A MODEL FOR ACTIVE CONTROL IN THE COCHLEA

K. Grosh* and Niranjan V. Deo †

* Department of Mechanical Engineering
Department of Biomedical Engineering
University of Michigan
Ann Arbor, MI 48109-2125
grosh@umich.edu

† Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48109-2125

The cochlea is the organ in the inner ear responsible for performing real-time, time-frequency analysis of sound. In the mammalian cochlea frequency analysis is achieved by means of spatial localization of the frequency content of the incoming sound to organized locations down the length of the fluid-filled cochlear ducts. This localization is made possible through the coupling of a structural membrane possessing slowly varying properties with a water-like ionic fluid. The fluid–structure coupling lowers the wave speed as compared to that in the fluid alone. Normal acoustic excitation of the auditory periphery results in a structural acoustic traveling wave whose peak response location is strongly frequency dependent giving rise to a place-frequency map down the length of the cochlea. The neural response to sound stems from three thousand spatially distributed cells that sense shear motion of the fluid.

The passive mechanics of the cochlea have been understood for nearly 50 years [1]. However, a mechanistic model predicting the active nonlinear response seen in a healthy cochlea is still lacking. We present a model based on the hypothesis that specialized active force generating cells in the cochlea called outer hair cells (OHCs) perform cycle-by-cycle active feedback in conjunction with the dynamics of the structures of the cochlea. *In vivo* experiments indicate that these unique cells possess the authority to drive the sensory epithelium at frequencies well above the audible frequency range, up to 100 kHz [2]. As neural signals cannot pass from the brain to the cochlea at sufficiently high speeds, control by higher cognitive processes is impossible at acoustic frequencies. Therefore, the local mechanics of the cochlear structures and the OHCs must realize the control algorithm. We use a linearized model of the OHC response about the resting state in our model (e.g., [3]). Furthermore, we incorporate the electrical environment in the cochlea using one dimensional cable representations of the electrical pathways along the various scalae and include the coupling of the electrical and mechanical degrees of freedom. It is well-known that the coupling of the mechanical and the electrical response of the cochlea is crucial to proper hearing. Acoustical stimulation gives rise to an electrical response (known as the cochlear microphonic) and electrical stimulation of the cochlea elicits acoustical emissions from the ear canal. A key missing element in most cochlear models is the explicit coupling of the electrical to the mechanical degrees of freedom. Our coupled mechanical–electrical–acoustic model demonstrates how such a system can replicate the frequency response characteristics of the cochlea. We examine the effects of fluid dimensionality and constitutive nonlinearities in our model.

References

[1] G. von Békésy, *Experiments in Hearing*, AIP , 1989.
[2] K. Grosh, J. Zheng, E. deBoer, A. L. Nuttall. "High frequency electromotility of the cochlea," J. Acoust. Soc. of Amer, **115** 2178-2184, 2004.
[3] N. V. Deo and K. Grosh, "Simplified nonlinear outer hair cell models," *J. Acoust. Soc. Amer.* **117**, 2141–2146, 2005.

Keywords: acoustics, cochlear mechanics