Spatial Cognition and Navigational Learning within the Sculpin Genus *Oligocottus*

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Writer's Comment: *For as long as I can remember, I have always been in awe of the ocean and the life that lives there. So when I was presented with the challenge of constructing my own research project at the UC Davis Bodega Marine Laboratory as part of my Marine Biology Immersion, I jumped at the opportunity. During my time at the lab, I became intrigued by how tidepool animals perceived and moved about the intertidal zone, so I chose to study the navigational skills of small tidepool fish known as sculpins. I worked countless hours for many weeks on my project before I was ready to reveal my findings to the laboratory professionals. When I later enrolled in Victor Squitieri's UWP 104E Science Writing course, I was assigned to write an experimental report in the format of an official scientific journal. My previous research was the perfect platform for this assignment, and I took the opportunity to rework my old project into a report worthy of professional presentation. My thanks go out to Professor Squitieri for his writing critique and guidance, as well as all the professors and personnel at the Bodega Marine Laboratory who helped make my research possible.*

Instructor's Comment: *Armed with a passionate interest in the navigational feats of teleosts, and fresh from fieldwork at the UC Davis Bodega Marine Laboratory, Andrew Maddox arrived in my UWP 104E Scientific and Technical Writing course eager to put his interest and expertise to work. In "Spatial cognition and navigational learning within the sculpin genus Oligocottus," Andrew ambitiously targets the style, specifications, and professional standards of the* Journal of Experimental Biology and Ecology, *an appropriately selected peer-reviewed scientific journal. Using a satisfying and clearly explained experimental design, Andrew found that over successive timed trials tidepool and fluffy sculpins learned to recognize a maze and negotiate its spatial configuration with measurably improved efficiency, thus confirming the hypothesis that sculpins possess a significant navigational aptitude.*

—Victor Squitieri, University Writing Program

Abstract

The ability to actively learn and remember is a cognitive ability that has long been studied in terrestrial vertebrates, but its application to aquatic vertebrates like fish is not as well understood. I tested the learning capabilities of the tidepool sculpin (*Oligocottus maculosus*) and the fluffy sculpin (*Oligocottus synderi*) by timing their ability to navigate a maze via a food cue over several trials on a short-term and long-term basis. After one trial in the maze, the sculpins were able to navigate in less than half of the time of their previous trial. Subsequent trials continued to produce navigation times that were faster than initial trials under both short-term and long-term conditions, indicating that the sculpins had learned to recognize and memorize the spatial construction of the maze and conceptualize their orientation as they navigated through it. The results of the experiment show that sculpins can quickly learn and memorize unknown terrain through experience to optimize navigation across a specified area.

Keywords

sculpin, cognition, maze, memory, navigation

1. Introduction

The learning capabilities of vertebrates have been of biological interest for decades, but most studies on this topic have focused primarily on terrestrial tetrapods. Research on animals such as rats (Moghaddam and Bures, 1996) have proven that many species throughout the vertebrate subphylum are capable of learning behavior attuned to specified environmental conditions and recognizing and memorizing spatial orientation, cognition that for centuries was reserved solely for human intelligence. Despite these findings, however, experimentation on the learning capabilities of aquatic vertebrates like fish has not been as well documented.

Previous studies on the cognitive abilities of fish have found that fish can learn to recognize and memorize experimental stimuli (Yue et al., 2004) and topography (Haight and Schroedor, 2011) under controlled conditions and in natural environments (Ueda et al., 1998). Test results have also concluded that fish can recognize visual and olfactory cues that can be used for navigation (Khoo, 1974). Most observed species for these studies have been those that occupy at least part of their life cycle in freshwater, but some experiments have recorded similar behavior in species that are exclusively marine. Intertidal sculpin species have displayed a homing instinct in field studies (Yoshiyama et al., 1992) that enables individual fish to return to specific tidepools after displacement, suggesting that sculpins can learn spatial terrain and recognize visual and olfactory cues as well.

In this experiment, I test the speed and ability of intertidal sculpin species to learn and recognize unique spatial design. Tidepool sculpins (*Oligocottus maculosus*) and fluffy sculpins (*Oligocottus synderi*) were acclimated from the wild and set to swim through a maze towards an olfactory food cue. Individual fish were run through the course repeatedly and the time taken to pass was recorded to determine recognition of route from the first exposure and subsequent trials. Recognition of spatial orientation would be shown by a decrease in navigation time over the course of several trials, indicating that the fish were learning the path and memorizing the location of passage points.

