BMC Neuroscience

Oral presentation

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Object localization through the lateral line system of fish

Julie Goulet*[1], Jacob Engelmann[2], Boris Chagnaud[2], Jan-Moritz Franosch[1] and J Leo van Hemmen[1]

Address: [1]Bernstein Center for Computational Neuroscience and Physik Departement T35, TU München, 85747 Garching bei München, Germany and [2]Institute for Zoology, University of Bonn, Poppelsdorfer Schloss, 53115 Bonn, Germany

Email: Julie Goulet* - julie@ph.tum.de

* Corresponding author

from Sixteenth Annual Computational Neuroscience Meeting: CNS*2007
Toronto, Canada. 7–12 July 2007

Published: 6 July 2007

BMC Neuroscience 2007, **8**(Suppl 2):S6 doi:10.1186/1471-2202-8-S2-S6

Fish use their lateral-line mechanoreceptive system to analyze water motion around their body. The functional unit of the fish lateral-line system is a neuromast. This is in essence a cupula, a gelatinous protuberance sticking into the water and deflected by local water flow. Deflections stimulate sensory hair cells at the basis of the cupula and in this way generate spikes in the lateral-line nerves. Neuromasts are either free standing on the skin (superficial neuromasts, SN) or in a system of sub epidermal canals (canal neuromasts, CN). It has been shown that SNs are sensitive to constant flow whereas CNs are not. Nobody, however, has ever proposed a mathematical model to relate the water perturbation in the fish environment to the water motion in the canal, the neuromasts displacement, and the spike flow in the afferent nerves. This is what we do here. The CN system consists of canals that are open to the external environment through approximately equidistant pores. Between each pair of pores at the surface one can find one or more neuromasts in the canal. A pressure difference between the pores induces water movement in the canal and hence stimulates the neuromasts. We solve the case of a small sphere oscillating near the body, study the effect of different terms of the hydrodynamics on the pressure map of the fish body and the ensuing neuronal excitation pattern, and show that the maximum and the two points where the pressure difference between two pores vanish suffice to enable a fish to determine the distance to a stimulus. Our theory has been confirmed by recording experiments. It has also been shown that even though a constant flow does increase the firing rate the effect induced by an oscillating dipole and the distance between the zeros can still be measured.

Acknowledgements

Project funded by the Bernstein Center for Computational Neuroscience – Munich.