Temporal coding in auditory neurons to electrical stimulation

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SUMMARY

Different electrically evoked response properties are elicited by similar acoustically differentiated AVCN units. Discharge entrainment and synchrony of some AVCN units is maintained throughout the electrical stimulus duration at all rates, similar to that described for auditory nerve fibres. Other units exhibit a decline in discharge entrainment over the duration of the electrical stimulus with increasing rate. Within this group of units, some exhibit a highly synchronous response while others show a decline in the response synchrony with increasing stimulus rate.

INTRODUCTION

Temporal coding of sound frequencies is based on a phase or time locked neural response and therefore the ability of neurons to respond in this manner may determine the degree of encoded temporal frequency information. The temporal response of the auditory pathway following intracochlear electrical stimulation will reflect the level of encoded temporal information. Frequency limits on phase-locking to electrical stimulation may restrict the useful temporal information available to cochlear implant patients. Electrophysiological studies (Moxon, 1971; Javel et al., 1987) have shown that the degree of response synchrony to charge-balanced biphasic electrical stimuli is far greater than that seen to acoustic stimuli. However, psychophysical studies on implantee's pitch perception (McKay, 1994) have indicated that accurate pitch percepts diminishes for stimulus rates above 400pps. Considerable interest has therefore been raised on the physiological temporal response properties of electrically stimulated auditory neurons. The present study aims to examine the physiological response properties of neurons in the Anteroventral cochlear nucleus (AVCN) to rates of electrical stimulation up to 1000pps

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MATERIALS AND METHODS

Ten healthy adult cats with normal hearing determined from the Auditory Brainstem Response to pure tones between 1.0 kHz and 24.0 kHz were used in this study. Cats were anaesthetised with pentobarbitone sodium (Nembutal; 45 mg/kg) I.P. and maintained with supplemental doses I.V. Core temperature was monitored with a rectal probe and maintained at 37±0.5°C using a D.C. homeothermic heating blanket. A tracheal cannula was inserted and CO2 and respiration rate monitor.

The animal’s head was secured in a stereotaxic frame, the external auditory meatus was transected, the ipsilateral pinna reflected and the bulla exposed. The cochlear nucleus was approached dorsally with aspiration of the cortex and the partial removal of the ossicle tentorium. The animals were unilaterally implanted to a depth of 7.5mm with a feline version of the Melbourne/Cochlear scala tympani electrode array consisting of 6 platinum electrode rings located on a cylindrical silastic carrier. Electrode diameter ranged from 0.4mm at the tip of the electrode to 0.6mm at the most basal ring. The distance between the rings, measured centre to centre was 0.75mm.

Acoustic stimuli were pure tone bursts, 50ms in duration with 5ms rise/fall time intervals and a repetition interval of 200ms. Electric stimuli were 50ms bursts of constant current charge balanced biphasic pulses ranging in amplitude between 0.5 and 2.5mA and delivered to an electrode pair (bipolar) with a repetition interval of 200ms. These bursts consisted of pulses at rates of either 200, 400, 600, 800 or 1000 pulses/sec (pps).

Isolated single unit responses were recorded by glass micropipettes, amplified by an Axoclamp 2B amplifier then passed through a sample and hold artifact suppressor and the timing of each spike recorded on a PDP 11/34 computer. Unit responses were displayed in peri stimulus time (PST), Interspike Interval (ISI) and period histograms following 50 repetitions of each stimulus. The direct electrical response analyzed in this study was isolated from any electrophonic response based on latency (Moxon, 1971; Javel, 1987). The response rate, entrainment (% response per pulse) and vector strength (VST) were analyzed quantitatively by input-output (I/O) functions.

RESULTS AND CONCLUSIONS

Tuning curves of the 11 units analyzed exhibited Qo values between 0.9 and 6.8 and showed characteristic frequencies (CF) ranging from 0.9 to 17.8kHz with CF thresholds between 4-63 dB SPL. Response types were predominantly primary-like (9/11 units). 1 unit was classified as exhibiting an onset response pattern and one unit displayed transient chopping characteristics. The majority of primary-like units displayed monotonic rate-intensity functions being either saturating (n=4), sloping saturating (n=3) or straight (n=1).

