Magnetic Affinity of Chiton

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ABSTRACT

Earth's magnetic field provides useful cues to many organisms, however increasing anthropogenic magnetic fields introduce magnetic anomalies that may alter animal behaviors. Many marine organisms can detect magnetic fields but responses to them vary amongst species, and little is known about how intertidal chitons respond to magnetic anomalies. To test for magnetic affinity, 12 *Katharina tunicata* chitons were placed in a behavioral arena with magnetic stimuli on one side of the arena, location preference was then recorded during 10 minute trials. The *Katharina tunicata* chitons spent significantly more time away from the magnetic stimulus than near it, spending an average of 75% away from the magnetic stimulus and 25% near. These results suggest that *Katharina tunicata* exhibit a negative affinity thus an avoidance behavior to static magnetic fields. These findings help deepen our understanding of how marine invertebrates respond to artificial magnetic fields and help predict their behaviors as increasing anthropogenic magnetic fields are induced in marine environments.

INTRODUCTION

In marine environments, magnetic fields are present due to both natural and anthropogenic causes. A magnetic field is an invisible field that exerts a magnetic force on moving charges and magnetic materials (Stern 1996). The Earth's magnetic field acts as a large dipole that provides a consistent source of directional information for many organisms. The Earth's magnetic field strength is approximately 50 μT, whereas small bar magnets can reach strengths near 10,000 μT (UT Austin). In addition to naturally occurring geomagnetic fields, anthropogenic electromagnetic fields (EMFs) are becoming increasingly common in marine environments due to subsea cables, electrical infrastructure, and other human technologies. EMF's consist of electric and magnetic fields generated through the movement of electrons (National Institute of Environmental Health Sciences 2026). As anthropogenic magnetic sources become more prevalent, understanding how marine organisms respond to both natural and artificial magnetic fields is increasingly important.

A variety of organisms have demonstrated the ability to orient, navigate, migrate, or behaviorally respond to magnetic cues, although the exact magnetoreceptors involved remain uncertain (Lohmann & Johnsen 2000). For natural magnetic fields, referring to the Earth's magnetic field at different places, migration and navigation are key factors when discussing the possible roles of this sense. Sea turtles are a good example of long distance navigators in marine environments. Recent evidence suggests that loggerhead sea turtles can distinguish between magnetic signatures and use these cues as a type of magnetic map (Lohmann et al., 2012). Sea turtles are not necessarily unique in this sense, as sharks have also been shown to use magnetic fields for map-like purposes. Many sharks are able to determine their geographical location rather than just using magnetic fields for orientation purposes (Keller et al. 2021). With these beneficial uses of natural magnetic fields, it would make sense that artificial magnetic fields may disrupt these useful natural senses.

In regard to artificial magnetic fields, it is no surprise that responses to these fields vary greatly among species. For example, the marine mollusc *Elysia leucolegnote* exhibited digestive impairment after exposure to intense static magnetic fields (Fei et al. 2023), suggesting potentially harmful physiological effects. In contrast, behavioral responses can range from attraction to avoidance. Glass catfish significantly preferred regions without magnetic fields when given a choice between magnetic and non-magnetic environments (Hunt et al. 2021), indicating avoidance behavior. Conversely, crabs were found to aggregate near subsea power cables and reduced their normal roaming behavior in the presence of anthropogenic electromagnetic fields (Scott et al. 2021). Dolphins also demonstrated shorter latencies to approach barrels containing magnets compared to sham controls, implying either attraction or curiosity toward magnetic stimuli (Kremers et al. 2014). These contrasting responses across taxa suggest that magnetic fields may influence organisms differently depending on species-specific sensory systems and ecological interactions.

Both natural and artificial magnetic fields are important with their various implications on marine animals. In order to better understand anthropogenic magnetic fields, the intertidal chiton *Katharina tunicata* is abundant along the coasts of Washington and provides a useful model organism for investigating behavioral responses to magnetic fields. Prior studies suggest that chitons are able to sense and adjust their orientation to altered magnetic fields around them (Sumner-Rooney et al., 2014), thus may also behaviorally respond to newly present magnetic anomalies. In this experiment, we tested whether *Katharina tunicata* exhibits attraction or avoidance behavior when exposed to a static magnetic field. Using a behavioral arena, individual chitons were placed in the center of the arena with a magnet underneath one side. The amount of time spent on either side of the arena was then recorded to determine whether chitons preferentially associated with or avoided the area with the magnetic anomaly.

