

Delay Lines and the Neurophonic Potential in the Sound-Localization Circuit of Birds

Nico Lautemann¹, Paula T. Kuokkanen², Richard Kempter^{2,3}, Hermann Wagner¹

¹RWTH Aachen, Biology II, Dep. of Zoology and Animal Physiology, Kopernikusstr. 16, D-52056 Aachen, Germany

²Institute for Theoretical Biology, HU Berlin, Germany

³BernsteinCenter for Computational Neuroscience, Berlin, Germany

Barn owls (*Tyto alba*) are nocturnal hunters that are able to catch their prey in complete darkness by only using auditory cues. The cue used to localize the azimuthal position of a sound source is the interaural time difference (ITD). ITD is the difference of the arrival time of a sound at the two ears. A variety of specializations at different levels and a separate neural circuit, the time pathway, have evolved to achieve the high temporal resolution.

The time pathway starts in the cochlear nucleus magnocellularis (NM). The axons of NM neurons project bilaterally to nucleus laminaris (NL), making NL the first binaural stage in the time pathway. The NL neurons are narrowly tuned to sound frequency and act as coincidence detectors. Simultaneous inputs from the right and left side cause the neurons to be maximally active. Firing frequency changes periodically in dependence of an imposed phase shift between the left and right inputs. Nucleus laminaris contains both a tonotopic map and a map of ITD. The projections from the ipsi- and contralateral NM form delay lines. The ipsilateral axon collaterals contact and penetrate NL from dorsal, while the contralateral axon collaterals run on the ventral side and transverse NL from ventral to dorsal. The map of ITD results from the synapses of the axon collaterals with NL neurons at different dorso-ventral depths (barn owl) or different medio-lateral positions (chicken). In this way a time-code present in the NM collaterals is converted into a place-code in NL neurons.

The key elements and features of such a sound-localization circuit have been proposed by Jeffress in 1948. Since then a large amount of evidence has been accumulated, supporting the hypothesis that this model is realized in birds. However, the existence of delay lines in the barn owl has not yet been directly shown. To do so, we used slices of the NM-NL circuit and recorded the extracellular multi-unit activity in NL at many different positions with multielectrode arrays (MEA) while electrically stimulating the NM inputs. The simultaneous measurement of response latency at many positions in NL allows to directly demonstrate the existence of delay lines.

Latencies changed within the NL of the barn owl from medial to lateral as well as in the dorso-ventral direction. Latencies between two neighbouring electrodes (distance: 200 μm) were about 34 to 250 μs corresponding to propagation velocities between 0.8 – 5.9 m/s. Thus, our preliminary data provide the first direct demonstration of delay lines in the barn owl.

We also want to find out more about the so-called neurophonic potential which is a frequency-following potential occurring in early stages of the time pathway. The possible sources of this potential in NL are the phase-locked signals from the afferents from NM, their synapses and the postsynaptic potentials of NL neurons. Theoretical considerations suggest the NM afferents to be the most likely sources of the neurophonic potential in NL of barn owls. We want to falsify that experimentally by blocking the postsynaptic activity to separate the different sources.