2. Materials and methods

2.1 Acquisition of fish

Sculpins were gathered from the intertidal zone near Mussel Point on the Bodega Marine Preserve. The species used for the experiment were the tidepool sculpin (*Oligocottus maculosus*) and the fluffy sculpin (*Oligocottus synderi*), which appear morphologically identical and occupy similar ecological niches. Fish were collected at low tide with handheld aquarium nets to minimize bodily harm upon capture. Eight fish in total were used in the experiment trials. Each test fish was photographed and measured for identification. Individual sizes of fish ranged from 2.5 cm to 12 cm as measured from the mouth to the base of the caudal fin. Smaller sculpins were held in a tank of 30 cm X 18 cm X 18 cm dimensions, while larger sculpins were held in a tank of 50 cm X 25 cm X 30 cm dimensions. All sculpins were acclimated for three days before the experiment and held between trials in these tanks, and fish were not fed during the acclimation period or within the holding tanks during the experiment.

2.2 Construction of maze

The experiment trials were conducted in a 142 cm X 54 cm X 35 cm tank with an inflow from one side and an outflow on the other side. The maze was constructed from plastic mesh that would allow water and food cue to travel freely but not allow the passage of fish. Four 55 cm X

15 cm strips were cut, and one circular 10 cm diameter hole was cut at central width near the end of two strips and at the center of one strip. The final strip was unaltered to serve as the back wall of the maze and prevent fish from entering the outflow. The strip with the central hole was placed 30 cm in front of the back strip, and the two corner hole strips were placed 30 cm ahead consecutively to create a 120 cm track with passage points in the center, left, and right sides of the mesh barriers. All strips were fastened to the tank with silicone glue and allowed to dry. Extra mesh was rolled into a tube and glued in the final chamber near the water inflow to serve as a permeable cage to store food that would serve as the source of the olfactory cue. The tank was filled to a 14 cm experimental water depth and allowed to run the night before the first trial.

2.3 Experimental design

Frozen squid was thawed and prepared as the olfactory cue for the sculpins. Several squid were squeezed in the final chamber of the tank and placed in the mesh cage to serve as a continuous source of olfactory cue. Water was allowed to run for five minutes before adding any fish to allow full dispersion of food cue to all sections of the maze.

Sculpins were individually drawn from their holding tanks with handheld aquarium nets and transported to the test tank in a basin filled with saltwater to keep fish submerged. The basin was then inverted 90 degrees within the first chamber of the maze and fish were allowed to swim into the test tank voluntarily. Fish were timed from the moment of settlement on the test tank floor until contact with the squid cage at the end of the maze. Total time spent in the test tank and time of active movement against the flow of water toward the barriers was recorded. Sculpins were then recaptured in handheld aquarium nets after completing the maze and placed back in the transport basin to be offered a small food reward before being returned to the holding tank and the next sculpin was drawn. Old squid would be occasionally removed from the cage between trials and replaced with new squid to renew the olfactory cue.

Trials were performed on each test sculpin individually once a day for four days to test for short-term learning. The sculpins were then held within the holding tanks with no trials for an additional four days with no feeding, which was then followed by a fifth trial to test for long-term memory. Times of total test tank occupation and directed movement were recorded for each trial with each sculpin.

3. Results

Sculpins tested in the maze showed a significant change in their navigation time over a short-term basis. During the first trial, sculpins spent a significantly greater amount of time navigating the maze than all trials that occurred afterwards. By the second trial, the navigation time dropped dramatically to a mean time less than fifty percent of the first trial mean time. Mean navigation times of the third and fourth trials were subsequently shorter than the second trial navigation time, but the mean time difference between the third and fourth trials was insignificant. The third trial had the shortest mean navigation time of all short-term trials, while the fourth trial mean time was greater by about three seconds.

The navigation trend witnessed in the short-term trials remained consistent in the long-term trial as well. The fifth trial mean time was about fifty percent less than the fourth trial mean time four days prior. The navigation times of all sculpins decreased significantly over the multiple trials and days from the first exposure to the maze (Fig. 1).

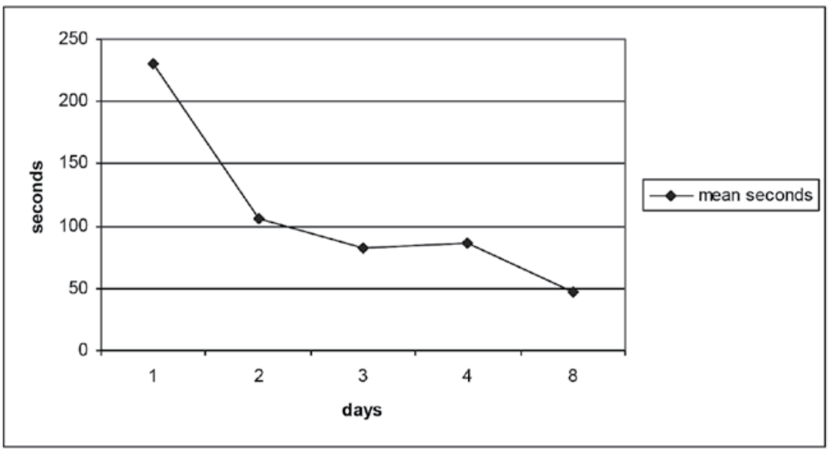

Fig. 1: Mean navigation time over the course of all days in the experiment.