MATERIALS & METHODS

Animal Collection/Care

We collected 15 *Katharina tunicata* chitons from Dead Man's Bay on San Juan Islands, and used 12 of them in total for this experiment. In order to collect and transport them, we used a metal scraper with rounded edges to pry them off of rocks in their natural habitats. Then, we housed them in natural seawater at the University of Washington's Friday Harbor Lab campus. They were supplied with many rocks with various algae on them for food, and were checked on daily in order to keep them all contained and healthy. We took note of their sizes and key features including the algaes on their backs in order to distinguish them apart, their average width being 4.5 cm ± 0.5 cm and average length being 8.25 cm ± 0.75 cm. They were returned to Dead Mans Bay just over a week after they were collected.

Experimental Design / Procedure

The arena was constructed with a 40 cm x 15 cm clear plastic container that is 12 cm deep, with white paper wrapped around the perimeter and bottom to take away any visual sensory cues. The arena was then set on a stand made of one inch thick cardboard, with 2 cut outs, one on the left and one on the right in order to slide the magnet under the arena (FIG 4). We drew a line down the middle on the white paper perimeter in order to differentiate the side of the arena the chitons gravitate to (FIG 3). The same 2 stacked neodymium 1.26”x 0.12” magnets (LOVIMAG) were used as the magnetic stimulus during the experiment, along with 4 overhead lights equally spaced that were shining down over the arena. For a single trial, the magnetic stimulus was placed on either the right or left side (FIG 4), then the chiton was placed perpendicular to the longitude of the arena. Once oriented to the middle, a 10 minute timer began, and we observed which side of the arena the chiton was on in 30 second intervals. The 12 individuals were tested one by one in two trials. Between each trial, we alternated the side the magnetic stimulus was on and replenished with both new seawater and a scrubbed arena.

Statistical Analysis

We transferred the raw count data to an excel spreadsheet after the experimental procedure was complete. This brought a total of 24 trials, where each specimen experienced a magnet on their left and right side. In order to analyze the data, we averaged the data from the 2 trials per subject (n=12) and used these averages in a non parametric Wilcoxon signed-rank test (Statistics Kingdom). Finally, excel was used to create the figures and visualize the data for this experiment.

RESULTS

The *Katharina tunicata* chitons spent significantly more time away from the magnetic stimulus side of the tank than near it (Wilcoxon signed-rank test: $Z = 2.35$, $N = 12$, $p = 0.018$, $r = 0.71$, FIG 2). On average, the individuals spent 450 s ± 42.6 s away from the magnet and 150 s ± 42.6 s near the magnet. The results show that 10 out of 12 subjects spent the majority of their time on the side of the arena away from the magnetic stimulus (FIG 1).

DISCUSSION

The responses of the chitons to the neodymium magnet stimulus suggest that magnetic fields do play a role in which side of the arena the chitons went towards, even further suggesting a negative affinity of magnetic anomalies on chiton behavior. If the magnetic stimulus did not affect the chitons, we would expect to see a random choice of which side the chitons went towards, resulting in a 50% for the side with the magnetic anomaly and 50% for the side lacking the magnetic anomaly. Because there was an average of 75% of the time spent away from the magnet and 25% spent near, this suggests that there is a negative correlation between chiton placement and artificial magnetic stimulus. Out of the average trial times, the individuals spent 450 s ± 42.6 s away from the magnet and 150 s ± 42.6 s near the magnet anomaly. This is a stark comparison of location during time spent, as it would have been 300 seconds for both if there had been no effective choice determining stimulus.

