Potential Advantages of High Pulse Rate Stimulation of Cochlear Implants

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Abstract: Lower thresholds and smaller stimulus currents may allow for the use of smaller cochlear implant stimulus electrodes and potentially more channels of stimulation within a given cochlea region. With high (2kpps) compared to low (125pps) pulse rate stimuli, inferior colliculus (IC) units have a significantly lower stimulus threshold [1]. The provision of a background "spontaneous" stimuli may provide, a further decrease in threshold current, a unit population with a larger range of thresholds and a more physiologically natural stimulus response. A low threshold, low current level, high pulse rate processing strategy capable of evoking background "spontaneous" firing in units is described. This background stimulus strategy has the potential to deliver more speech information to cochlear implant patients.

INTRODUCTION

Cochlear implants are used to provide hearing sensation to the sensorineurally deaf. Bipolar electrical stimulation of a scala tympani cochlear implant produces a decidedly deterministic firing pattern in a group of auditory nerve fibres proximal to the stimulating electrode pair. One consequence of this deterministic group response is the simultaneous stimulation of excitatory and inhibitory nerve fibres. This results in a large number of inferior colliculus units showing no excitatory response [2].

In the auditory nerve the degree of synchrony in the neural array has been labelled an important cue and has been related to a patients' ability to recognise individual pulse shapes [3]. Likewise in the auditory nerve [4] and inferior colliculus [5] neural coding has been related to the group response of fibres. The presence of a spontaneous firing rate in auditory nerve fibres effectively decreases the threshold of auditory units [6].

A more stochastic pattern like that evoked with acoustic tonal stimuli is required. A strategy is proposed that delivers a more stochastic firing pattern in an array of auditory nerve fibres. This strategy uses the findings of our previous study [1] that showed the threshold of units in the IC to bilateral electric stimulation decreases with pulse rate. The present study proposes a stimulation strategy capable of reducing the degree of deterministic firing in the auditory neural array. This strategy is based on the findings of a series of electrophysiological experiments. The proposed strategy utilizes a high pulse rate low current level stimulation to introduce "spontaneous" background activity across all electrodes.

METHODS

Cats (2-4kg) were anaesthetised with Ketamine™ (40mg/kg, i.p) and Rompun™ (30mg/kg, i.p). The anaesthetic level was maintained by supplementary doses of Nembutal™ (5-10mg/kg, i.v). Feline versions of the multi-channel bipolar Melbourne/Cochlear scala tympani electrode array were implanted into a Neomycin deafened cochlea. The contralateral cochlea was Neomycin deafened, implanted and electrically stimulated whilst the ipsilateral cochlea was left intact and acoustically stimulated.

Recording microelectrodes were placed in the inferior colliculus. Stimuli were 40ms bursts of biphasic charge balanced (100us/phase) electric pulses (125-4000 pulses/s). Electric stimuli were presented as pulse trains at constant current or charge levels called burst stimuli. Unit threshold was established for octave steps in pulse rate from 125 to 4kpps [1]. Electrically evoked rate level and frequency transfer functions [7,8] were derived for units with only one pattern of response.

The care and use of animals reported on in this study were approved by the University of Melbourne Animal Experimentation Ethics Committee and the Royal Victorian Eye and Ear Hospital Animal Research Ethics Committee.

RESULTS

Approximately 61% of units had a fixed pattern of response to electric stimuli. At least 37% of these units have "increasing" rate level functions. 80.5% of "increasing" functions show an increase in spike rate for all increases in current level (2.5mA maximum). These results suggest one mode by which current level may be encoded is in the spike rate of many IC units.

In the IC threshold decreases with pulse rate [1]. Given these threshold shifts, a population of units was analysed at high and low current levels (each measured relative to unit threshold at each pulse rate). In a population of ICC units, when using high, low and constant charge level octave steps in pulse rate, the proportions of units with increasing, single peak, saturated or complex frequency transfer functions are similar. These results suggest one mode by which pulse rate may be encoded is in the spike rate of many IC units.

DISCUSSION

Even at high pulse rates simultaneous pulse rate and current level information appears partially and simultaneously encoded in spike rate [7,8]. Consequently, a high pulse rate signal processing strategy is proposed to produce a more stochastic firing in a group of nerve fibres in response to electric stimulation.

Inferior colliculus units can lack spontaneous activity. This is particularly true of many monaural units deriving input from a deafened cochlea. Auditory nerve fibres have a range of thresholds to electrical stimulation. These fibres also have a response latency dependant on past firing history and their level of depolarisation. With a deafened
cochlea spontaneous activity in auditory nerve fibres is often very low or not present. A fact that tends to facilitate deterministic responses. One solution to the problem of a producing a less deterministic response can be found by combining high pulse rate stimulation and utilizing threshold and latency characteristics of auditory nerve fibres. High pulse rate stimulation produces a more stochastic firing than low pulse rate stimulation [8]. To explain this more stochastic firing it is postulated [8]: (i) that for a similar increase in excitatory and inhibitory drive, as a consequence of an increase in pulse rate (at pulse rates >300 and <800 pulses/sec), the increase in excitatory input will dominate and produce a second higher mode of stimulation and; (ii) that with high as compared to low pulse rate stimulation the firing pattern of electrically responsive units is less deterministic and that this would lead to an increase in the driven response of units as a consequence of a reduced level of inhibition. This less deterministic response may be a result of a threshold shift, a consequence of a high pulse rate temporal summation process [1]. The system proposed produces a stimulus that characterizes the voiced/unvoiced decision as background activity. Five to ten percent (arbitrary) of the useful current level range is represented by sinusoidal (voiced) or random (unvoiced) or sinusoidal (voiced) activity (Figure 1). Speculatively, such a system might provide a more natural neural response, a more stochastic group firing, a decrease in stimulus threshold and another avenue for providing voiced and unvoiced information to cochlear implant patients.

CONCLUSIONS

In previous studies [1,7,8] we have shown there is an increased dynamic range and firing rate associated with stimulation at higher pulse rates which is in accord with other authors for stimulation rates up to 800pps [9]. There is also a decreased threshold associated with high pulse rate stimulation [1]. Very high pulse rate stimulation generates a more stochastic response [8]. The combination of these findings together with the background stimulation proposed means smaller currents may be used for stimulation. Smaller currents are more localised, can stimulate a smaller cochlear region (frequency region) and require a smaller electrode surface area. More electrodes could be located within a specific tonotopic cochlear (frequency) region. The result being an increase in tonotopic (frequency) resolution. Finally, the high pulse rate stimulus is likely to be more efficacious, produce less lateral inhibition, and potentially able to carry more spectral information.

REFERENCES: