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Electrophysiological and Psychophysical Measures of Amplitude Modulation Discrimination in Cochlear Implant Users

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ABSTRACT

Cochlear implants (CIs) work by dividing the incoming acoustic signal into a limited number of frequency channels, extracting the slowly varying amplitude envelope in each channel and using this to modulate the level of electrical pulses delivered to the auditory nerve fibres. The amplitude modulation (AM) cues that are transmitted are crucial for speech understanding and an individual's abilities to perceive different rates of AM is related to speech perception. The use of these cues can be affected by interference from adjacent channels caused by current spread which is further exacerbated if traumatic electrode placement or poor neural survival occurs. We have tested eleven adult CI users with a psychophysical measure of across-channel modulation interference (AMCI), to determine discrimination of different rates of AM in the presence of interferers and an electrophysiological correlate, the electrically-evoked auditory change complex (eACC).The eACC is a cortical potential in response to a change in an ongoing stimulus,i.e. AM rate change. Ability to discriminate AM rate (based on AMCI and eACC) is related to speech perception. If eACC to AM rate changes can be developed it can be used with children and also to identify poorly discriminated CI electrodes, to guide re-mapping.

1. INTRODUCTION

The wide range in speech perception performance that is observed in the population of cochlear implant (CI) users (Holden et al., 2013) can be partially attributed to the viability of the electrode-neural interface (Bierer, 2010). Issues at the interface can be caused, for example, by poor neural survival or traumatic electrode insertion. This can result in broader current spread than when the interface is well preserved, resulting in channel interaction, which in turn blurs the internal representation of the sound and leads to poor speech perception (Cohen et al., 2003; Eisen and Franck, 2005; Bierer, 2007).

Cochlear implant users are predominantly reliant upon slow temporal envelope fluctuations in speech for perception. Poor delivery of these envelope cues due to cross-channel interference degrades speech recognition post-operative outcomes (Shannon et al., 1995; Fu, 2002). Modulation detection thresholds have been used to locate electrodes that are poor at delivering amplitude modulation (AM) (Galvin and Fu, 2005; Garadat et al., 2012) and a relationship has been observed between the number of electrodes accurately conveying modulations and speech perception. As the different rates of modulation can be important for conveying important speech features (Rosen et al., 1992), this research focusses on supra-threshold modulation rate discrimination. There are two phases to the research, firstly looking psychophysically at within-channel modulation rate discrimination in the presence of interferers from adjacent channels and secondly at an electrophysiological measurement of the ability to detect within-channel changes in modulation rate using the electrically evoked auditory change complex (eACC). The eACC is an EEG response to a change in an ongoing stimulus and considered to be a sensitive indication of perceptual discrimination. It has been shown to be sensitive to changes in electrode (Mathew et al., 2017; He et al., 2014), detection of speech in noise using acoustic stimuli (Brint, 2017) and for mapping the temporal modulation transfer function (Han and Dmitrejivic, 2015). The eACC has not been used to look at modulation discrimination within a single implant channel.

We wanted to know if psychophysical measures of modulation discrimination are related to speech perceptual abilities. For the eACC to modulation discrimination we wanted to determine if a response could be measured for modulations rates that can be discriminated by the listeners.

2. METHODS

Two different experiments were conducted, the first (*Experiment 1*) of which was a psychophysical measure of within-channel modulation discrimination in the presence of an interferer and the second (*Experiment 2*) was an electrophysiological eACC measure of modulation discrimination.

2.1 Participants

Experiment 1

Eighteen normal hearing listeners and eight Advanced Bionics Cochlear Implant users participated. All were adults and native speakers of English. The normal hearing listeners were all screened for normal hearing at 20 dBHL from 250 – 8000 Hz. Cochlear Implant participants met the following additional criteria.

- Full intra-cochlear electrode insertion
- Advanced Bionics cochlear implant users
- Post implant activation experience of more than 9 months
- Post lingual onset of severe/ profound bilateral hearing loss

Experiment 2

Six normal hearing listeners and five Nucleus cochlear implant users participated. All were adults and native speakers of English. Cochlear Implant participants met the following additional criteria.

