

SMELLING WITH HAIRY LITTLE NOSES: THE PHYSICAL DESIGN OF OLFACTORY ANTENNAE

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INTRODUCTION

Appendages bearing arrays of hair-like structures serve important biological functions in many animals from a variety of phyla: feathery gills take up oxygen, chemosensory hairs on olfactory antennae capture odorant molecules, filamentous suspension-feeding structures catch single-celled algae, setulose appendages create ventilatory or feeding currents, and bristly legs or wings propel little animals through the surrounding water or air. To perform any of these functions, an array of hairs must interact with the surrounding fluid. We have been studying the fluid dynamics of arrays of cylinders to elucidate basic rules governing how hairy appendages work (Cheer & Koehl 1987; Koehl, 1995). The present study uses these rules to determine how the physical designs of olfactory antennae affect how they filter chemical information from the environment (Koehl 1996; 2001).

Many animals use chemical cues in the water or air around them to detect mates, competitors, food, predators, and suitable habitats. The first step in processing olfactory information, before neural filtering, is physical capture of odorant molecules from the surrounding fluid. Many crustaceans capture scents by flicking antennules that bear arrays of chemosensory hairs. We studied how the hydrodynamics of crustacean olfactory antennules flicking in turbulent odor plumes physically alters the spatio-temporal patterns of concentration arriving in the receptor area.

METHODS

We conducted high-speed video analyses of antennule flicking kinematics and SEM determination of antennule morphometrics (Goldman & Koehl 2001). Dynamically-scaled physical models and mathematical models were used to quantify the small-scale flow fields around antennule chemosensory hairs and the diffusion of odorant molecules to hair surfaces (Koehl 2001). Planar-laser-induced fluorescence was used to measure the fine-scale structure of odor plumes in turbulent water currents in a flume, and the instantaneous patterns of odorants arriving among the sensory hairs on antennules flicking in such plumes were recorded using high-speed, high-magnification video (Koehl *et al.* 2001).

RESULTS AND DISCUSSION

Lobsters and mantis shrimp flick their olfactory antennules in a critical Reynolds number range for their particular arrangements of chemosensory hairs (Reynolds number, Re , represents the relative importance of inertia to viscosity). They flick in the Re range in which the ability of water to

penetrate into the hair array changes with velocity. We found that water flows through the hair array during the rapid flick, but not during the slower return stroke. In turbulent water currents, odor plumes are made up of fine-scale filaments of scent whose pattern varies with distance from the source. Water carrying these patterns of concentration penetrates into the array of chemosensory hairs only during the rapid flick, and is retained until the next flick.

SUMMARY

We used the antennules of spiny lobsters and mantis shrimp to analyze the critical first step in determining the spatial and temporal patterns of odor pulses arriving at receptors: physical interaction of the olfactory organ with an odor plume. The chemosensory hairs these olfactory antennules operate in a range of Re and hair spacings in which changes in velocity can have profound effects on the flow near the hairs, and thus on their performance in capturing molecules from the surrounding fluid. Our work has revealed how lobster olfactory antennules hydrodynamically alter the spatio-temporal patterns of concentration in turbulent odor plumes. Antennules flick: water penetrates into their chemosensory hair array only during the fast downstroke, carrying fine-scale patterns of concentration into the receptor area. Hence, because of the hydrodynamics of their antennules, these animals take discrete odor samples in space and time (i.e. they sniff).

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