A possible explanation for these behaviors, may align with the leading hypothesis regarding chitons ability to sense and orient these magnetic fields being due to a compound called magnetite. Magnetite is an iron oxide that coats the front teeth of the chitons (McKoey et al.). This compound has been previously found in many radular teeth of chiton species, and they seem to be using magnetoreception for navigation purposes (Sigwarts). Nonetheless, these findings are in agreement with many other studies demonstrating that marine animals can detect and behaviorally change due to magnetic stimuli. The chitons preferentially avoid magnetic stimulus, as only 2 out of 12 of them exhibited nonavoidance behavior (FIG 1.), similarly to the behavior of the glass catfish (Hunt et al. 2021). In contrast with prior studies where dolphins were increasingly interested in their magnetic stimuli (Kremers et al. 2014) behaving oppositely to the chitons in this study. This avoidance behavior that was seen in the *Katharina tunicata* chitons suggests that responses to magnetic fields are highly variable to different taxa. The ecological use of the sense demonstrated from this study remains unclear, unlike long distance migratory animals such as the turtles and sharks which use these cues for geomagnetic information and navigation (Lohmann et al., 2012; Keller et al. 2021).

In the future, increasing the trial time duration may be beneficial to record more accurate preferential choices. Nonetheless, the findings of this experiment suggest that magnetic fields may influence location preference in chitons. Possible reasons for this magnetosensing ability may be to locate home scars or grazing patches they regularly maintain. If these magnetic sensing abilities are used for small scale location cues, it may be potentially interrupted by anthropogenic magnetic fields such as subsea cables or magnetic material on boats or docks. The implications of this study may be advantageous in using magnets to deter chitons from unwanted areas or areas they would be unsafe. Future research to further investigate this phenomenon could be done by increasing the magnetic field strength to see if there is a threshold at which changes in location preference begin or stop. Along with testing multiple chiton species rather than one, perhaps *Mopalia lignosa* to see if this trend is consistent with other species.

Acknowledgments

I would like to acknowledge the following people and entities for their assistance with this project. Thanks to the Mary Gates funds for funding this experience. Thank you to Megan Diether, and Miranda Roethler for providing a foundation of knowledge for this project. Along with the research mentors, Jen Ortiz and Emily Bews, and my research lead Hazel Havens. Additional thanks to the Zoobot class of 2026 for being such a wonderful cohort.

