COCHLEAR IMPLANTS FOR CAT AND MAN & WHAT WE LEARN FROM A MODELING STUDY

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INTRODUCTION

In cochlear implants, by trains of electrical pulses, neural signals are generated that should match the natural signal pattern in the auditory nerve of a normal hearing person. The auditory nerve in man consists of about 30.000 cochlear neurons connecting the sensory cells in the cochlea with the cochlear nucleus, the first auditory processing unit in the brain. Each of these neurons has a cell body (soma) and two processes (axons). Such a structure can be compared with an insulated wire, but the neuronal cable is an organic volume conductor, the insulation consists of sheets of cell membranes (myelin) and for conduction the signal (action potential) needs amplifications in active zones (non-myelinated regions, nodes of Ranvier) via a system of voltage sensitive ion channels.

Cats are experimental animals to study the relationship between stimulus currents and artificially generated signals in the auditory nerve in order to optimize stimulation parameters but this methodology caused a fundamental problem.

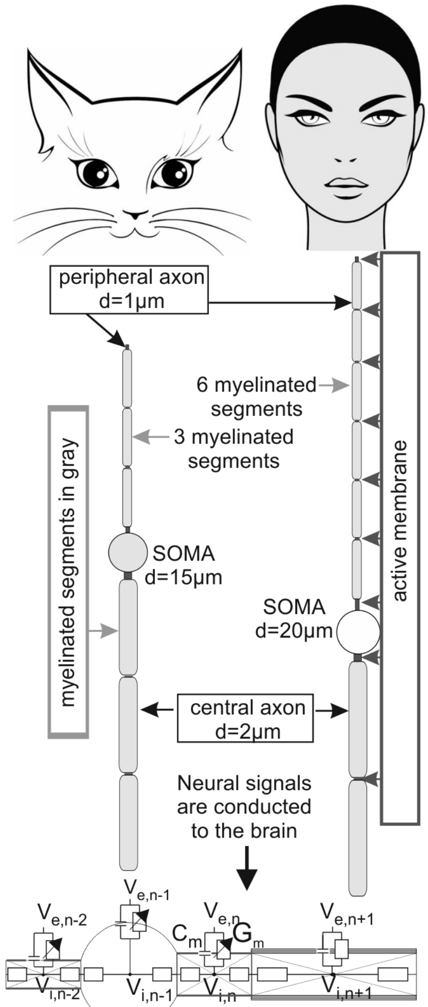

Fig. 1. Cat vs. Man: Cochlear neurons in man have longer axons, their somas are a bit larger and not myelinated [1]. Bottom: Electric circuits to simulate neural signals in a neuron.

FUNDAMENTAL OF THE PROBLEM

The main problem using experimental findings form cat data for cochlear implant stimulus parameters is the unexpected impact of the longer human peripheral axon (6 segments, Fig. 1)[1,2]. Negative stimulus pulses need essentially less intensity to generate action potentials within the peripheral axon in cat, but in man the minimum intensity is for positive pulses. As the researchers trusted on the experimental cat data this unexpected polarity effect was not considered in cochlear implants built for humans. Here, new morphometric data are used in a simplified model where the neuron's axis is a straight line to demonstrate the higher sensitivity of the human cochlear neuron to the positive stimulus polarity[1].

Voltage sensitive ion channels make the excitation of the cell membrane of a neuron possible. The excitation process of a single active part can be described by 4 non-linear differential equations[2,3]. Single active membrane segments (marked as active compartments in Fig. 1) are combined (also with passive elements) via intracellular resistances (Fig. 1, bottom). The resulting system of ordinary differential equations is stimulated either via current injection at the first compartment (simulating natural excitation from the hair cell) or via the applied electric field that causes different extracellular potentials V_e along the neuron. For technical details see references 1, 2 and 4.

