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Research Paper

Temporal and spectral contributions to musical instrument identification and discrimination among cochlear implant users

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Abstract *Objective:* To investigate the contributions of envelope and fine-structure to the perception of timbre by cochlear implant (CI) users as compared to normal hearing (NH) listeners.
Methods: This was a prospective cohort comparison study. Normal hearing and cochlear implant patients were tested. Three experiments were performed in sound field using musical notes altered to affect the characteristic pitch of an instrument and the acoustic envelope. Experiment 1 assessed the ability to identify the instrument playing each note, while experiments 2 and 3 assessed the ability to discriminate the different stimuli.
Results: Normal hearing subjects performed better than CI subjects in all instrument identification tasks, reaching statistical significance for 4 of 5 stimulus conditions. Within the CI population, acoustic envelope modifications did not significantly affect instrument identification or discrimination. With envelope and pitch cues removed, fine structure discrimination performance was similar between normal hearing and CI users for the majority of conditions, but some specific instrument comparisons were significantly more challenging for CI users.
Conclusions: Cochlear implant users perform significantly worse than normal hearing listeners on tasks of instrument identification. However, cochlear implant listeners can discriminate

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differences in envelope and some fine structure components of musical instrument sounds as well as normal hearing listeners. The results indicated that certain fine structure cues are important for cochlear implant users to make discrimination judgments, and therefore may affect interpretation toward associating with a specific instrument for identification.

Introduction

Cochlear implant processors are predominantly designed to transmit cues relevant to speech. With current processor technology many users attain scores on speech recognition tests close to those of their normal hearing counterparts, particularly in quiet. However, despite advancements in processing technology, music perception and enjoyment remain challenging and, in many cases, the perceived quality of music degrades post-implantation from prior-to-deafness.[1] Music and speech share some acoustic similarities, but music appreciation involves perception of additional acoustic cues that may not be perceived accurately, or at all, by the cochlear implant user.

Fundamental elements of music include rhythm, melody and timbre. Rhythm is the regular recurrence of a stimulus over time. In music, it represents the temporal pattern, or the tempo, of a song and is often represented as beats per minute.[2,3] Rhythm is the element of music that is most accurately conveyed in cochlear implant processors,[4] to the extent that cochlear implant users can discriminate rhythmic patterns as well as normal hearing listeners.[1,3,5–7]

The ability to recognize rhythmic cues is important to recognizing melody; however, melody recognition also requires accurate pitch perception. The organization of varying pitches within a distinct rhythmic pattern creates melodies[3,8] and requires the listener to recognize the direction and magnitude of pitch changes.[2] Pitch perception and/or pitch pattern discrimination are challenging tasks for cochlear implant users[2–5,9,10] resulting in significantly poorer performance than normal hearing listeners on tests of melody recognition.[3,5]

The most complicated component underlying music perception is timbre. Timbre perception is the ability to distinguish two sounds of the same pitch, duration and loudness played by two different instruments.[11] Timbre is multidimensional and characterized by the envelope of the sound as well as the fine-structure of the frequency spectrum.[1,3] The physical structure of the instrument (e.g., big/small, straight/convoluted, brass/wood/string) and mode of playing (e.g., blowing/plucking/striking/bowing) define the envelope of the sound, as well as the spectral distribution of the harmonics and the relative relationship to the fundamental frequency.[12,13]

The envelope of a musical note can be described by the rise time (i.e., attack) and release time, as well as the sustained portion (i.e., duration);[14] the former two shaping the envelope and the latter representing the fine structure and harmonics (Fig. 1). Timbre perception requires the ability to detect subtle changes in the envelope and fine structure. Cochlear implants emphasize the transmission of speech cues, which is heavily dependent on the envelope of sound,[15] thereby providing less emphasis on the fine structure cues pertinent to music perception. Studies of instrument identification have revealed that timbre perception marks the greatest distinction between normal hearing and hearing with cochlear implants. That is, while instrument identification is a very challenging task for cochlear implant users, it is uniquely an easy task for normal hearing listeners.[16] Cochlear implant users can correctly identify instruments playing notes approximately 45% of the time while normal hearing listeners usually identify above 90%.[5,6,16]

It remains unclear why timbre is not satisfactorily perceived by cochlear implant users, and whether the cause of this arises from: 1) poor processing by the external device; 2) poor transmission of processed information across the electrode-nerve interface; 3) poor perception (i.e., interpretation) by the acoustically-deprived central auditory system; or a combination of these. The purpose of this study was to investigate perception of timbre components by cochlear implant users as compared to normal hearing listeners. Specifically, this study investigated whether envelope and fine-structure cues important for instrument identification are perceived by cochlear implant users, and if so, whether the cues are perceived similar to normal hearing listeners.

Materials and methods

Experiments were performed to interrogate different aspects of timbre perception. Experiment 1 investigated whether CI users can identify an instrument (i.e., different timbre cues) as well as subjects with normal hearing. Experiments 2 and 3 investigated whether the appropriate cues are heard by the CI user independent of whether they are correctly associated with a specific musical instrument. These experiments were designed to determine whether acoustic cues associated with timbre perception are interpreted by the auditory system, or are underrepresented by the implant itself, either through processing of the acoustic signal or an inability to transmit in high enough fidelity to the auditory nerve.[17]

Experiment 1: instrument identification envelope cues

Ten adult cochlear implant users, ages 21–81 years (avg 58, SD 19), and 8 normal hearing controls, ages 30–63 years