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FIGURES

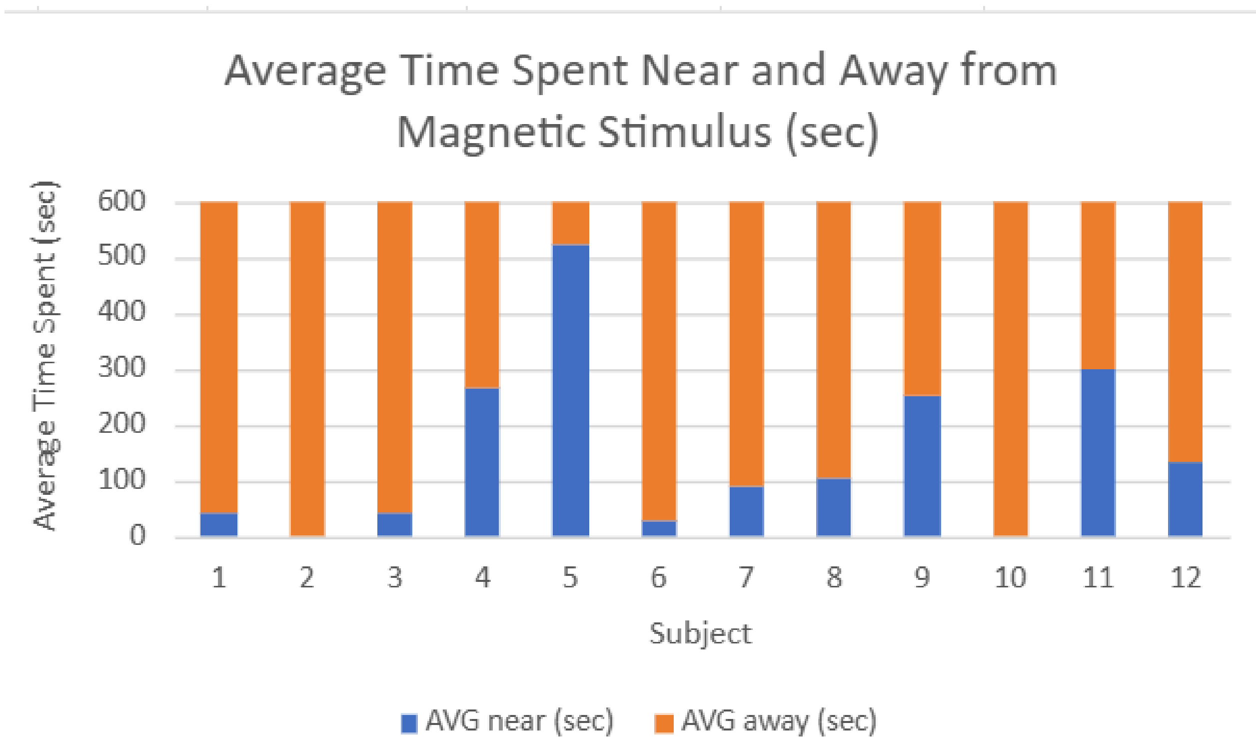

Figure 1. Average time spent near and away from magnetic stimulus by 12 *Katharina tunicata* individuals. Values represent mean time in seconds spent on the side of the area containing neodymium magnet (AVG near (sec)) and mean time in seconds spent on the side of the arena not containing neodymium magnet (AVG away (sec)).

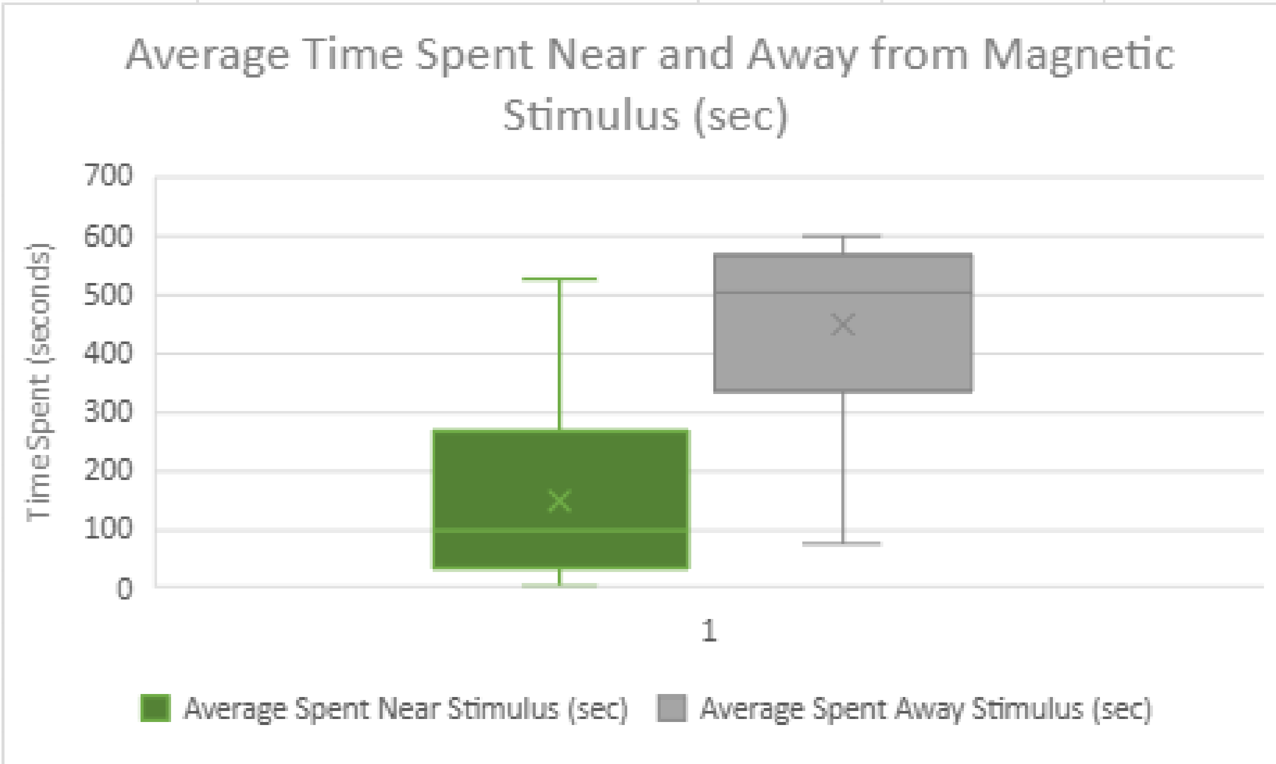

Figure 2. Distribution of average time spent near and away from the neodymium magnetic stimulus by *Katharina tunicata*. Boxes represent the interquartile range (25-75th percent), center lines indicate the median, x symbols the mean. Chitons spent significantly more time away from stimulus (mean = 450 sec) than near it (mean = 150 s) during 10 minute trials (Wilcoxon signed-rank test: $Z = 2.35$, $N = 12$, $p = 0.018$, $r = 0.71$).