4. Discussion

The results of the experiment support my hypothesis that intertidal sculpins can quickly learn and recognize spatial orientation and memorize unique navigational paths. Most sculpins were very slow at navigating their way through the maze to the food cue on their first trial run. However, even after just one run, it was apparent that the sculpins had learned and memorized the general locations of the passage points. By the second trial, all of the sculpins were navigating the maze faster than their previous trial times and most continued to create faster times as more trials progressed. While the fish rarely passed through the maze flawlessly, the decreasing navigational time trend strongly suggests that tidepool sculpins and fluffy sculpins can learn and navigate using visual and olfactory cues as many other fish species can (Odling-Smee and Braithwaite, 2003).

This experiment also demonstrated that the navigational memory of intertidal sculpins can be applied to both short-term and long-term scenarios. The first four trials were conducted on consecutive days and the mean navigation times got progressively shorter as the sculpins developed a short-term memory of the maze through repetition. After these trials, the sculpins were left in their holding tanks with no experimental activity for four days to test if memory of the course had been retained into long-term memory. The results of the fifth trial indicate that the sculpins did in fact remember how to navigate through the maze even after not seeing the course for several days; they even achieved a navigation time that was significantly shorter than any previous trial! The short navigation time on the long-term memory test could have been caused by increased hunger as the sculpins were not fed during the inactive period, but the same result would have likely been seen if testing had persisted in the inactive days since most fish often chose not to consume food rewards after the completion of short-term trials. One way to test this observation in future experiments would be to individually feed test sculpins a food reward on each inactive day to keep hunger level constant between short-term and long-term trials.

Results from similar experiments follow a trend that is consistent with my experiment results. Maze tests on zebrafish (Haight and Schroedor, 2011) show that these fish can quickly learn the spatial structure of mazes and the locations of passages to decrease navigation time to a food cue even after one set of trials. Tests on salmon (Yue et al., 2004), cichlids (Hert, 1992), and goldfish (Warburton, 1990) have also demonstrated that visual recognition of a location is important for efficient navigation. The sculpins in my experiment displayed visual recognition of important features of the maze as the fish would often immediately turn their bodies in the direction of the next barrier's passageway right after entering a new section. This recognition of spatial orientation has also been recorded with intertidal sculpins navigating back to a particular home range after relocation in the field (Polivka and Chotkowski, 1998) via an innate homing instinct (Yoshiyama et al., 1992). The sculpins were likely using visual and olfactory cues to determine their spatial orientation (Khoo, 1974) and navigate around the intertidal zone.

Learning and behavior can vary between individuals, and my data was often confounded by examples of variation among my test sculpins. Individual navigation times of the sculpins did decrease over the course of the experiment, but the total time spent in the test tank for each trial often differed greatly between individual fish and showed no significant trend throughout the entire experiment. When placed in the maze during any trial, sculpins would also lay motionless on the tank floor and on barrier mesh or swim and rest within the entrance chamber for several minutes before actually heading for the passage. Sculpins with generally longer navigation times often had a tendency to perform such irrelevant actions throughout the experiment, while sculpins with shorter navigation times were usually more eager to respond to the food cue, and these individual behaviors persisted throughout all trials.

Sculpins also sometimes displayed behaviors that could distract them from navigating during experiment trials. One example of consistent undesirable behavior was a tendency to repeatedly swim along the entire length of a barrier regardless of where the actual passage was located. This behavior was possibly due to solid squid detritus that would occasionally pass through the cage and float down the current. Debris would often get stuck in mesh at the bottom and at the water surface, and these small sources of localized food cue may have distracted the fish and caused temporary deviation from their navigation paths. In later trials, some fish also experienced a slight increase in navigation time due to small particulate traveling at the bottom, which they learned to pursue and mouth instead of following the real navigation path! A possible improvement to prevent these distractions could be to dice food cues into large solid chunks instead of using the whole squid.

The results of this experiment support my hypothesis that intertidal sculpin species can quickly learn and recognize spatial orientations and memorize efficient navigational routes on both a short-tem and long-term scale. This cognitive ability has many adaptive uses that can help these species thrive in the non-uniform terrain of the intertidal zone. Further research on this subject could involve adding stationary landmarks to determine if topography can influence navigational routes or signal specific areas as safe or unsafe for habitation. The full contribution of specific senses and cues can also be tested by eliminating stimuli to all but one sense, such as navigating in complete darkness. The ability to learn and remember new surroundings quickly is a complex behavior that has enabled vertebrates to colonize many environments that would initially appear too unpredictable and unstable to inhabit, and could even be considered a defining adaptive feature that sets vertebrates apart from other animal phyla.

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