- Full intra-cochlear electrode insertion
- Nucleus cochlear implant users

- Post implant activation experience of more than 9 months
- Post lingual onset of severe/ profound bilateral hearing loss

2.2 Procedures

Experiment 1

Psychophysical modulation discrimination task. A within-channel modulation discrimination task in the presence of interferers from adjacent channels was adapted from Moore et al. (2017). A carrier sinusoid with a frequency the same as the centre frequency of the filter of the experimental channel was used. AM was applied to this carrier. And the individual heard an AM rate of 4 Hz in one interval and 8 Hz in the other and their task was to indicate which sound had the "faster" AM. Interfering sounds were presented to adjacent channels with speech envelope modulations were applied to the sinusoids presented to those channels. The ratio of modulation depth of the target (8 Hz) and reference sound (4 Hz) were adjusted adaptively using a 2-down 1-up adaptive procedure tracking the 71% threshold. Good AM discrimination is indicated by a low ratio.

This task was repeated for a number of electrodes along the array but only the first six electrode data is analysed here because this was common for all participants.

Speech perception testing. The coordinate response measure was used for evaluating speech perception. In this implementation of the test a sentence was presented in the presence of a single competing speaker. The target sentence was presented in the form "Ready Baron got to COLOUR NUMBER now" and the colour and number can change in the sentence e.g. "Red six" and the person indicated what they heard on a touchscreen. The level of the competing sentence was adaptively adjusted to reach the Speech Reception Threshold where 50% of the speech is heard. Stimuli were presented over a loudspeaker placed 1 metre in front of the participant and they responded using a touchscreen.

Each measure was conducted twice and an average of the two thresholds used in the analysis.

Experiment 2

EEG recordings and analyses. Recordings were made using a 64-channel high resolution BioSemi Active Two electro-encephalology (EEG) recording system with channels arranged according to the international 10–20 system. Scalp channels around the CI receiver package were not connected (typically 1-5 electrodes).
Artefact was removed by down sampling (1000 Hz) initially, band-pass filtering between 2-30 Hz (zero-phase, third-order Butterworth filter) and referencing to the contralateral mastoid. Eye movement and eye blink artefacts were removed and spatial filtering used.

Stimuli. For the cochlear implant users the stimuli were directly presented to electrode 16 using the Nucleus Implant Controller (NIC) version 3. Biphasic pulses were modulated with either 19 or 35 Hz AM rates, or the nearest rates which could be discriminated, all stimuli were checked in advance to ensure that they were discriminable. For the normal hearing listeners a 500 Hz sinusoidal carrier was used and AM was applied to the sinusoid, again modulation rates near to 19 and 35 Hz that were discriminable were used. All stimuli were loudness balanced and presented with 100% modulation depth. The stimulus presentation was continuous with modulation rates being switched every 2 seconds. Responses to each change were averaged together and the Hotelling T^2 test was used to determine if there was a significant response.

3. RESULTS

Experiment 1

At the time of article preparation results were available for 18 normal hearing and 8 cochlear implant users. Therefore trends but not final analyses will be reported. Figure 1 shows the distribution of scores for modulation depth discrimination. In general, the distributions of scores are similar for the two groups, suggesting that cochlear implant users are able to perform the task and discriminate between 4 and 8 Hz modulation within a channel.

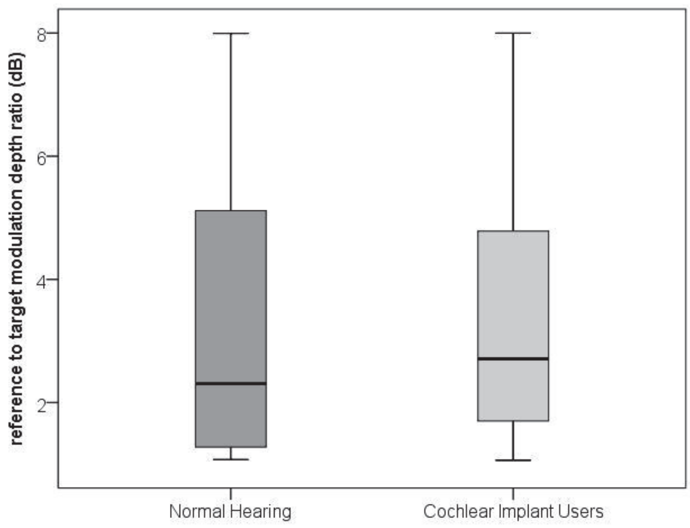

Figure 1. Range of scores for the normal hearing group compared to the cochlear implanted group for modulation depth discrimination. Note that lower is better performance on this task.

