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13. ABSTRACT (Maximum 200 words) Lake Michigan mottled sculpin exhibit a naturally-occurring and unconditioned prey capture behavior that can be evoked by real (live prey) and artificial (vibrating sphere) hydrodynamic sources in the absence of visual or chemical cues. This behavior consists of (1) an initial orienting response towards the source, (2) a step-wise approach towards the source and (3) a final strike at the source. This behavior is largely controlled by the spatially-distributed lateral line system, which, when blocked, leads to an almost complete disappearance of the prey capture behavior. In a series of behavioral, physiological and modeling experiments, we have (1) described and analyzed the pathways followed by sculpin to the dipole source to identify the behavioral strategies and mechanosensory cues used by fish in finding the source, (2) measured and modeled (a) the pressure-gradient field around a low frequency (50 Hz) dipole (vibrating sphere) source and (b) the responses of peripheral lateral line nerve fibers to the same source in order to determine how excitation patterns along the lateral line system represent the location and distance of the source, and (3) compared and contrasted the physiological response properties of peripheral lateral line fibers and cells in the first-order brainstem nucleus to determine how the peripheral representation of source location is enhanced or transformed by neural circuits in the central nervous system.				
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FINAL REPORT

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PRINCIPAL INVESTIGATOR: Dr. Sheryl Coombs with co-investigators
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INSTITUTION: Parmly Hearing Institute, Loyola University of Chicago

GRANT TITLE: Localization of Low Frequency Hydrodynamic Sources by Fish.

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OBJECTIVES: (1) To identify the behavioral strategies and sensory cues used by fish in localizing nearby, low frequency hydrodynamic sources, (2) to determine how source location is encoded by the lateral line system, (3) to determine how the peripheral representation of source location is enhanced or transformed by neural circuits in the central nervous system (CNS).

APPROACHES: **Behavioral approaches** involve videotaping the naturally-occurring, unconditioned approach and strike behavior of free roaming fish (mottled sculpin, *Cottus bairdi*) towards low frequency dipole sources (6 mm-diameter, 50 Hz vibrating sphere). **Modeling approaches** use MATLAB computer programs (computational matrices) to model the (1) dipolar stimulus field and expected excitation patterns along the lateral line and (2) neural circuitry underlying CNS processing. **Physiological approaches** employ extracellular recording techniques to record spike activity from either the brain or cranial lateral line nerves in response to a dipole source (the same used in behavioral experiments) that slowly (4 mm/sec) changes its location along the length of the fish.

ACCOMPLISHMENTS: **Behavioral Experiments:** To identify the behavioral strategies used by fish in localizing hydrodynamic sources, we videotaped and analyzed over 400 pathways followed by blinded sculpin to a dipole source (50 Hz vibrating sphere) when the lateral line system was intact (Coombs & Conley 1997a,b). To discriminate between two alternative mechanisms for encoding source location: (1) computations based on bilateral differences in time and/or level of excitation and (2) a unilateral representation of source location in the pattern of activity along the sensory surface, we videotaped and analyzed the orienting behavior of blinded sculpin after site-specific, unilateral ablations of the lateral line system (Conley & Coombs 1998). **Modeling Experiments:** We used the dipole flow field equations to model excitation (pressure-gradient) patterns along the trunk lateral line canal of goldfish and sculpin for (a) different distances and orientations of a 50 Hz dipole source (Coombs et al. 1996) and (b) different inter-pore distances of the lateral line canal (Coombs 1996). To verify that models were reasonable representations of the actual flow field and stimulus to the lateral line system under conditions used in behavioral and physiological conditions, we used (1) a hydrophone to measure how well pressure-gradient patterns in experimental set-ups compared to modeled patterns and (2) extracellular recording techniques to measure how well modeled and measured pressure-gradient patterns were encoded by lateral line nerve fibers (Coombs et al

