Grand Challenge Research on Seismic Sensing- Obtaining a Meaningful Readout

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Certain golden moles, including *Eremitalpa*, are well-known to have disproportionately large auditory ossicles. For instance, the mass of each malleus in the *Eremitalpa* is approximately 0.1% of the animals total body mass, compared to only 0.001% in the comparably-sized laboratory mouse, *Mus musculu*s, and only 0.00004% in humans. Several authors have suggested that these hypertrophied ossicles are adaptations for detecting ground vibrations, perhaps by *inertial bone conduction*. Employing a physical model of inertial bone conduction, Mason investigated this possibility further. He concluded that the geometries of the enlarged ossicles of *Eremitalpa* made them especially suitable for the detection of low-frequency ground-borne vibrations of very low amplitude (low-frequency microseismic signals). The golden mole might use this ability in order to navigate, and possibly also to identify and locate prey on or beneath the sand.

Our results imply not only attraction toward active vibration sources, but a concomitant ability of the mole to determine the directions of those sources. Two hypotheses for directional sensitivity in sand-swimming golden moles have been discussed- (1) use of interaural time or phase difference in the propagating seismic wave, and (2) the localization potential of having non-parallel axes of rotation of the middle-ear ossicles. Utilization of interaural time or phase difference would require that a substantial component of the vibration imparted to the right side of the mole's skull be independent of that imparted to the left side (i.e., that the skull not vibrate entirely as a unit). Such independence of motion awaits verification. The morphology of the mole's middle-ear ossicles strongly implies directional sensitivity with respect to the particle motion of the seismic wave. Information about the direction of the source would be carried by a horizontal component of particle velocity that is aligned with the direction of seismic-wave propagation. In sand, seismic waves are propagated as surface (Rayleigh) waves or compressional (P) waves. The conduction velocity of Rayleigh waves in loose sand is approximately 40-50 m/s, yielding a wavelength of approximately 80-100 cm at 500 Hz and greater than that for lower frequencies. The particles in a Rayleigh wave follow elliptical paths. Within two-tenths of a wavelength of the surface, the horizontal motion at the top of the ellipse is directed toward the source; at the bottom of the ellipse it is directed away from the source. Below that depth, the elliptical motion is reversed. The sand-swimming moles were within 16 cm of the surface, making them well within two-tenths of a wavelength for the spectral components of our stimuli. By trial-and-error, seeking the direction of greatest stimulation, the mole could utilize the horizontal particle motion monaurally. Radiographs of the middle ear suggest that the axes of rotation of the golden mole's right and left ossicular chains are not parallel to each other in the horizontal plane. Thus, obliquely incident horizontal particle motion would excite the two ossicular chains to different extents, and the difference would bear information regarding source direction. This opens the possibility of binaural localization of the seismic source. The grand challenges remaining for this remarkable seismic detection system would be to (1) capture a more complete understanding of the mechanisms underlying localization of low-level seismic signals by animal specialists, and (2) to construct an artificial golden mole ear using the biosensing principles we learn from analyzing the golden mole middle ear.