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REVIEW

Music perception in adult patients with cochlear implant

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ABSTRACT

The music perception and more specifically the appreciation of music is a common aspiration among cochlear implant (CI) adult users. In the majority of patients, only rhythm perception is reported to be similar to that of listeners with normal hearing. Melody and timbre recognition requires more spectral and temporal fine structure cues that are not well supported by the CI representation: for these reasons music appreciation represents actually a true challenge for adult CI users. This review will take into account the available recent literature about the perception of rhythm, melody and timbre in adult CI users. Furthermore, some hints about rehabilitation of CI users to the music perception and appreciation will be presented.

KEYWORDS

Music; deafness; cochlear implant

Introduction

Nowadays, cochlear implantation is a safe procedure even in patients that in past would have been poor candidates such as old patients [1], patients with auditory deprivation [2] or with severe malformations of the inner ear [3]. While good speech understanding is achieved by most cochlear implant (CI) users [4–6], demand is rising for new aspirations such as music perception and appraisal [7–9]. After speech perception, the appreciation of music is the next most common aspiration among CI users, especially for those patients that used to appreciate music before the hearing loss or with hearing aids. According to Ford [10], 'the capacity to perceive and assimilate music resides in the brain, and although hearing loss may impose certain limitations upon the extent to which musical potential is realized, it does not negate the presence of innate musicality'. Nevertheless, it should be considered that among the three cardinal elements of music, i.e. rhythm, melody and timbre, in most implanted deaf patients only rhythm perception is reported to be similar to that of listeners with normal hearing. In fact, melody and timbre recognition requires considerably more spectral and temporal fine structure cues that are not well supported by the CI representation [11], even with technically sophisticated sound processors. Different problems arise when taking into consideration the three main aspects of music; this review will take into account the recent literature available about the perception of rhythm, melody and timbre as well as the impact of rehabilitation with music in adult CI users.

Rhythm

Temporal and rhythmic discrimination abilities of patients with CI are generally similar to those of normal hearing subjects [12–14]. The sense of rhythm, in music, is related to the ability to use gross temporal cues in the onset of sounds. It should be noted that these cues are very different from the higher-frequency components of the acoustic signal that provide pitch information subjects [14]. CI users perform similarly to normal hearing people also when asked to identify if a rhythmic pattern is isochronous or not [15], reflecting a near-normal capacity of correct temporal processing. However, rhythm information in complex music is provided by different instruments, and the pattern perceived by a CI user may result in overlapped and indistinguishable. In relation to these aspects, unsurprisingly, it has been reported that CI users prefer a simpler and rhythmic music [16].

Pitch

Perceiving an adequate pitch is extremely difficult for a CI user, for a series of issues. First of all, most of the patients with CI lack low frequencies' stimulation:

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some authors report that this lack is caused by the incapacity of the electrode to reach and stimulate the apical regions of the cochlea [17–18] for surgical reasons. However, recent data suggest that even if the insertion of the electrode is deeper, no benefit is achieved in terms of low-frequency perception [19–20]. Moreover, pitch information is conveyed by spectral cues (which refer the cochlea spatial organization) and temporal cues; both information is nearly totally disrupted in CI users, especially temporal cues are saturated above 300 Hz (although this value can vary between patients). Similarly, spectral cues (space-pitch cues) are impaired because of imprecise stimulation of the spiral ganglion neurons by CI electrodes, mainly concerning neurons for lower frequencies [21]. Consequently, the CI users report that the sound is generally compressed, and its dynamic range is reduced. As a result, polyphonic pitches are often perceived as fused, especially when their frequencies are relatively near [22], and therefore patients with CI tend to prefer simple melodies, like country or pop music; also, patients tend to define more pleasant music that underwent a sound processing that reduces the number of harmonics played by the instrument [23].

Lack of precise frequency identification also causes incapacity in CI users to understand sound consonance, which is generated in normal hearing people by simple frequency ratios between sound: this precision is lost in the CI stimulation [24]. In conclusion, looking at the more complex aspects of music related to pitch perception, which are melodic motion and contour [25] and emotional information [26], they are extremely hard to perceive for CI users, although melodic contour perception can improve with music training [27]. In order to improve pitch detection by CI users, different strategies are being developed: some authors suggest the importance of hearing preservation during cochlear implantation surgery in patients with preserved lower frequencies, to give the possibility of an electroacoustic stimulation [28]; other studies focus on alternative electrode stimulation patterns in order to improve pitch perception, especially in polyphonic settings [29].

Timbre

The term musical timbre (also called 'tone colour') refers to the specific different features that enable the listener to differentiate the same tone when played by different instruments. These differences lie both in the temporal envelope of sound, and in the composition of the frequency spectrum, in terms of contribution of harmonics. Harmonics are precise integer multiples of the frequency that defines the pitch of the sound, named fundamental frequency.

In CI users, sound is split in several frequency bands in order to split the signal into different electrode channels. Each electrode electrically stimulates a wide region of neural fibres, thus comprising a series of contiguous frequencies much broader than one of the normal hearing subjects: consequently, place-coding is largely impaired.