RESULTS AND DISCUSSION

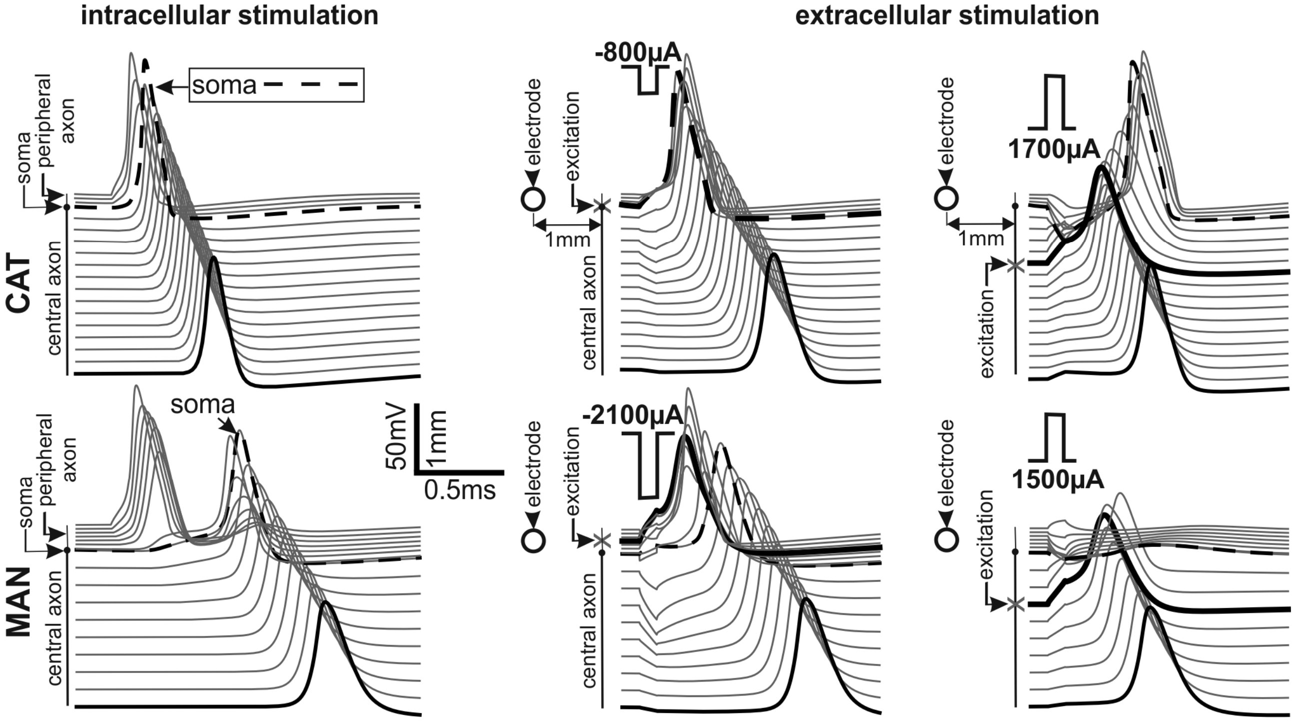

Figure 2 demonstrates two key differences between cat and man. For intracellular stimulation a 0.1ms stimulus current of 100pA is injected in the first compartment causing a propagating action potential which needs in man (because of the nonmyelinated soma[2]) about 0.68ms longer to pass the displayed 2.7mm long section on the way from the receptor cell (inner hair cell) in direction to the cochlear nucleus in the brain. Cat's signal is quicker! Most impressive is the polarity sensitivity. In cat positive pulses need about the doubled intensity to elicit an action potential, but in man it is vice versa: excitation is essentially easier with positive pulses. Note, for positive pulses excitation is generated rather far from the electrode in the central axon and that the quickest signalling with cochlear implants is expected for positive pulses – here, concerning signal speed, man is better than cat. Similar results as predicted by our simulations are seen in tests of implant users[5].

CONCLUSION

Rather small changes in geometry caused surprising results. Computer simulations reduces the importance and number of animal experiments in many cases, also in cochlear implant research.

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