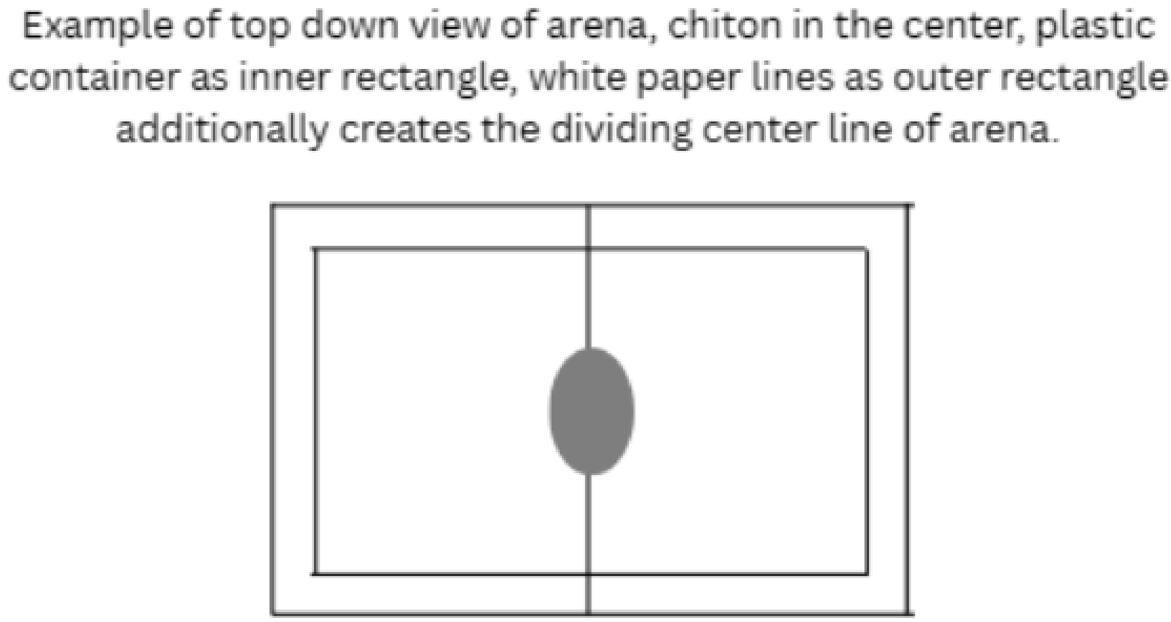

Figure 3. Demonstrates the set up of the arena as a top down image. Shows the outer rectangle as a white paper perimeter along with having the dividing line as seen through,the inner rectangle as the plastic container, with the chiton placed along with the dividing center axis.

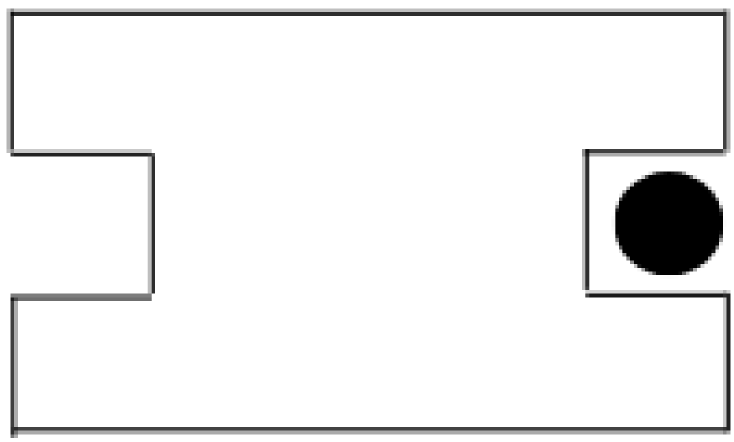

Figure 4. Demonstrates the top down view set up of the platform, made of 1 inch thick cardboard, with cut outs in the right and left middle sections in order for the 2 stacked neodymium magnets (LOVIMAG) to slide in those open areas.