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ABSTRACT

The hearing organ of lizards is the basilar papilla, which is homologous to the mammalian organ of Corti. We are investigating the mechanical properties of the basilar papilla and its stereociliary bundles. By combining video microscopy, stroboscopic illumination, and computer vision, we can determine sound-induced displacements of papillar structures with a resolution of 1 nanometer. From images taken at multiple planes of focus we can reconstruct the three-dimensional shape and position of the papilla at each measured phase of sound stimulation. In cross-section for a given longitudinal position the papilla moves as a rigid body, rocking about an axis on the neural side. Because the axis of rotation is on the neural side, the drive for hair bundle deflection is larger for more abneural hair cells. Although each cross-section moves as a rigid body, the motion of cross-sections varies with longitudinal position, particularly at high frequencies: (1) the motion of the basalmost (high-frequency) end of the papilla increases near 5 kHz. This increase is largest for the basalmost 50 µm of the papilla, and decreases steadily to nothing over the next 100 µm. (2) Above 2 kHz, the phase of lateral motion of the papilla increasingly lags that of transverse motion. We have seen phase lags as large as 1/3 cycle at 10 kHz. (3) Above 5 kHz, the phase of lateral motion in the basalmost end of the papilla lags that of the center of the papilla. We have seen phase lags as large as 1/4 cycle at 10 kHz. This phase lag with position is not seen in the transverse component of motion. The increase in papilla motion at 5 kHz in the basalmost region may serve to increase the sensitivity of that region's hair cells, which have best frequencies near 4 kHz. The phase lag between lateral and transverse motion causes the papilla to move in an elliptical rather than a pistonlike fashion at some frequencies. The functional consequence of such elliptical motion is unclear. These results suggest that the mechanical properties of the papilla are anisotropic.

MIT Micromechanics Group

Mechanical Properties of the Basilar Papilla of Alligator Lizard

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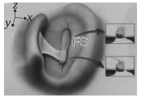
DOES THE BASILAR PAPILLA SIMPLY ROTATE?



In models, basilar papilla motion is simple rotation[2,3,7]

In measurements, more complex motions have been seen[1,4,5]

How does the basilar papilla move?

Does papilla motion account for limitations of models?

- 30 dB range of thresholds[6]
- "Extra" low-pass filter needed in models[2,3,7]

DOES THE BASILAR PAPILLA EXHIBIT MULTIPLE MODES OF MOTION?

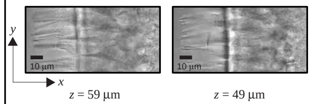
Multiple modes of motion play a role in most models of cochlear mechanics
(5,8 for review)

Does the alligator lizard cochlea have multiple modes of motion?

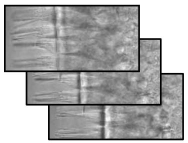
Are these modes important for hearing?

3-D IMAGING OF EXCISED PAPILLA

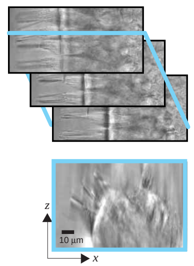
1. ACQUIRE 2D IMAGES AT MULTIPLE FOCAL PLANES



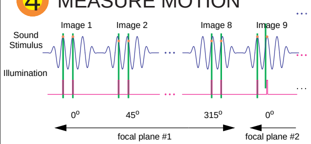
2. ASSEMBLE INTO 3D IMAGES



3. RESLICE 3-D IMAGES



4. MEASURE MOTION

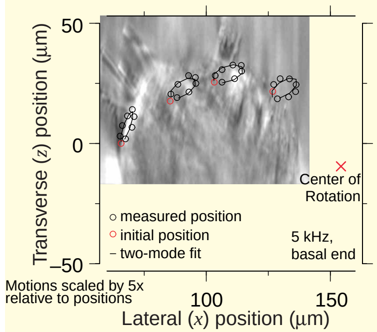


take 3-D images at several phases of sound stimulus

measure motions of papilla and hair bundles from images

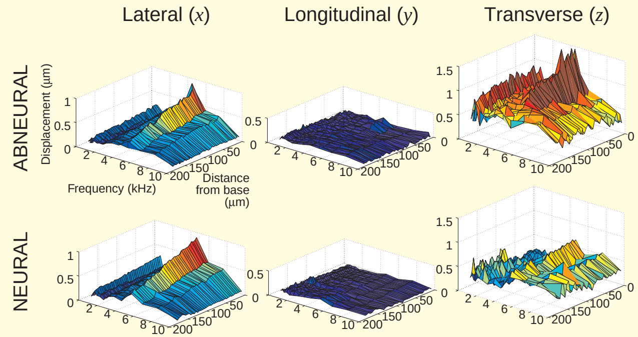
PAPILLA MOTION VARIES WITH POSITION AND FREQUENCY

The Basilar Papilla Has a Translational and a Rotational Mode



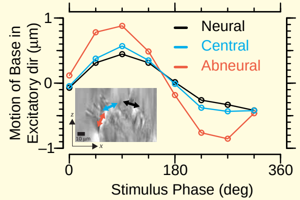
- Motions are elliptical
- Motion on the abneural side is primarily transverse
- Motion on the neural side contains lateral and transverse components
- best 2-mode fit has 1.96° peak rotation and 1.77 µm peak z translation (lines)

Motion Varies With Frequency and Longitudinal Position



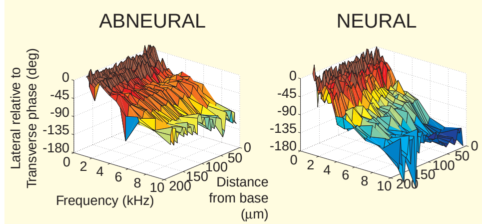
- Displacement peaks near 5 kHz
- Peak is largest at basal end
- Lateral (x) motion is similar on the neural and abneural sides
- Transverse (z) motion is larger on the abneural side
- Longitudinal (y) motion is small

Excitatory Stimulus Varies With Lateral Position



- Motion is largest for abneural hair bundles

Lateral Motion Lags Transverse Motion



- Lag increases with frequency
- Lag is larger on neural side

DISCUSSION

- The basilar papilla exhibits multiple modes of motion
- Papilla motion can be described by one translational and one rotational mode
- Both modes affect hair cell excitation
- Lateral variations in the excitatory component of motion do not account for 30 dB range of thresholds
- Increased papilla motion in the base near 5 kHz may increase the sensitivity of high-CF hair cells
- Phase lag of lateral relative to transverse motion resembles that of a second order low-pass filter
- Individual structures within the mammalian cochlea may also exhibit multiple modes of motion

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