this is a 1000 word abstract submitted to the:

Twelfth Annual Computational Neuroscience Meeting CNS*2003

Sound localization across the frequency range

Petr Marsalek, Jiri Kofranek

e-mails: marsalek@karlin.mff.cuni.cz, kofranek@mbox.cesnet.cz
Charles University Prague, Department of pathological physiology,
U nemocnice 5, Praha 2, CZ-128 53, Czech Republic

Higher animals are able to localize the direction of incoming sound across the horizontal plane. The accuracy of the sound localization is well known. In humans it is circa 4 angular degrees at the best sensitivity range. When studying, how the auditory system accomplishes this, several questions arise: Q1: How does the neural pathway process the sound incoming into the two ears? How does the pathway look and what are the neuronal assemblies is known from experimental works in 1960-ies [1, 2]. Q2: What is the maximal precision, or best performance, of the sound localization system? This has been experimentally mapped in various species including barn owls, dogs and humans in 1990-ies [3]. Now we can ask how the neural circuitry does it. A classical physiologists view of neural processing of synaptic inputs is that they are summed up and in this concept any nonlinearities are discarded. Yet the theories of sound localization imply rather multiplication of inputs from the two sides. Q3: Is there a neural circuit, which implements multiplication instead of summing? Under certain conditions biophysically plausible neural circuit can implement multiplication [4, 5]. Q4: Is the mechanism for sound localization different in different frequencies (with respect to the neural circuitry)? It is known from anatomy for a long time that there are two distinct pathways. What is less known are quantitative descriptions of what do the neurons in these pathways. The low frequency circuit is a bit simpler [6]. The high frequency circuit uses an additional mechanism of passing input from one side through inhibitory neuron [7]. Q5: Is there an unifying concept of how these two circuits work? How is their output combined to yield an unified percept of lateralized sound source? We ordered these questions from simpler and older to newer and more controversial. In the presented work we address the later questions.

We model the first nuclei in the pathway. We describe them at the level of neuronal spikes and spike generating mechanism. The pathway starts with inner ear (cochlea). Auditory input, which is continuous in time, is discretized into spike trains at the cochlear sound processing stage. We describe how the input is discretized. Spike trains are relayed in successive nuclei along the pathway. The pathway consists of the two subsystems, one operates at a lower frequency band, and another at higher frequencies. The distinction between the two is also in their dominant use of two different cues of sound direction. The low frequency system uses interaural time delay and the other subsystem uses interaural intensity difference. An interesting property of the model is that is shows how encoding type described in the first subsystem gradually changes into the encoding type of the second subsystem as the frequency of sound changes to higher values.

The coexistence of the two subsystems is also witnessed by the best performance of the sound localization pathway. Across the frequency range, there is a notch in a sensitivity at the border of the frequency ranges of the two subsystems.

In the model, several input quantities are used on the input side: loudness, main frequency, and incoming sound direction, implicitly contained in the interaural time difference and in the interaural intensity difference. Then the spike train characteristics are derived from the input quantities. These are mean firing frequency, spike train statistics, and a degree of phase locking to the low frequency sound envelope. A deterministic algorithm for the spike generation is described. We compare the descriptions in the two subsystems. We propose an encoding scheme based on this comparison. We show that a neuron which detects coincident arrivals of spikes from two neurons can function as a multiplier. This means that within some limited frequency range, its average output frequency is proportional to the product of average input frequencies. We give an unified formula applicable in the two subsystems. Further we show how individual spikes are computed in these systems.

Acknowledgments

Supported by the grant of Czech Ministry of Education # VZ111100008 (physiome.cz)

References

[1] J. M. Goldberg and P. B. Brown. Response of binaural neurons of dog superior olivary complex to dichotic tonal stimuli: Some physiological mechanisms of sound localization. *J. Neurophysiol.*, 32:613–636, 1969.

[2] J. E. Rose, N. B. Gross, C. D. Geisler, and J. E. Hind. Some neural mechanisms in the inferior colliculus of the cat which may be relevant to localization of a sound source. *J. Neurophysiol.*, 29:288–314, 1966.

[3] M. Konishi. Similar algorithms in different sensory systems and animals. In *Cold Spring Harbor Symposia on Quantitative Biology*, pages 575–583. CSHL Press, New York, 1990.

[4] M. V. Srinivasan and G. D. Bernard. A proposed mechanism for multiplication of neural signals. *Biol. Cybernetics*, 21:227–236, 1976.

[5] P. Marsalek. Coincidence detection in the Hodgkin-Huxley equations. *BioSystems*, 58(1-3):83–91, 2000.

[6] P. Marsalek. Neural code for sound localization at low frequencies. *Neurocomputing*, 38-40(1-4):1443–1452, 2001.

[7] P. X. Joris and T. C. Yin. Envelope coding in the lateral superior olive. I, II and III. *J. Neurophysiol.*, 73(3):1043-1062, 1995; 76(4):2137-56, 1996; 79(1):253-69, 1998.