A model of auditory nerve responses to electrical stimulation

Cochlear implants (CI) stimulate the auditory nerve (AN) with a train of symmetric biphasic current pulses comprising of a cathodic and an anodic phase. The cathodic phase is intended to depolarize the membrane of the neuron and to initiate an action potential (AP) and the anodic phase to neutralize the charge induced during the cathodic phase. Single-neuron recordings in cat auditory nerve using monophasic electrical stimulation show, however, that both phases in isolation can generate an AP. The site of AP generation differs for both phases, being more central for the anodic phase and more peripheral for the cathodic phase. This results in an average difference of 200 μs in spike latency for AP generated by anodic vs cathodic pulses. It is hypothesized here that this difference is large enough to corrupt the temporal coding in the AN. To quantify effects of pulse polarity on auditory perception of CI listeners, a model needs to incorporate the correct responsiveness of the AN to anodic and cathodic polarity. Previous models of electrical stimulation have been developed based on AN responses to symmetric biphasic stimulation or to monophasic cathodic stimulation. These models, however, fail to correctly predict responses to anodic stimulation. This study presents a model that simulates AN responses to anodic and cathodic stimulation. The main goal was to account for the data obtained with monophasic electrical stimulation in cat AN. The model is based on an exponential integrate-and-fire neuron with two partitions responding individually to anodic and cathodic stimulation. Membrane noise was parameterized based on reported relative spread of AN neurons. Firing efficiency curves and spike-latency distributions were simulated for monophasic and symmetric biphasic stimulation. The simulations were in line with the average data for firing thresholds and spike latencies for both, monophasic anodic and monophasic cathodic stimulation. The model also correctly predicted the shift in latency as a function of stimulation level. With the ability to account for the responsiveness to cathodic and anodic phases of electrical stimulation, this model can be applied to account for the response to arbitrary pulse shapes. The evaluation of the neural response to symmetric biphasic pulses helps to estimate the mutual interaction between the two pulse phases. A successful model can be generalized as a framework to test various stimulation strategies and to quantify their effect on the performance of CI listeners in psychophysical tasks.

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