1996, Coombs & Conley 1997b, Coombs et al 1998). Finally, we used behavioral results from pathway experiments to model how lateral line excitation patterns along the left and right side of the fish's head would change as fish approached dipole sources (Coombs & Conley 1997b). **Physiological Experiments:** To determine (1) the relationship between modeled pressure-gradient patterns and neural response patterns and (2) how peripheral representations of source location are enhanced or transformed by neural circuits in the central nervous system (CNS), we recorded the responses of 165 first-order brainstem (medial) nucleus cells and 52 peripheral lateral line nerve fibers in mottled sculpin and goldfish to the changing locations of a 50 Hz dipole source (Coombs et al. 1996, Coombs & Conley 1997b, Coombs et al 1998).

CONCLUSIONS: Behavioral results from blinded mottled sculpin with intact lateral line systems show that approach strategies used by these fish in finding dipole sources include (1) moving in a direction that increases the pressure difference along the head while keeping it consistently low (between 1 and 10 Pa) across the head, (2) keeping the source lateralized (on average, 30° to the side of the head) and (3) avoiding approach positions that are perpendicular to the flow line or that place the fish in the pressure null area of the dipole field (Coombs & Conley 1997a). Site-specific deficits in the angular accuracy of the initial orienting response and the absence of abnormal approach pathways after regional and unilateral blocking of the lateral line system argue that fish are relying on a point-by-point spatial representation of source location along the sensory surface rather than computations based on bilateral comparisons (Conley & Coombs 1998). **Physiological results** from both mottled sculpin and goldfish show that responses of primary lateral line nerve fibers to different source locations can be predicted from pressure-gradient patterns in the stimulus field, but that those of cells at the next level of the nervous system (principal output cells of the first-order brainstem nucleus) have been transformed considerably relative to the peripheral inputs. **Modeling results** have shown that the approach and strike behaviors of mottled sculpin (i.e. their ability to localize vibratory sources) can largely be predicted on the basis of information available in spatial excitation patterns along the lateral line system. In particular, changes in the spatial distribution of pressure gradient directions (phase), available only when the source is lateral (as opposed to directly in front of the fish), appear to enhance the ability of sculpin to determine source distance and thus, may account for approach strategies in which the source is lateralized. Without such information, misses are more likely to occur and successful strikes are more likely to be launched from short distances only. Modeling results on receptive field organizations in medullary cells indicate that a simple, feed-forward, lateral inhibitory network can account for at least two types of organization (excitatory center/inhibitory surround and inhibitory center/excitatory surround) measured physiologically in the first-order brainstem nucleus of the mottled sculpin.

SIGNIFICANCE: Taken together, behavioral, physiological and modeling results support the hypothesis that spatial excitation patterns along the lateral line system play a significant role in encoding source location. Lateral line nerve fibers faithfully encode both the amplitude and direction (phase) of the pressure-gradient field surrounding a dipole source. Information about source azimuth is contained in the spatial location of the peak excitation (pressure-gradient) level, whereas information about source distance is contained in the spatial extent of excitation. The locations at which pressure-gradients change directions may provide additional information about the spatial extent of excitation and its location. Transformations that occur in the CNS appear to enhance the ability of the system to encode changes in both pressure-gradient amplitudes and directions. First-order brainstem cells with inhibitory-center/ excitatory-surround receptive-fields respond best to changes in pressure-gradient directions, whereas those with excitatory-center/inhibitory surround organizations respond best to changes in pressure-gradient amplitude.