Following acoustic characterization the response of units to electrical stimuli of 200, 400, 600, 800 and 1000pps were recorded. The discharge of primary-like units seen in PST histograms to direct electrical stimulation occurs at precise instants following the stimulus pulse. This is also highlighted in the period histograms as a narrow cluster of spikes and the ISI histograms as a single interval. A similar trend was evident in the onset unit’s response to low pulse rates (200 and 400pps). However, in response to 600pps there appears to be a decline in the discharge rate over the stimulus duration. At 800pps the unit responds only to the onset of the electrical burst with no further discharge throughout the stimulus. The electrically-driven discharge of the transient chopper unit were not so precisely timed and even in response to the lower pulse rates, at high intensities a significant decline in discharge was evident throughout the stimulus.

Examination of the electrically evoked rate-intensity functions shows a continuum of response patterns distributed across unit types, similar to that seen for acoustically evoked rate-intensity functions. For units with monotonic rate-intensity functions two response patterns could be identified. Units in one group, exhibited discharge rates that closely match the stimulus rate, progressively reaching higher levels with increasing stimulus rate. These units exhibit very small dynamic ranges where the discharge rates saturate within a few dB of threshold. With increasing stimulus rate saturation of discharges was seen to occur at progressively higher intensities. The second group of monotonic functions produced discharge rates that closely matched stimulus rates of 200 and 400pps. Discharge rates evoked by 600 and 800pps were, however, significantly lower than the stimulus rate. The discharge rate-intensity pattern of the onset unit fell into this response group. Three AVCN units exhibited non-monotonic discharge patterns with respect to increasing stimulus intensity. The transient chopper unit comprised one of these units. The variation in AVCN unit response to electrical stimulation was found not to correlate with the acoustically identified unit types. These differences in discharge patterns may be associated with different synaptic connections (Ostapoff et al., 1994) and further work on the intracellular response of AVCN units will help identify the possible functional differences.
To analyse how the discharge pattern of units in the AVCN change throughout the stimulus duration, responses were sampled at specific times throughout the 50ms electrical stimulus burst. These times correspond to 0, 10, 20, 30 and 40ms post stimulus onset. The responses to the first 2 pulses at each time window were sampled. With the exception of 2 units exhibiting 100% entrainment in response to all stimulus rates across all time windows, entrainment declines with higher stimulus rates, particularly at later times in the stimulus duration. This is illustrated in the plot of entrainment in figure 1A. A similar decline has been reported by Javel (1987) for auditory nerve fibres were it was argued, adaptation of the fibres accounted for this decrease. Such a decline in entrainment of AVCN unit responses would suggest a loss of stimulus encoded temporal information.

Irrespective of unit CF, the degree of phase-locking evoked by the electrical stimuli was high. An analysis of VST at specific time windows throughout the stimulus duration showed the two units with 100% entrainment for all stimulus rates at each stimulus time window also showed maximum VST across the same stimulus conditions. Interestingly for some other units, precise synchrony was attained in response to all stimulus rates irrespective of a decline seen in their response entrainment while others showed a marked decrease in VST throughout the stimulus over increasing pulse rates (Figure 1B). These data suggest that although some AVCN units are able to phase-lock to high rate pulsatile electrical stimuli, the level of response at higher pulse rates may not be adequate to code those rates correlating with the psychophysical studies (Eddington et al., 1978; McKay, 1994) showing pitch perception to decline with rates of electrical stimulation exceeding 300-400pps. Encoding of temporal frequency for electric and acoustic stimuli in the auditory system may therefore be dependent on the adequate response of a population of units.

REFERENCES

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SUMMARY

The anterior division of the station of the auditory pathway to intracochlear electrical stimulation results in units which are able to follow pulsatile electrical stimuli at rates equal to the fundamental frequency of the stimulus. At these rates, when deterministic response was not seen, increasing response rate of stimulation resulted in decreasing encoding ability. These observations on units may suggest the way cochlear implants operating at high rates may improve speech recognition in Cochlear implants.
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Title:
Temporal coding in auditory neurons to electrical stimulation

Date:
1997

Citation:

Persistent Link:
http://hdl.handle.net/11343/26989

File Description:
Temporal coding in auditory neurons to electrical stimulation

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