In figure 2 the scores for modulation discrimination are plotted against speech perception scores on the coordinate response measure task.

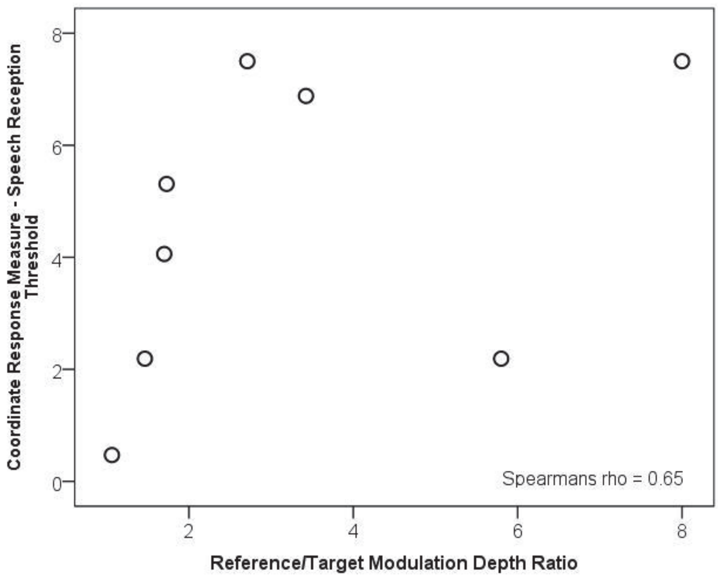

Figure 2. Speech Reception Thresholds plotted against the reference/target modulation depth ratio. Lower is better on both tasks.

Preliminary interpretation of the relationship between modulation discrimination suggests that for cochlear implant users that there is a relationship with speech perception up to a reference/target modulation discrimination ratio of 4.

Experiment 2

The results of experiment 2 indicated in all cases where an individual could discriminate modulations perceptually that they could also be measured electrophysiologically. This was the case for both normal hearing and cochlear implant users. Figure 3 shows individual and averaged results for the P1-N1-P2 eACC response for cochlear implant users. The pale lines are responses for individuals and the dark line indicates the average response. The responses are robust and large.

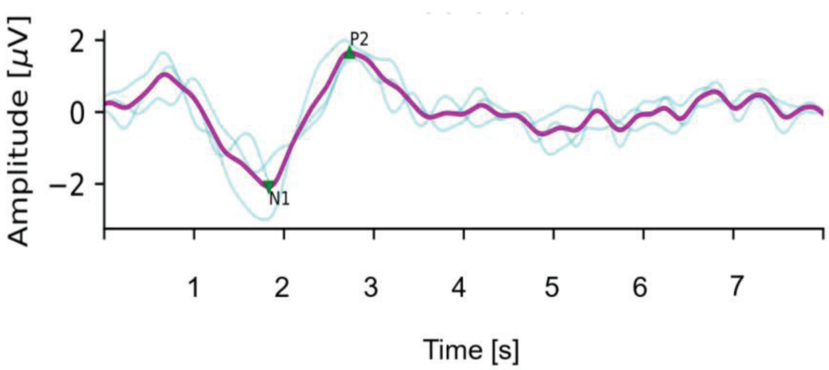

Figure 3 Shows individual and averaged P1-N1-P2 eACC responses. The light lines indicate individual data and the dark line is the averaged response across participants.

4. DISCUSSION

The findings show that modulation rate discrimination can be measured in cochlear implant users and that the ability to discriminate between different rates in the presence of interferers on adjacent channels could be related to speech-in-noise perception. An electrophysiological analogue to the response was evaluated using the eACC and it showed that the response was robust in cochlear implant users. Both the psychophysical and electrophysiological measures can be used to determine if an electrode is effectively delivering modulation information to the cochlear implant user. This information could be used for re-mapping the implant and informing training intervention in cases where there is an electrophysiological response but not a behavioural response.

5. CONCLUSIONS

Modulation rate discrimination has the potential to indicate how well a cochlear implant user is able to make use of important modulation information in speech.

Intellectual Property

There is no requirement to obtain permissions from authors for the use of intellectual property within the content of the manuscript as all figures and images are original.

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