Individualized models of the auditory nerve response to cochlear implant stimulation

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Background, Cochlear implants (CIs) restore hearing for profoundly deaf people by stimulating the auditory nerve fibers (ANFs) directly with electrical pulses. Several stimulus-, electrical field- and ANF-properties affect the responsiveness of the ANF to a particular stimulation pulse, with pulses of a sequence interacting in a complex fashion. Optimization of the CI's stimulation pattern for its ANFs response thus holds great potential for improving CI stimulation strategies.

Material and methods, We present a functional model for the ANF response to single pulses and pulse-train sequences and show that it can reproduce the most relevant aspects of the ANFs response. The model builds on the biphasic leaky integrate-and-fire model by Horne et al. (Front. Comput. Neurosci., 2016) which we have extended to include elements that simulate refractoriness and facilitation/accommodation by affecting the model's threshold value momentarily after supra- and subthreshold stimulation. Together with an electrical field propagation model and a nerve density estimation the model can predict the response of tonotopically arranged nerve fibers to stimulation on multiple CI electrodes. The model features a limited set of parameters which can be estimated from two-pulse masking measurements using evoked compound action potentials (ECAP) and psychophysical threshold and loudness growth measurements in patients.

Results, We show that our revised model can reproduce neurophysiological data from single-neuron recordings considering refractoriness, facilitation, accommodation and spike-rate adaptation phenomena that affect the responsiveness of the ANF to ongoing pulsatile stimulation. The model can be fitted to published ECAP and psychophysical data of individual patients and reproduce them.

Conclusions, The new phenomenological ANF model capable of reproducing spatio-temporal interaction effects at nerve level for multi-electrode electrical stimulation can be fitted to the individual characteristics of patients. The model thus paves the way for future detailed analysis of evoked nerve activity, loudness and binaural modeling and the prediction of inter-individual differences. In future work, modeling psychophysical behavior will permit the evaluation of individual stimulation parameters with the aim to improve CI strategies.

Keywords: Cochlear implant, model, ECAP, individualization, auditory nerve

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