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Research Paper

Changing stimulation patterns can change the broadness of contralateral masking functions for bilateral cochlear implant users

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CI
Cochlear implant
ILD
Interaural level difference
ITD
Interaural time difference
MOC
Medial olivocochlear
NH
Normal hearing
OAE
Otoacoustic emission
OHC
Outer hair cell
SNHL
Sensorineural hearing loss

ABSTRACT

Past studies have found that contralateral masking functions are sharper than ipsilateral masking functions for cochlear implant (CI) users. This could suggest that contralateral masking effects are only sensitive to the peak of the masker stimulation for this population. To determine if that is the case, this study investigated whether using broader stimulation patterns affects the broadness of the contralateral masking function. Contralateral masking functions were measured for six bilateral CI users using both a broad and narrow masker. Findings from this study revealed that the broad masker resulted in a broader contralateral masking function. This would suggest that stimulation outside of the peak of the masker affects contralateral masking functions for CI users.

1. Introduction

Auditory masking reflects the increase in the detection threshold of a probe signal in the presence of a masking signal. Masking can occur both within ear (ipsilateral masking) and across ears (contralateral masking). While ipsilateral masking for normal hearing (NH) listeners is thought to largely reflect peripheral mechanisms such as suppression of the basilar membrane mechanics (Plack and Oxenham, 1998; Wegel and Lane, 1924), contralateral masking is thought to reflect the activation of the contralateral efferent medial olivocochlear (MOC) pathway (Puria et al., 1996; Warren and Liberman, 1989; Zwislocki, 1971). The contralateral efferent MOC pathway directly innervates the outer hair cells (OHC) in the cochlea and, when activated, suppresses the OHC activity. This in turn reduces inner hair cell activation in the contralateral (probe) ear, thus elevating thresholds at the cochlea (Collet et al., 1994; Liberman and Brown, 1986; Smith and Keil, 2015; Warr and Guinan, 1979).

However, contralateral masking has also been found with cochlear implant (CI) users (Aronoff et al., 2015; James et al., 2001; Lin et al., 2013; van Hoesel and Clark, 1997), where the MOC pathway is unlikely to affect perception, given the direct stimulation of the auditory nerve by the cochlear implant. This suggests

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that an interaction between the bilateral signals may be taking place within the central auditory system in this population. There is evidence that some effects associated with contralateral masking are different in the two populations, consistent with different underlying mechanisms. For example, unlike with NH listeners (Dirks and Malmquist, 1965; Hughes, 1940; Ingham, 1957; Mills et al., 1996; Zwislocki, 1971; Zwislocki et al., 1968), there is no change in masked thresholds with changes to the masker intensity and onset delay for CI users (Lin et al., 2013). Similarly, while the magnitude of contralateral masking is dramatically smaller than that of ipsilateral masking, for NH listeners (Mills et al., 1996; Zwislocki et al., 1968), the magnitude of contralateral and ipsilateral masking can be similar in CI users (Aronoff et al., 2015).

There are also some similarities between CI users' and NH listeners' contralateral masking functions. One such characteristic is that contralateral masking functions are sharper than ipsilateral masking functions (Aronoff et al., 2015; Mills et al., 1996). The underlying mechanism for this sharpening is unclear. It may indicate that the contralateral masking effect reflects only the influence of the peak of the masker. This is particularly important for CI users where techniques are being developed that manipulate the spread of the electrical field using multi-electrode stimulation (Berenstein et al., 2008; Bierer and Middlebrooks, 2002; Jolly et al., 1996; Landsberger et al., 2012; Landsberger and Srinivasan, 2009; Spelman et al., 1995; Srinivasan et al., 2010; Wu and Luo, 2014). If stimulation away from the peak affects contralateral masking patterns, this could suggest that multi-electrode stimulation techniques could also affect how signals interact within the central auditory system. The goal of this study is to determine whether the peak of the masker alone affects masking functions for CI users. To do that, contralateral masking functions were measured utilizing maskers that varied in broadness.

