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In-phase amplitude modulation on different numbers of electrodes

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Abstract. It is known that fine temporal information is important for pitch perception. However, current commercial speech processors discard most fine temporal information other than amplitude modulation. The amplitude modulation outputted from the processing strategies is often out of phase, reducing their effectiveness as a pitch cue. In two experiments, we examine if presenting in-phase amplitude modulations on multiple electrodes improves the detection and discrimination of the rate of modulation. The data suggest that for all subjects, both detection and discrimination are improved when the amplitude modulation is presented in-phase on either three or five electrodes relative to presentation only on one electrode. However, no improvements were observed when increasing the number of electrodes with amplitude modulation from 3 to 5. These results suggest that in-phase amplitude modulation on a few electrodes can be used as a method for improving the perception of fine temporal information. © 2004 Published by Elsevier B.V.

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1. Introduction

Patients who have received cochlear implants tend to be quite poor at discriminating pitches of complex sounds [1]. This poor discrimination can be attributed to problems with the cues presented by current processing strategies (i.e., ACE, CIS, or Speak). Using these strategies, two cues for interpreting complex pitch are presented to the listener. Unfortunately, both of these cues provide ambiguous information. One of the cues is the spectral shape of the electrode outputs. Examination of electrodograms of sung vowels have suggested that a shift in a fixed number of semi-tones does not result in consistent

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shifts in spectral shape. The other cue available to an implanted patient is the temporal cue of amplitude modulations of current. However, the modulated outputs are often out of phase on adjacent electrodes. The result is a distortion or elimination of the useful information provided by the amplitude modulation [2].

It is hypothesized that if amplitude modulation of current is applied in-phase on multiple electrodes, the amplitude modulation will be more salient. In this manuscript, two experiments are presented that examine a subject's ability to either detect amplitude modulation or discriminate the rate. In all conditions, stimulation is present on five electrodes. Performance is compared when one, three, or five of the five electrodes is presented with in-phase amplitude modulation.

2. Experiment 1 methods

Stimuli were presented to four subjects with Nucleus CI 24 implants via a Spear research processor. Each stimulus consisted of bi-phasic pulses on five different electrodes in the medial through apical range of the electrode array. The pulses were previously calibrated to be of equal loudness on all five electrodes. The subject's task was to determine which of four sounds in a trial was different from the other sounds. The three similar stimuli (the reference stimuli) consisted of stimulation on all five electrodes at constant current levels. The different stimulus (the target stimulus) presented in-phase amplitude modulation of current on one, three, or five of the electrodes while the remaining electrodes were presented at steady current levels. The amplitude modulation of current was presented at 100 Hz. The overall level of each of the four stimuli was randomly jittered by three current levels so as to prevent identification of the target stimulus by a subtle change in loudness. Subjects were instructed to ignore the differences in loudness of the stimuli.

Using a one-up one-down adaptive forced choice task, we adjusted the modulation depth of the current modulation on the target stimulus until 10 turning points were measured. The average of the last six turning points was used as an estimate of the minimum detectable modulation depth in Nucleus current steps. This procedure was repeated until we had collected five estimates of the smallest detectable amplitude modulation per condition.

To ensure that loudness was not a cue we loudness balanced each reference stimulus to the corresponding target stimulus with parameters set to the final adjusted values to ensure that the difference in loudness were smaller than the jitter (± 3 Nucleus current levels).

3. Experiment 1 results

A summary of the results for experiment 1 is reported in the left panel of Fig. 1. For all four subjects, the minimum detectable modulation depth was greatest when only one of five electrodes was presented with amplitude modulation of current. Similarly, for all four subjects, the minimum detectable modulation depth was smallest when all five electrodes were presented with amplitude modulation. A one-way repeated-measures

