Comparison of Psychophysical and Neural Thresholds in Response to Electrical Stimulation of the Cochlea in Guinea Pigs

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Abstract: Recent studies have shown that the spatial pattern of currents used on individual channels of cochlear implants can have large effects on speech recognition and other measures of electrical-stimulus perception. This study is one of a series that seeks to understand the neural patterns of response underlying those effects. Guinea pigs were deafened in one ear and implanted with an electrode array in the scala tympani. Psychophysical strength-duration functions were obtained for bipolar and monopolar stimulation in animals trained using positive reinforcement, operant conditioning techniques. Single-unit and unit-cluster responses were recorded from inferior colliculus in the same animals, or in non-trained guinea pigs deafened and implanted in a similar manner. In these preparations, thresholds for neural responses were near or below the psychophysical thresholds at all phase durations. Thus, the paradoxical discrepancies between neural responsiveness and behavioral stimulus detection observed in previous comparisons made across animal models did not occur in this preparation. This seems to be a useful paradigm for determining the spatiotemporal patterns of neural activity that underlie electrical-stimulus perception.

INTRODUCTION

Cochlear implants function by inducing appropriate spatiotemporal patterns of neural activity by electrical stimulation of the cochlea (1). Recent studies have shown that the spatial pattern of currents used on individual channels of cochlear implants, as determined by electrode configuration and electrical current configuration, can have a large effect on speech recognition and other measures of electrical-stimulus perception (2-6). The neural patterns of response underlying these effects are not easily predicted from existing experimental models. In addition, attempts to determine the neural response patterns associated with a particular function, measured psychophysically, have been unsatisfactory when the neurophysiological and psychophysical data are obtained from different subjects. For example, thresholds obtained from auditory nerve fibers in cats are typically higher than the psychophysical thresholds obtained from other animal models or from human subjects (7). Interestingly, the slopes of the strength-duration functions for these fibers are shallower than those of the psychophysical strength-duration functions (8-9). In order to better understand the relationship between perception of electrical stimuli measured psychophysically and the underlying neural response patterns, we have initiated a series of neurophysiological and psychophysical studies using a common animal model for both types of investigation. The recording site chosen for these studies was the central nucleus of the inferior colliculus (ICC). For our purposes, a more central nucleus has advantages over the auditory nerve recording site for several reasons: (a) accessibility of the neurons with less risk of physical trauma; (b) orderly, measurable spatiotopic organization (10); and (c) a representation of neural information that has undergone some central neural processing.

METHODS

Guinea pigs were deafened in one ear by local perfusion of an antibiotic (Neomycin sulfate) and implanted with an electrode array in the scala tympani. The scala tympani implant consisted of two electrodes: a 0.45 mm diameter spherical electrode on the apical end of the implant and a band electrode (0.4 mm in diameter and 0.6 mm long) located basal to the spherical electrode, separated by a gap of 0.75 mm. A wire implanted under the cleidocephalic muscle served as a return electrode for monopolar stimulation.

Behavioral subjects were trained using positive reinforcement, operant conditioning techniques to perform tasks that could be used for reliable behavioral assessment of psychophysical detection thresholds (11-12). The animals were trained using acoustic stimuli, then implanted, and tested with electrical stimuli. Psychophysical strength-duration functions (detection threshold vs electrical pulse duration) were obtained using symmetric biphasic pulses ranging in phase duration from 25 μsec to 1.6 msec. Two electrode configurations were used, monopolar stimulation to achieve a broad current field and bipolar stimulation to achieve a narrower field.
Responses of single units and unit clusters were recorded from the psychophysically trained animals, and from non-trained guinea pigs deafened and implanted in a similar manner and for a similar time as the psychophysically trained subjects. Animals were anesthetized with Ketamine and Xylazine. Neural responses were recorded in the ICC contralateral to the stimulated cochlea using glass micropipettes filled with Ringer’s solution. The ICC was systematically sampled with micropipette penetrations from a dorsal approach. At the end of each experiment, the animals were sacrificed and the brains processed histologically to reconstruct the recording locations. Thresholds of neural response were determined by auditory and visual monitoring of action potentials and peri-stimulus time histograms. Neural strength-duration functions were determined for the same range of pulse durations used in the psychophysical experiments. Spatial tuning curves were constructed by plotting unit thresholds vs location of the units along the cochleotopically organized axis of the ICC, as described by Snyder et al. (10).

RESULTS

In these preparations, thresholds for neural responses were near or below those for psychophysical thresholds at all phase durations. The thresholds for the most sensitive neurons, near the tips of the spatial tuning curves, were several dB below the psychophysical detection thresholds. Slopes of the psychophysical and neural strength-duration functions were similar, averaging -5.1 dB/doubling for bipolar stimulation and -5.7 dB/doubling for monopolar stimulation. Neural strength-duration function slopes varied from unit to unit and may be related to position of the unit or unit cluster in the spatial tuning curve.

DISCUSSION

The paradoxical discrepancies between neural responsiveness and behavioral stimulus detection observed in previous comparisons made across animal models do not present a problem in this preparation. This preparation seems to be a useful one for determining the spatiotemporal patterns of neural activity that underlie electrical-stimulus perception. The observation that thresholds for the most sensitive neurons are several dB below the average psychophysical thresholds suggests that integration across multiple neurons is required for stimulus detection. A question that remains to be answered is whether the number of neurons activated at the psychophysical threshold for monopolar stimulation is greater than the number activated at the threshold for bipolar stimulation.

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