifying emotional prosody (51) and the speed of their evoked electrical response to changes in prosody is higher (52).

Speech and music training at the level of the brainstem produces changes in neural structure, and these changes are visible in FFR and ABR responses of speech (41, 46). However, the feedback of cortical efferent pathways in active conditions (in the presence of attention) should be taken into account (53). The improvement of the FFR response (53) is followed by a shorter latency and larger amplitude in the P1-N1-P2-N2 response set. This response set comes from the primary auditory cortex A1 and the non-primary auditory cortex (41). Music training also facilitates cortical responses to speech stimuli in the long term, which may be due to the effects of cognitive processing (46). Because music therapy is thought to enhance processing Hearing goes down and induces the constructability of the brain at different levels, even in the more superficial layers (1) In general, the similarities between language and music, in terms of neurological and cognitive function, are associated with superior language skills due to music, which is the context It has provided a significant benefit for the apply of music in language and speech disorders.

Music-Based Education in Cochlear Implant Users

In this section, we investigate the effects of music-based education on various aspects of understanding psychoacoustic phenomena and understanding language, speech, and hearing in cochlear implant users.

Zero pitch, which corresponds to frequency, the oscillation cycle number per second, is a vital cue for both language and music. In speech, pitch is related to the fundamental frequency concept, that is, the frequency of vibration of the vocal cords. F0 as well as vocal harmonics F2 and F1 etc. are essential cues for identifying tones, vowels, gender of speaker, and information conveyed using prosody. In tonal languages, pitch changes play a role in grammatical categories and distinguishing words. In music, pitch distinguishes a high note from a low note, and is thus the basis for creating a melody. More importantly, small pitch changes are very important in music, but not in speech (1).

Pitch discrimination ability in hearing-impaired people improved after music therapy. Studies on CT user children have reported differences in F0 discrimination between children in a family environment with and without music (54). Children who live in a musical environment show a larger amplitude and a shorter latency following F0 changes in the evoked potential P3a, which indicates a change in the dynamics of their brain function (55). In an intervention study after two sessions of weekly music training at school, a similar improvement was reported, although it was not related to improved speech understanding in noise (56).

The ability to distinguish and estimate sound delay is very important in speech for recognizing consonants. This makes a difference between voiced consonant pairs. For example, the difference between B and P is the relative timing between the start of the explosion and the start of the sound, which is called the start-time relationship. In music, the distinction of lateness is related to the recognition of various rhythmic patterns as well as the different interpretations of the same melodic sound (1). CI user children suffer from deficits in late discrimination abilities that lead to phonological comprehension and phonological awareness problems (1). A correlational study has shown better phonological discrimination abilities in CI children following 1.5 to 4 years of music training (57). Therefore, music education can be a valuable resource for rehabilitation. In research, Yoon Lu and colleagues studied the effect of teaching the pitch sequence format (melodic contour) on speech understanding in noise, consonant discrimination, and prosodic understanding in cochlear implant users. In this review, tasks were designed and presented based on two mechanisms (distance and delay). The obtained results showed that people in both groups benefited from the melodic contour training in understanding the evidence of speech dynamics (formant transition) in silence, but its effectiveness was less in unfavorable hearing environments (40).

Both music and speech are determined by a rhythm hierarchy. Short units such as notes and phonemes are embedded in longer units such as melodic or word phrases. The frequency distribution of items in each level is not random and follows a regular and repeatable pattern among languages. In speech, phonemes occur around 15-40 Hz (15-40 times per second), words around 1-2 Hz, and syllables around 4-8 Hz (58). These rhythms allow the brain to calculate predictions and expectations about when the next sound will come. In addition, the extraction of temporal structure is also involved in interpersonal coordination and group games, where fine temporal coordination, good temporal predictions, and subtle differences in time jumps between players are required (1). There is a lot of evidence in different clinical populations in rhythmic music training favor (1). Short rhythmic training can strengthen the ability to use temporal structure in hearing-impaired people. A study reveals that appropriate rhythmic introductions with the standard target sentence structure can assist in better repeat words, phonemes, and sentences in CI user children (59). Studies have also shown that 30 minutes of rhythmic education leads to better recognition of rhythmic order. The word becomes CI during verbal exchanges and more accurate turn-taking (60) in children aged 5-10.

Reverberation is a more subtle sound property that is related to high-level features such as temporal and harmonic correlations. Two sounds can have the same pitch and delay but various resonances. For example, the only difference between a note on a piano and the same note on a clarinet is their resonance. In speech and music, resonance is important for classification. Despite the differences in resonance, the musician must distinguish the chords or notes, even if they are played by various musical instruments. Similarly, the listener must recognize phonemes even if different speakers pronounce them with various sounds (1).

Music-based training in CI user children is also effective in improving resonance perception. In the perceptual processing section, the following points can be mentioned: verbal (61) and non-verbal (6) working memory has been damaged in CT user children, and music training has shown improvement of working memory in hearing-impaired people (1). In CI children who sing at home, speech understanding in noise improves and hearing-impaired children who receive music education have better auditory scene analysis (57). Also, in various studies of CI children with music-based training understanding music has shown a better emotional performance (1, 40). Cheng *et al*. investigated the effects of music-based education on speech and music comprehension in children with cochlear implants and the results showed a significant improvement (32). Fuller *et al*. investigated and compared two approaches to music-based training in cochlear implant users and their effects on speech and music comprehension. The musical exercises and social interactions of the two groups were different from each other. Each approach emphasized one of the downward and upward processes. The results showed that a combination of both approaches can provide more benefits for cochlear implant users (29).

Conclusion

Studies reveal that music education can have a facilitating impact on different aspects of language and speech processing. It seems necessary to address cognitive abilities through music education along with abilities of low-level sensory to treat hearing comprehension. Because the long-term aim is to improve hearing-impaired communication, group playing and music in particular provide an attractive social situation and a useful tool for language development, especially the social aspects of language, such as language flexibility, turn-taking, role-playing or it's even a joke. These aspects have a significant effect on the life quality of the hearing impaired.

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