2. Methods

2.1. Subjects

Six bilaterally implanted subjects participated in this study. All participants had Advanced Bionics CII or HiRes 90k implants. All subjects were experienced bilateral CI users, ranging from 2 to 14 years of bilateral CI experience. Further subject details are provided in Table 1.

2.2. Apparatus

The experiment was conducted using the Bionic Ear Data Collection System (BEDCS v1.18, Advanced Bionics, Valencia, CA), which was controlled by custom Matlab software. Stimulation in each ear was controlled by separate computers. Each implant was directly controlled and connected via a Platinum Series Processor (PSP) connected to a clinicians programming interface (CPI).

2.3. Stimuli

Stimulation Parameters: Electric pulses had a phase duration of approximately 32 μs and a pulse rate of 1000 pulses per second. These are within the range of stimulation parameters used within a typical clinical setting.

Probe Signal: The probe stimulation delivered to current-steered locations in the left implant was a 20 msec monopolar anodic leading biphasic pulse train. Current steering was used by stimulating two adjacent electrodes, simultaneously and in phase, creating a virtual channel with an electrical field centered at a region in between the physical locations of the stimulated electrodes (Firszt et al., 2007). By manipulating the relative amount of current on each of the two stimulating electrodes, virtual channels could be created at any point between the two physical electrodes. Without utilizing virtual channels, the masking functions would be limited to probes with a minimal spacing of one whole electrode, which may provide insufficient accuracy to measure the peak of the sharp contralateral masking functions seen for CI users (Aronoff et al., 2015). The probe signal was presented at periodic intervals with 5 msec jitter to minimize subjects' ability to anticipate the probe timing.

Contralateral Masker: The masker stimulation was delivered to the right CI. Two masker conditions were utilized. The *narrow masker* condition consisted of monopolar anodic leading biphasic pulse stimulation at electrode location 8. The *broad masker* condition consisted of the same stimulation of electrode location 8 (center electrode), with the same stimulation intensity as the narrow masker condition, while simultaneously stimulating both electrode 7 and electrode 9 in phase at 10% of the intensity of electrode 8 (i.e., the center electrode) (Fig. 1). Electrodes 7 and 9 will be referred to here as flanking electrodes, not to be confused with the term flanking bands used in acoustical comodulation masking release studies. The intensity magnitude of 10% of the center electrode was chosen for the flanking electrodes because pilot data indicated that it resulted in a clearly detectable increase in loudness, but also allowed for the stimulation level for both maskers to be audible. The stimulation level for the center electrode for both masking conditions were set so that the narrow masker was at a comfortable or soft but comfortable loudness level while the broad masker, with the additional flanking electrode stimulation, was not uncomfortably loud. The electrode location for the masker was chosen to be at the center of the 16 electrode implanted array to minimize the likelihood of contralateral masking peaks beyond the extent of the implanted array.

Since the broad masker used the same stimulation intensity at electrode 8 as the narrow masker, but with additional current from in-phase stimulation of the flanking electrodes, the current level was initially determined for the broad masker at a loud but comfortable level to minimize the risk of presenting uncomfortably loud sounds. All participants reported hearing the narrow masker and it was typically described as being at either a comfortable or a soft but comfortable level.

Table 1
Subject details provided. Under the Gender column, M indicates male and F indicates female. L indicates the left ear and R indicates the right ear throughout the table. SNHL indicates sensorineural hearing loss.

Subject ID	Gender	Age (years)	Age at onset of hearing loss (in years)	Etiology	Duration of processors activated (in years)
I05	M	58	5	Unknown	L & R:13
I06	F	58	38–39	Genetic SNHL	L:2; R:4
I07	M	55	30	Familial	L & R: 2
I10	F	50	29	Sudden (autoimmune)	L:2; R:3
I11	M	68	L: 9-10; R: 57	Unknown	L:3; R:11
I14	M	55	in 20s	R:progressive; L:sudden	L:3; R:4

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