PUBLICATIONS (for total period of grant)

- Conley, R.A. and S. Coombs (1998). Dipole source localization by mottled sculpin. III. Orientation after site-specific, unilateral blockage of the lateral line system. *J. Comp. Physiol.* 183: 335-344.
- Coombs, S, J. Mogdans, M. Halstead and J. Montgomery (1998). Transformations of peripheral inputs by the first order brainstem nucleus of the lateral line system. *J. Comp. Physiol.* 182: 609-626
- Montgomery, J.C. and S. Coombs (1998). Peripheral encoding of moving sources by the lateral line system of a sit-and-wait predator. *J. Exp. Biol.* 201(1): 91-102.
- Coombs, S. and J.C. Montgomery (1998). The lateral line system in fishes and amphibians. In: *Comparative Hearing: Fishes and Amphibians*. (A.N. Popper and R.R.Fay, eds.) Springer-Verlag, N.Y.
- Coombs, S., Braun, C.B. and Donovan, B. (1998) The role of lateral line canal neuromasts in prey capture behavior by the mottled sculpin. *Proceedings of the 5th International Congress of Neuroethology*. San Diego, Ca. Aug. 1998
- Aboud, J. and Coombs, S. (1998) Mechanosensory control of vertical head posture during prey capture behavior by mottled sculpin. *Proceedings of the 5th International Congress of Neuroethology*. San Diego, Ca. Aug. 1998
- Coombs, S. and R.A. Conley (1997a). Dipole source localization by mottled sculpin. I. Approach strategies. *J. Comp. Physiol.* 180:387-399
- Coombs, S. and R.A. Conley (1997b). Dipole source localization by mottled sculpin. II. The role of lateral line excitation patterns. *J. Comp. Physiol.* 180:401-415
- Coombs, S. and R.R.Fay (1997). Encoding of dipole near fields by the goldfish auditory system. *Neurosci. Abst.* 23(1): 179.
- Coombs, S, J. Mogdans, M. Halstead, and J. Montgomery (1997). Responses of cells in the first-order lateral line brainstem nucleus suggest rudimentary amplitude and phase-encoding pathways. Association for Research in Otolaryngology, St. Petersburg Beach, Fla. Feb. 1997
- Conley, R. and S. Coombs (1997). Spatial excitation patterns, not bilateral computations, are important for source localization by the

- lateral line system. Association for Research in Otolaryngology, St. Petersburg Beach, Fla. Feb. 1997
- Alborg, L. , S. Coombs and J.G. New (1996). Strike behavior in the muskellunge, *Esox masquinongy*: Relative contributions of lateral line and visual sensory systems. Neurosci. Abstr. 22: 446
- Conley, R.A. and Coombs, S. (1996). The use and misuse of lateral line excitation patterns in determining source location by the mottled sculpin. Association for Research in Otolaryngology, St. Petersburg Beach, Fla. Feb. 1996
- Coombs, S. (1996). Interpore spacings on canals may determine distance range of lateral line system. Soc. Neurosci. Abstr. 22:
- Coombs, S., M. Hastings and J. Finneran (1996). Measuring and modeling lateral line excitation patterns to changing dipole source locations. J. Comp. Physiol. 178: 359-371.
- Coombs, S. and R.A. Conley (1995). Approach strategies used by mottled sculpin in localizing dipole sources. Soc. Neurosci. Abstr. 21:
- Coombs, S. and Conley, R.A. (1995). Source distance determination by the mottled sculpin lateral line. In: M. Burrows, T. Matheson, P.L. Newland and H. Schuppe (Eds.) *Nervous Systems and Behavior. Proceedings of the 4th International Congress of Neuroethology.* p 349.
- Montgomery, J., Coombs, S. and M. Halstead (1995). Biology of the Mechanosensory Lateral Line in Fishes. Rev. Fish Biol. & Fisheries 5: 399-416
- Coombs, S. (1995). Natural orienting behaviors for measuring lateral line function. In: *Methods in Comparative Psychoacoustics* (R. Dooling, R.R. Fay, G. Klump and W.C. Stebbins, eds). Birkhauser. 237-248.
- Montgomery, J., Coombs, S., Conley, R.A. and Bodznick, D. (1995). Hindbrain sensory processing in lateral line, electrosensory and auditory systems: A comparative overview of anatomical and functional similarities. Audit. Neurosci.1: 207-231.