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AMPLITUDE MODULATION DISCRIMINATION IN COCHLEAR IMPLANT LISTENERS: EFFECTS OF CARRIER FREQUENCY AND 'INTERFERING' MODULATED SIGNALS

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ABSTRACT

For cochlear implant (CI) listeners, speech comprehension relies on sensitivity to amplitude modulation (AM) cues across different electrode channels. For a given channel, envelope sensitivity may be impaired for many reasons, not least due to the spread of electrical current and/or neural degeneration.

We used a psychoacoustic task to explore AM discrimination in adult CI listeners (n=12). Listeners discriminated a 40 Hz sinusoidally amplitude-modulated (SAM) pure tone from a 13 Hz SAM tone in a three-interval task, where the modulation depth was varied adaptively. Testing was conducted in the presence or absence of speech envelope modulated interferer tones targeting neighboring electrode channels (± adjacent+1). Stimuli were delivered through headphones, all front-end noise reduction features were de-activated on the speech processor, and the level of each interval was roved (3 dB). By varying carrier frequencies, we measured AM thresholds across a range of targeted electrodes.

AM discrimination was poorer in the presence of interferers, and poorer at higher carrier frequencies. CI performance is also compared to normal hearing cohort (n=12): Although performance was more variable across CI listeners, both groups achieved comparable mean thresholds. Individual thresholds will be correlated with panoramic ECAPs and measures of speech in noise performance.

Keywords: *cochlear implants, amplitude modulation, psychophysics*

1. INTRODUCTION

Cochlear implants (CIs) most commonly function by filtering the acoustic signal into a limited number of frequency channels. The amplitude modulation (AM) envelope within each channel is extracted, and used to modulate a fixed-rate electrical pulse train delivered by a corresponding intra-cochlear electrode. For the perceived sound to correspond meaningfully with the external source, the listener must detect, track, and discriminate temporal envelope cues, both within and across channels. Many factors may limit the transmission of AM cues to a CI listener, but those most pertinent to this research concern the spread of electrical current within the cochlear, and the extent of neuronal survival of the auditory nerve at the corresponding frequency region. Any measure which could estimate these factors on an individual basis would likely prove helpful in guiding implant fitting [e.g., 1, 2, 3].

To this end, we are currently testing and comparing a range of measures to characterize information transmission and selectivity at different electrode sites within the cochlear. These measures include evoked responses to changes in AM rate [4], panoramic ECAP recordings [3], behavioral measures of stream segregation, and behavioral measures of AM discrimination [5]. A overview of the latter measure is presented here, alongside data from two experimental conditions.

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2. METHOD

2.1 Listeners

Twelve CI listeners who used Cochlear® devices took part. During the experiment, listeners used their everyday map, but with any noise reduction and automatic scene classification (SCAN) features disabled via clinical software. Twelve normal hearing (NH) listeners also took part and were presented with the default stimuli described below.

2.2 Stimuli

The test signal typically comprised an acoustic tone, of a frequency corresponding to the centre frequency (CF) of electrode 16. This was 1000 Hz for those with maps comprising default electrode-frequency allocations. Listeners discriminated a 'target' test signal from two 'reference' signals. The target rate of sinusoidal AM (SAM) was 40 Hz, and the reference rate of SAM was 13 Hz.

When present, two interferers were presented with frequencies corresponding to the CFs of electrodes 17 and 15 (875 Hz and 1125 Hz by default). Each interferer was modulated with an envelope extracted from an independent sample of speech [6], lowpass filtered at 50 Hz.

Stimuli were presented via an RME Fireface UCX soundcard (Haimhausen, Germany) and Sennheiser HD-600 headphones (Hannover, Germany). Each stimulus component was presented at a random level between 62-65 dB SPL, as calibrated using a Tektronix MDO3024 oscilloscope (Beaverton, OR, USA).

2.3 Method

In a 3I-3AFC adaptive procedure; listeners discriminated a target test signal from two reference signals. There was a 500 ms silence between intervals, and visual feedback was provided.

The experiment used a two-down, one-up adaptive procedure to estimate the 71% correct point on the psychometric function [7]. The depth of SAM applied to the test signal was varied, starting at 80% (i.e., where 100% corresponds to full modulation). The step size was a factor of 1.7 for the first two reversals, reduced to 1.4 for another two reversals, and finally held at 1.15 for four reversals. The geometric mean of the final four reversals is taken as the threshold estimate.

Interferer modulation depth began at 10%, but *increased* when test signal modulation *decreased*, and vice versa. At each step change, interferer modulation depth was scaled by the same factor as that for the test signal.

Listeners completed two runs of each of experimental conditions, and their final threshold estimate was taken as the geometric mean of the estimates derived both each run.

3. RESULTS AND DISCUSSION

Mean thresholds for both CI and NH groups are plotted in Figure 1. Performance was broadly similar across the two groups – both were able to discriminate modulation rates at relatively shallow modulation depths in the absence of interferers, but the presence of interferers markedly impaired performance. A mixed-design ANOVA confirmed a significant effect of interferers [$F(1,22)=161.55$, $p<0.001$, $\eta_p^2=0.88$], but not of group [CI vs. NH, $F(1,22)=2.21$, $p=0.15$, $\eta_p^{2=}0.09$]. The interaction was not significant [$F(1,22)=1.17$, $p=0.29$, $\eta_p^2 0.05$]

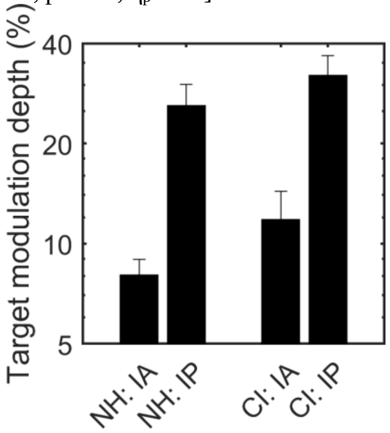

Figure 1. AM discrimination thresholds normal hearing (NH) and cochlear implant (CI) listeners. The task was performed in the absence (IA) or presence (IP) of interferers. Error bars indicate +1 standard error.

Overall, these results show that the task is generally suitable for CI listeners – all performed below ceiling and above floor. The comparable performance between CI and NH groups is consistent with other research showing that CI listeners are broadly as sensitive to SAM as those with NH [8,9]. Further data will be presented which explores 1) changes in performance over carrier frequencies/electrode locations, and the extent to which greater individual variability across frequencies in the CI group may be indicative of poorly functioning electrode regions, 2) correlations between behavioral measures of SAM discrimination and objective measures (ECAPs and EEG-observed cortical evoked responses), and 3) correlations between AM discrimination thresholds and a measure of speech in noise performance [10].

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