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Music enjoyment with cochlear implantation

Charlotte Prevoteau [a,1], Stephanie Y. Chen [b,1], Anil K. Lalwani [b,c,*]

[a] University Hospital of Rouen, Department of Otolaryngology, Head & Neck Surgery, Rouen, France
[b] Columbia University Cochlear Implant Center Department of Otolaryngology-Head and Neck Surgery, New York, NY, United States
[c] Division of Otology, Neurotology and Skull Base Surgery, Department of Otolaryngology, Head & Neck Surgery, Columbia University College of Physicians & Surgeons, New York, NY, United States

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ABSTRACT

Since the advent of cochlear implant (CI) surgery in the 1960s, there have been remarkable technological and surgical advances enabling excellent speech perception in quiet with many CI users able to use the telephone. However, many CI users struggle with music perception, particularly with the pitch-based and melodic elements of music. Yet remarkably, despite poor music perception, many CI users enjoy listening to music based on self-report questionnaires, and prospective studies have suggested a disassociation between music perception and enjoyment. Music enjoyment is arguably a more functional measure of one's listening experience, and thus enhancing one's listening experience is a worthy goal. Recent studies have shown that re-engineering music to reduce its complexity may enhance enjoyment in CI users and also delineate differences in musical preferences from normal hearing listeners.

1. Historical background

During the late eighteenth and nineteenth centuries, the first electric stimulations to enable hearing were developed [1,2]. These early techniques utilized gross extra-auricular electrical stimulation by a battery connected to probes placed within the external auditory canals bilaterally, inducing a "jolt," warmth, and the sensation of "crackling," "buzzing," and "ringing". By the early twentieth century, researchers began experimenting with auditory nerve stimulation by an electrode. In 1957, In Paris, the first electrode was implanted intra-auricularly by André Djourno and Charles Eyriès, introduced in contact to the auditory nerve in humans, to electrically stimulate [3].

The first true cochlear implant (CI), in which the device was introduced through the cochlea to stimulate the auditory nerve, was implanted in 1961 by the American otologist William House in collaboration with neurosurgeon John Doyle [2,4]. This first device involved the implantation of a bare induction coil with five electrodes, and enabled patients to discriminate basic frequencies and identify words in closed sets. This development inspired a wealth of physiological research to understand pathways of hearing and optimize technology, which led to the implantation of the first multichannel cochlear implant in 1964. Since then, there have been continued advances in CI technology, including the development of a percutaneous button to contain the induction coil of the CI, miniaturization of electronics components, development of new surgical plastics, and improvements in surgical technique. In addition, there have been many advances in CI hardware. For example, recently developed processing strategies including HiRes 120, Fine Structure Processing (FSP), and high-definition continuous interleaved sampling (HDCIS), enable enhanced temporal resolution and pitch differentiation (First

* Corresponding author at: Division of Otology, Neurotology, and Skull Base Surgery, Department of Otolaryngology, Head & Neck Surgery, Columbia University College of Physicians and Surgeons, 180 Fort Washington Avenue, Harkness Pavilion HP818, New York, NY 10032, United States.
E-mail address: anil.lalwani@columbia.edu (A.K. Lalwani).
[1] Co-first authors (contributed equally to work).

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et al., 2009, Otol Neurotol; Looi et al., 2011, International Journal of Audiology; Roy et al. 2015, Ear and Hearing).

2. Speech perception

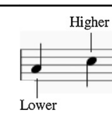
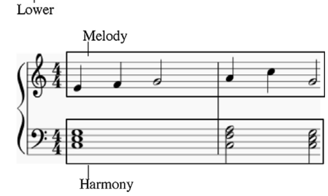
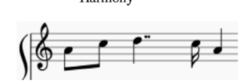
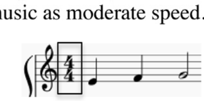
While there were low expectations for the performance of the first CI, which was created as an aid for lip reading in patients with profound sensorineural hearing loss, CI hearing outcomes have improved dramatically over the last thirty years, particularly with regards to speech perception. In 1995, the National Institute of Health issued a consensus statement reporting hearing outcomes of approximately 12,000 implanted patients, with most individuals achieving scores above 80% on high-context sentence tests without visual cues [5]. Notably, a study by Gifford et al. [1] demonstrated that many patients achieve at least 90% on standardized tests of sentence intelligibility in quiet, with 28% achieving 100% on the HINT (Hearing in Noise Test) sentences test. This ceiling effect made it difficult to adequately assess hearing outcomes in CI users. Thus, more difficult speech recognition tests including the Consonant Nucleus Consonant (CNC), AzBio Sentences, Bamford-Kowal-Bench Sentences in Noise (BKB-SIN), were identified as better measures for speech perception performance and are currently components of the Minimum Speech Testing Battery. Using these more rigorous measures for CI users, many studies have reported significant improvements in speech perception following implantation [6–8]. In addition, many CI recipients are able to use the telephone [9]. Of note, speech perception in noise remains difficult for most CI recipients [10–12], likely due to the increased complexity of the acoustic waveform, inferior quality output of speaker telephones, and the poor spectral detail of current CI devices [13].

3. Music perception

Despite remarkable advances in speech perception in quiet, the perception of music remains difficult for most CI recipients compared to normal hearing listeners [14,15]. The authors have chosen to focus this review on music perception and enjoyment in post-lingually deafened CI adults. Before discussing studies of music perception, it is important to first define fundamental elements of music.

A useful method to classify musical features is to divide them into *spectral*, *temporal*, and *combined spectral-temporal*

Table 1
Classification and definitions of musical elements.

Category	Musical element	Definition	Example
Spectral	Pitch	Quality that allows a listener to classify a musical sound as relatively high or low; often quantified as a frequency.	
	Melody	Succession of several pitches in sequence to form a musical phrase.	
	Harmony	Multiples pitches played simultaneously.	
Temporal	Rhythm	Composed of temporal patterns of musical sounds.	
	Tempo	Rate or speed of a musical piece, in beats per minute.	 In this example, the tempo is set at 80 quarter note beats per minute. Allegretto is another tempo marking that describes the music as moderate speed.
	Meter	Recurring pattern of accents, with stressed and unstressed beats that divide each bar. Often classified by the number of beats per measure, or the time signature.	 In this example, the 4/4 time signature demonstrates that each bar contains 4 quarter-note beats.
Spectral-temporal	Timbre	Sound characteristic that enables a listener to distinguish one instrument from another, even when played at the same pitch and loudness.