This results in an alteration of the precise intervals between harmonics. CI users rely more on temporal fluctuations in the envelope of the electrical current to identify the fundamental frequency of sound [24], but these cues are effective only for fundamental frequencies under 300 Hz [30]. Enhancing place-coding strategies, especially for higher frequencies could result in better timbre perception in patients with CI [31].

The limitation in CI encoding sound information results in an altered timbre perception by users and a consequent worse performance in timbre discrimination tasks [32]; although, since temporal information is quite accurately preserved, CI users can use specific temporal cues to discriminate between instrument category (percussion, wood, brass, string), due to the difference in the temporal envelope of sound.

Rehabilitation

In contrast to speech, the range of fundamental frequencies (F0) and loudness levels for music is significantly greater. Accurate perception of the F0 itself is not imperative to speech recognition for non-tonal languages such as Western languages, while the F0s of individual notes is necessary for melodic recognition.

A profound deafness compromises the ability to discriminate music interval, tone sequences with ascending or descending notes, or simple melodic structures: this can be observed also when the tunes are familiar and are played as a sequence of isolated notes without accompaniment or harmony.

Consonance and dissonance are fundamental concepts of musical harmony: even if some cultural and historical differences exist, the pitch relationships between musical sounds can be perceived either as harmonically stable (in case of consonant chords) or as 'unstable' (in case of dissonant chords), generating a musical tension that requires a harmonic resolution.

CI users are often unable to discriminate simultaneous sounds with a different pitch, showing confusion

between acoustic stimuli consisting in a single sound and in chords [33] and also struggle to distinguish between consonant and dissonant chords [34].

This results in an impaired appraisal of polyphonic melodies, which are common in western music. As a consequence, CI users seem to prefer simple monophonic music rather than more complex and polyphonic melodies. For this reason, they generally like musical genres with a relatively simple structure, such as pop or country music, and they do not appreciate more complex genres, such as classical music [35–37]. Music appraisal is related to many individual variables, such as the duration of hearing loss, age, musical training, listening experience and pre-implant formal music training [8,38]. Better music perception and appraisal in CI listeners have been observed after long-time music rehabilitation and training [11,25,39]. Also, there are significant differences between different types con CI users: pre-verbal and long-time deprived patients experience music as more enjoyable than post-lingual patients, maybe due to the lack of musical memory in the former group of patients [39–40].

The development of new rehabilitation instruments can have a great additional value in this field: for example, Oliver et al. [41] introduced a computer-based music rehabilitation programmes called the Interactive Music Awareness Programme (IMAP). Using this application, it is possible to create, manipulate and play music with different combinations of instruments, rhythms and pitch ranges. Moreover, remixing or re-engineering music in order to reduce complexity in terms of the number of instruments and harmonics may result in a more enjoyable experience for CI users [42–43].

A satisfactory level of musical perception can have positive effects on quality of life for CI patients as it is for NH subjects [44].

Questionnaire data analysis of thirty CI adult patients has confirmed that an improvement in music experiences is closely linked with an improvement in QoL, while avoidance of music experience may have negative implications [44]. The patients were asked questions on music and quality of life, and they associated the role of music in life with positive emotions, quiet and social involvement. However, they also revealed negative feelings due to their difficulties in music perception and consequently ability to appreciate music.

The limitations of current CI technology, in fact, may affect the pleasantness of music perception and music activities, and this can have negative implications in the social and psychological sphere [45].

However, there is evidence that an appropriate auditory training may help CI patients to improve their music perception abilities [46–47].

Gfeller et al. [48] evaluated CI patients' perspectives on music in everyday life in order to obtain information for new research ideas. Forty CI users were asked to answer questionnaires about two different music experiences: purposeful listening and background music in conjunction with the spoken conversation. The results of the study confirmed CI users' problems with the enjoyment and the comprehension of music and the negative impact of background music on speech perception.

It was found that CI users have access to inadequate resources for improving their music experiences and skills.

The psychosocial functions of music listening were particularly emphasized, and almost all patients expressed a desire to have specific rehabilitation training programmes, especially with practical content.

In any case, the requirements for training were found to be different depending on the characteristics of the patient, underlining the need for a clinical variety of options that take account of subjective demand and background musical skills [48].

Conclusion

This review shows that music appreciation represents a true challenge for adult CI users, since only rhythm perception is reported to be similar to that of normal-hearing subjects.

On the contrary, most implanted deaf patients appear unable to reach a degree of pitch, harmony and timbre discrimination suitable for the appraisal of complex polyphonic music. However, a prolonged music rehabilitation and training has been reported to be potentially beneficial to improve music appraisal performance.

Novel perspectives in music rehabilitation are offered by technological progress concerning CI fitting strategies and sound processors, as well as the availability of novel digital applications such as music manipulating software. In addition, the positive effect of music perception and music-related rehabilitation programmes are non-negligible even in CI users.

Even if today some limits related to the electric stimulation provided *via* CI seem to be difficult to overcome, a great amount of resources are invested in order to provide a better music perception in CI users. Most probably, the availability of new arrays (in terms of materials and distribution of the

electrodes in it) and the development of new stimulation strategies will be extremely helpful, as they were for the speech understanding at the dawn of the cochlear implantation.

In conclusion, we also must face the fact that pop and country music as well as percussion instruments will most likely be the first to be appreciated by our patients.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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