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# Responses from Single Units in the Dorsal Cochlear Nucleus to Electrical Stimulation of the Cochlea

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An aim of the electrical stimulation strategy of a cochlear implant is to mimic the response of the auditory system to acoustic stimuli, so that hearing sensations generated by the implant can be recognisable and useful to the implantee. To help improve our understanding of how the brain responds to electrical stimulation of the auditory nerve we have examined the responses of dorsal cochlear nucleus (DCN) units to both acoustic and electrical stimulation of the cochlea in a hearing animal. This work extended our previous studies which have compared the responses to electrical and acoustic stimulation in the auditory nerve [1] and the ventral cochlear nucleus [2].

Our studies addressed two questions:

(1) What are the responses of DCN units to electrical stimulation of the auditory nerve?

(2) Was it possible to identify acoustic and electrical stimuli which generated similar responses from individual DCN units?

By answering questions 1 and 2, it may be possible to deduce the electrical stimulus parameters which should be employed in cochlear implant speech processing strategies to mimic acoustic-like responses from neurons of the dorsal cochlear nucleus. The generality of observations from the cochlear nucleus could then be tested at other nuclei within the central auditory pathways.

## *Methods*

Single unit recordings were made from barbiturate-anaesthetised cats. The auditory nerve was activated by bipolar electrical stimulation of the cochlea using an electrode array similar to that used in the University of Melbourne-Cochlear Pty Ltd. Multiple Electrode Cochlear Implant. This stimulating electrode consisted of platinum bands mounted on a cylindrical carrier which fitted freely into the basal turn of the scala tympani and could be implanted without affecting the ABR thresholds to acoustic tone pips and clicks. The electrical stimulus was a 100-ms train of biphasic current pulses (100–200 μs/phase), delivered at 100–200 pulses/s. The stimulus current was 1.6–2.0 mA. The acoustic stimuli were 100-ms-duration acoustic tones and wideband noise at high stimulus intensity (93 dB SPL). The noise activated a broad cochlear region while the cochlear region activated by the characteristic frequency tone was less broad. The electrical stimulus, characteristic frequency tone and wideband noise stimuli were presented to each unit encountered. The poststimulus time histogram (PSTH) is the result of 50 presentations of the stimulus (presented every 400 ms).

## *Results*

The envelope of the PSTH's in response to electrical stimulation exhibited 'primary-like' [3], 'onset' [3] or 'negative response' [4] and less frequently 'pauser' [3] or 'buildup' [4] patterns. Acoustic stimuli generate PSTH patterns with similar response envelopes [3, 4], and in this respect the range of DCN unit responses were similar in response to both acoustic and electrical stimuli. However, the action potentials in response to the electrical stimulus occurred in a narrow time window following each stimulus pulse and, therefore, were much less temporally dispersed than responses to acoustic stimuli. Note that responses of auditory nerve fibres [1] and ventral cochlear nucleus units [2] to electrical stimulation are much less temporally dispersed than responses to acoustic stimulation.

The second question was addressed in table 1. Each of the matrices summarises the incidence of PSTH patterns obtained from two stimuli (one acoustic and one electrical), and their interrelations. For example, the rows of the first matrix were the grouping of units into three major classifications, primary-like, negative response or onset (NR/O), pauser or buildup (P/B) according to their response to noise. The PSTH pattern grouping of the same unit to electrical stimulation is found in the columns. Units were counted if the discharge rate (during the stimulus) in response to *both* stimuli was within 50 spikes/s. Therefore, units were identified in which the responses to two types of stimulation were similar according to

*Table 1.* The number of units sharing the same PSTH pattern and a similar discharge rate in response to a 100-ms-duration electrical pulse train and a 100-ms-duration acoustic stimulus

| Noise pattern | Electrical pattern | | | |
|---|---|---|---|---|
| | PL | NR/O | P/B | total |
| PL | 6 | 2 | 1 | 9 |
| NR/O | 1 | 6 | 1 | 8 |
| P/B | 2 | 1 | 2 | 5 |
| Total | 9 | 9 | 5 | 23 |
| **CF tone pattern** | **Electrical pattern** | | | |
| | PL | NR/O | P/B | total |
| PL | 0 | 1 | 0 | 1 |
| NR/O | 3 | 5 | 3 | 11 |
| P/B | 3 | 0 | 0 | 3 |
| Total | 6 | 6 | 3 | 15 |
| **CF tone pattern** | **Noise pattern** | | | |
| | PL | NR/O | P/B | total |
| PL | 1 | 0 | 1 | 2 |
| NR/O | 0 | 5 | 0 | 5 |
| P/B | 3 | 0 | 0 | 3 |
| Total | 4 | 5 | 1 | 10 |

The stimulus intensity was high for both the acoustic and the electrical stimulus. The only units counted were those in which the discharge rate in response to both stimuli was within 50 spikes/s.

PL = A sustained response throughout the stimulus. For acoustic stimuli this corresponds with the chopper and primarylike PSTH patterns. For the electrical stimulus this meant that the P1 PSTH pattern was observed. NR/O = An onset or negative responser PSTH pattern to the stimulus; P/B = a pauser or buildup PSTH pattern to the stimulus.

both indices, PSTH pattern and discharge rate. From this analysis it was observed that responses to noise were similar to those from electrical stimulation in 14 of 32 units, but responses to a CF tone were similar to those from electrical stimulation less often (5 units of 32). It was concluded that, in hearing animals, the PSTH response to noise and electrical stimuli corresponded more frequently than the responses to electrical stimulation and a CF tone.

An essential control experiment was to demonstrate that the DCN responses recorded from hearing animals were due primarily to activation of the auditory nerve by the electrical stimulus, and not electrophonic mechanisms. This was tested by comparing DCN responses to electrical stimulation in hearing animals with those in animals deafened by neomycin irrigation of the scala tympani. The excitatory and inhibitory responses were very similar in hearing and deafened cats and, therefore, they were probably generated by the same mechanisms. Since electrophonic mechanisms were not active in the deafened animal the responses to electrical stimulation in both hearing and deaf animals were probably due to direct activation of the auditory nerve by the stimulus current. Thus there were reasonable grounds for using a hearing animal to contrast the responses of DCN units to acoustic and electrical stimulation of the auditory nerve, as performed in this study.

## *Conclusions*

The PSTH and discharge rate responses to electrical stimulation and noise stimulation corresponded more frequently than the responses to electrical stimulation and CF tone stimulation. Therefore, some aspects of acoustic noise may be mimicked with a cochlear implant by presenting a high stimulus current, 100–200 pps pulse train. It is plausible that the correspondence of PSTH patterns and discharge rates in response to electrical stimulation and noise occurs because both stimuli activate a broad spatial extent of the cochlea.

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