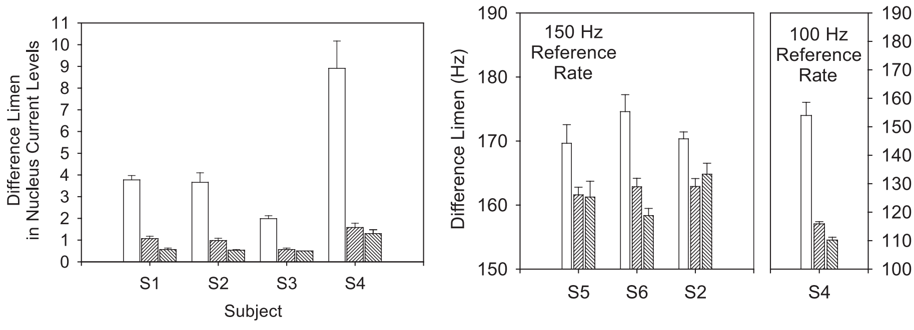

Fig. 1. The left panel shows the summary of results for the first experiment while the right panel shows the summary of results for the second experiment. The different shadings of the bars indicate the conditions. White bars indicate one electrode with amplitude modulation. Bars with lines going from down-left to up-right indicate the condition with three electrodes with amplitude modulation. Bars with lines going from up-left to down-right indicate the five amplitude modulating electrode condition. Error bars represent 1 standard error of the mean.

ANOVA was calculated for the data detecting a significant effect of number of electrodes (F=8.026, p<0.05). All pairwise comparisons were made post hoc using the Holm–Sidak method. With an overall α=0.05, the one amplitude modulating electrode condition was found to be different than either the three or five amplitude modulating electrode conditions. However, no differences were detected between the three and five amplitude modulating conditions.

4. Experiment 2 methods

The purpose of the second experiment was to determine the minimum detectable difference in rate of amplitude modulation. The equipment for the second experiment was the same as the first experiment. Four subjects with Nucleus 24 implants participated in this study. In this experiment, each stimulus consisted of stimulation on five electrodes. One, three, or five of these electrodes are stimulated with in-phase amplitude modulation of current while the remaining electrodes are stimulated with a steady level of current. The steady levels of current and peak level of the amplitude modulation were loudness balanced. Modulation depths were set to the smaller of either 50 Nucleus current levels or 80% of the dynamic range. The rate of amplitude modulation for the reference stimuli was 150 Hz for three subjects and 100 Hz for one subject while the rates of amplitude modulation for the target stimuli were at higher rates. Using a one-up one-down adaptive four-interval forced choice task, we adjusted the rate of amplitude modulation for the target stimulus to estimate the minimum discriminable difference in rate of modulation.

To insure that the difference that the subject was not using loudness as a cue, all stimuli were presented with a random current level jitter. The level for the jitter was calculated by balancing the loudness of each reference stimulus with the loudness of the same stimulus with a modulation rate of 300 Hz because 300 Hz was considered to be the maximum rate likely to be used. The jitter used was three times the difference in level in Nucleus current steps between the two stimuli.

5. Experiment 2 results

All four subjects required a greater difference in amplitude modulation rate to distinguish the conditions where only one of the five electrodes were presented with amplitude modulation compared to the other conditions. A one-way repeated-measures ANOVA was calculated for the data detecting a significant effect of number of electrodes ($F=6.416$, $p<0.05$). All pairwise comparisons were made post hoc using the Holm–Sidak method. With an overall α set to 0.05, the condition with amplitude modulation on one electrode was significantly different than either the three or five electrode amplitude modulation conditions. However, no differences were detected between the three and five electrode conditions. A summary of this data is presented in the right panel of Fig. 1.

6. Discussion

The results of these two experiments suggest that in-phase amplitude modulation of current on multiple electrodes can be used to improve perception of fine temporal information. Furthermore, the benefits of in-phase amplitude modulation can be achieved when only a subset of the electrodes conveys the amplitude modulation. With this knowledge, a series of potential modifications can be made to current commercial processing strategies by imposing in-phase amplitude modulations on the outputs. The additional fine temporal information conveyed by the amplitude modulation could be placed on all electrodes to deliver a fundamental frequency. Another possibility is that amplitude modulation could be used to mark electrodes that should be perceptually grouped together for various reasons (such as those electrodes conveying formant information).

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