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Short Communication

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Binaural Sound Processing in Noise and Reverberation for Listeners with Cochlear Implants

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There have been many studies investigating binaural processing in listeners with cochlear implants (CIs). Binaural sound processing refers to the ability to process information through both ears, which will help improve the sensitivity to sounds, the ability to localize sounds, and understanding speech in noise [1]. Cochlear implant, an electronic device, bypasses the damaged inner hair cells to directly stimulate the auditory nerve to restore hearing for listeners with severe to profound sensorineural hearing loss (SNHL). Studies of CI users demonstrate that two implants provide more benefit than one in terms of speech perception in quiet and noise and sound localization [2,3]. However, even with two implants, CI users still have difficulty understanding speech and localizing sounds, especially in noisy and reverberant environments [4-6].

Studies of listeners with bilateral cochlear implants (BCIs) have found poorer than normal localization performance in noise, in reverberation, and in noise plus reverberation conditions [5,6], with decreased localization accuracy at a higher Signal to noise ratio and a shorter reverberation time compared to listeners with normal hearing (NH). Listeners with BCIs also demonstrated poorer speech understanding ability than listeners with NH in noise [4]. Regarding the reverberation effect, it was found that speech perception performance decreased as reverberation time increased and the performance started to be affected at 0.3-0.7 s reverberation time for listeners with unilateral cochlear implant (UCI) [7]. The adverse combined effect of noise and reverberation was found for listeners with UCI [8]. No study has systematically investigated the reverberation effect and the combined effects of noise plus reverberation on speech perception for BCI users.

There are two main reasons causing decreased binaural benefit for listeners with CIs. One is that the binaural cues including interaural time difference (ITD) and interaural level difference (ILD), are not fully preserved due to limitations of software design (e.g, signal processing strategies) and compression circuits [9]. The other reason is that the noise reduction and reverberation control algorithms in CI device are not fully developed to prevent the adverse effects of noise and reverberation on sound processing.

ITD is the time difference of a sound travels to left and right ears. ILD is the sound level difference between two ears due to the head shadow effect. The central auditory system has the ability to process ITD and ILD to help determine the location of the sound source and spatially separate the speech from the noise to improve speech perception in noise [10]. However, these two binaural cues that are important for sound localization and speech perception, will be negatively impacted by noise and reverberation that typically exist in the daily life environments. Noise and reflected sounds will act like maskers or competing sounds to reduce the sound level, and they will affect the ILD depending on the direction and the distance difference of the maskers in relation to the left and the right ears; whereas the reflected sounds, depending on the arriving time to the ears, will interact with the original sound and then affect the timing cues. Therefore, noise and reverberation will affect binaural processing and decrease binaural benefit even for listeners with normal hearing.

CI has been proven a great rehabilitation device for listeners with severe to profound SNHL [2]. Although current signal processing strategies try to preserve the temporal fine structure of the signals and increase the number of channels, the real activated channel numbers are limited or not stimulated simultaneously considering the sound information obtained in each channel or to avoid channel interaction [11]. For example, there are eight to twelve channels activated out of 22 available channels in ACE strategy of cochlear corporation devices; channel sequential (HiRes-S) instead of paired (HiRes-P) stimulation is used for some patients due to channel interaction for advanced bionics devices. Limited channel stimulation with limited electrodes placed through the cochlea cause unfaithful representation of the frequency organization along the auditory nerve, therefore it cannot fully represent the physical characteristics of the signals. In addition, to avoid peak clipping causing distortion, the automatic gain control set up in the processor will start to compress the signal once the level reaches the knee point, which will affect the level cues. Furthermore, the noise reduction algorithm in the processor will affect the sound level cues and reduce the spatial separation between noise and speech. All the above effects on the time and level cues will affect the binaural processing and decrease the binaural benefit. It was found that compared to ITD, ILD is the dominant cue for sound localization for listeners with BCIs [12]. The spectral and temporal cues contribute to phoneme recognition in quiet and noise but with limitations for listeners with CIs [13].

As technology improves, noise reduction algorithms advance in cochlear implant to help reduce the adverse effect of noise. For instance, the nucleus 6 processor of cochlear corporation has smartIQ, an automatic program, to detect different environments, help reduce background noise, wind noise, etc. Also, directional microphone helps increase signal to noise ratio and improve speech perception in noise. However, no effective reverberation algorithm has been developed. In addition, everyday environments have different combinations of noise and reverberation, which brings more challenge to CI users.

It is important to obtain information about various combined effects of noise and reverberation on speech perception and localization performance for listeners with CIs to provide concrete information for a better CI design, and help audiologist develop a better rehabilitation plan (e.g., a training program) to achieve better binaural benefit. More training in different environments may help improve speech perception and sound localization for listeners with CIs [6,14]. In addition, a better design of noise reduction and reverberation control algorithms and an improved speech processing strategy to preserve binaural cues will help improve hearing in noise and reverberation and hence achieve a better quality of life for listeners with CIs.

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