Active sensing movements are modulated by the strength of sensory feedback in weakly electric fish*

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Active sensing is the expenditure of energy, often in the form of movement, for the purpose of sensing the environment. The weakly electric fish *Eigenmannia viriscens* images its environment using two main sensory modalities: vision and electric sense. The glass knifefish is a model species for its ability to precisely track moving sources of shelter. When tracking in the dark, the fish wiggles its body back and forth in order to active increase electrosensory feedback and prevent perceptual fading. We hypothesized that the fish will adapt this active sensing behavior to maintain sufficient sensory feedback.

A custom closed-loop experimental rig allows us to move a "shuttle" in real time with a gain directly proportional to the movements of the fish. In this way we can suppress or enhance sensory feedback that the fish experiences due to its active sensing movements (Fig. 1)

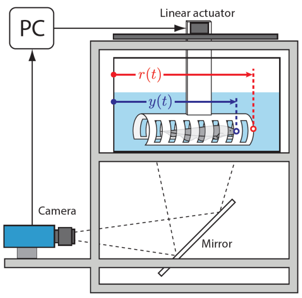

Figure 1: The closed-loop experimental apparatus used to suppress or enhance reafferent sensory feedback in real time. Image courtesy of LIMBS laboratory.

At each of two gain values, -100% and +22%, we performed "closed-loop" trials in which the shuttle moves with gain proportional to the motions of the fish. The position of both the fish and shuttle were recorded throughout the course of 60 second trials in the dark. Each recorded shuttle trajectory was played back in five "open-loop" trials. Five additional closed-loop trials were performed for comparison at each gain value. All trials were randomized to avoid ordering effects, and this was performed on five fish (n = 5).

At gain value -100%, we found that the fish moved less in the closed-loop trial than it did in any of the five open-loop playback trials, for all three recorded trajectories. The opposite effect was seen, though not as strongly, with gain value +22% (Fig. 2). All five fish demonstrated statistical significance ($p < 0.0001$) for the negative gain value, and one fish demonstrated significance ($p < 0.005$) for the positive gain value (one-sided binomial test).

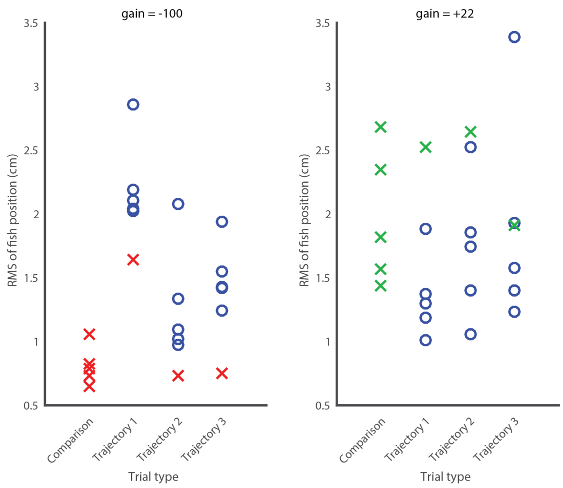

Figure 2: Results from one representative fish. Red and green crosses represent closed-loop trials with negative and positive gain respectively. Blue circles represent open loop trials.

In general, we observed less active sensing motion when sensory feedback was enhanced using a negative gain. Conversely, more active sensing motion was observed when sensory feedback is suppressed using a positive gain. In short, manipulating the gain of sensory feedback modulates the active sensing behavior of the fish. This result supported our hypothesis that the fish adapts its active sensing motions based on the strength of sensory feedback.

This work opposes the traditional view of the nervous system being tuned to behavioral demands by showing a clear case in which active sensing behavior is tuned to the demands of the nervous system (Fig. 3). Additionally, a quantitative characterization of active sensing would provide key insights for optimal sensor placement and design in robotic systems. Such systems could maximize sensory information by utilizing active sensing via motion that adapts to environmental feedback. Future work will involved further mathematical analysis of active sensing behavior as well as neural recordings from the optic tectum during closed-loop behavioral experiments.

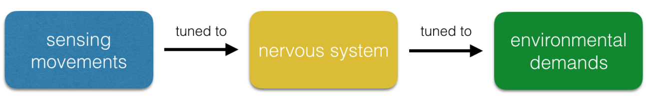

Figure 3: Visualization of a neural tuning paradigm in which active sensing movements are tuned to sensory demands, which are in turn tuned to the demands of the environment.

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