

Electroreception in bonnethead (*Sphyrna tiburo*) and Atlantic sharpnose (*Rhizoprionodon terraenovae*) sharks: Behavioral responses to electric stimuli

M. Caitlin Fisher-Reid - Brandeis University

Introduction

All elasmobranch fishes can detect electric fields using small pit organs in their snouts, the ampullae of Lorenzini. The morphology of the ampullae permits detection of both small local electric fields produced by other biological organisms, and large uniform electric fields, such as the earth's magnetic field (Tricas, 2001). This electric sense is known to play a role in many behaviors observed in elasmobranchs. Studies have shown ampullary usage in detection and capture of prey (Kalmijn, 1971, 1978, Kajiura and Holland 2002, Kajiura 2003), and social behaviors (Tricas et al. 1995). Theoretical models have also been constructed which propose that geomagnetic induction of electric current could play a role in orientation behavior (Kalmijn 1978, 1982, Paulin 1995).

Despite our long-standing documentation of electric sense in elasmobranchs (first documented by Kalmijn, 1966), few studies have actually examined the behavioral responses associated with the electrosensory system, and until very recently no studies of this kind have been done on sphyrid sharks. The family Sphyrnidae is composed of what are more commonly known as the hammerhead sharks. These sharks all have an expanded head morphology to varying degrees. On one end, there is the only slightly expanded head of the bonnethead shark (*Sphyrna tiburo*); the other morphological extreme being the winghead shark (*Eusphyrna blochii*), whose head shows the greatest lateral expansion in the family. Several theories have been proposed to explain why the members of this family have evolved such a strange head morphology, such as the enhanced electroreception hypothesis, (Kajiura 2001, Kajiura and Holland 2002). This hypothesis proposes that the evolution of the sphyrid head morphology might have been driven by enhanced electroreceptive capabilities produced by either more receptive pores, or longer pore canals, both of which are thought to confer greater sensitivity to electric fields (Kajiura 2001, Tricas 2001, Brown 2002).

Kajiura and Holland (2002) were the first to test the enhanced electroreception hypothesis in their comparative study of the predatory behavioral responses of sphyrid and carcharhinid sharks to electric stimuli. Kajiura and Holland (2002) chose to study the scalloped hammerhead shark (*S. lewini*) and the sandbar shark (*Carcharhinus plumbeus*) in a semi-natural environment in Hawaii. This choice was based on local, abundant, similarly sized animals with similar diets and feeding habits, allowing for the most direct comparison across families. While Kajiura and

Holland (2002) were unable to determine conclusively that sphyrnids were more sensitive to prey-simulating electric fields, they did find that the cephalofoil provides a greater lateral search area, possibly increasing the probability of prey encounter, and that the cephalofoil enhances maneuverability, possibly aiding in prey capture.

A later study by Kajiura et al. (2003) found that the cephalofoil, while not directly involved in maneuvering, allows the shark to maintain a lock on the electrical signal during a turn. Kajiura et al. (2003) found that sphyrnids were better able to execute sharp turns when compared to carcharhinids, holding their head in one place while the trunk of their body turned. That is, their bodies do not roll when they turn, unlike carcharhinids. This method of turning allows them to keep the cephalofoil centered on the object they are detecting, so that they do not lose track of it mid-turn.

It is unknown how other sharks respond to prey-simulating electronic stimuli, and still unclear if the cephalofoil does or does not enhance the electroreceptive system of sphyrnid sharks. This proposal aims to attempt further research addressing these questions. The data gained from this experiment will help clarify the assumptions made by the enhanced electroreceptive hypothesis, and if nothing else increase our knowledge of the electroreception of sharks and its role in feeding behavior.

The subjects of study will be the bonnethead shark, and the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*). These two species were chosen for several reasons. The bonnethead represents the smallest cephalofoil when compared to other sphyrnids, while the Atlantic sharpnose belongs to a monophyletic genus within Carcharhinidae, and appears to be more closely related to the sphyrnids than the other carcharhinids (Naylor, 1992). The genus *Rhizoprionodon* is also basal to the genus *Sphyrna*, suggesting that the hammerheads evolved from the sharpnose sharks (Naylor, 1992). Both sharks are abundant, and local to the west coast of central Florida, where the study will be based. Since this is a study of predation behavior, it is also important that both of these species have similar diets of crustaceans, mollusks, and small teleosts (Cortes et al., 1996, Gelsleichter et al. 1999).

Hypothesis

There will be a noticeable and quantifiable difference in the behavioral response to a prey-simulating electric stimulus between the bonnethead and Atlantic sharpnose sharks. Bonnethead sharks will show intermediate ability to maneuver and an intermediately sized search area when responding to prey-simulating electric dipoles, compared to the scalloped

hammerhead and sandbar sharks, (Kajiura and Holland 2002), and they will be more maneuverable and sample a greater search area than the Atlantic sharpnose shark.

Objectives and Goals

1. To determine if a controlled laboratory environment and multiple stimuli of different strengths resolve whether or not sphyrnids are more sensitive to electric stimuli than carcharhinids.
2. To run trials on a total of 10-15 sharks of each species.
3. Determine threshold levels for detection of electric fields for both species.
4. Sacrifice captive animals after behavior trials for subsequent head morphology studies and pore counts.
5. Future Study: Determine if the sexual dimorphism in mature bonnetheads affects electroreception

Research Plan and Methods

Subjects will be captured by gill net (200 yds x 10 ft x 4.5 in) fishing in Tampa Bay, FL, during May and June. Charlotte Harbor, FL and Yankeetown, FL, will serve as backup locations. Strong, healthy animals will be transported back to Mote Marine Laboratory in a transport trailer rented from a local aquarium. Any bycatch will be measured (FL only) and released alive if possible. Upon capture, the sharks will be measured (PCL/FL/TL/STL), weighed, sexed, and tagged with standard S-tags, location of capture will be noted, and water quality data taken. Although the maturity of the subjects is not particularly important; Kajiura (2003) has found that the predatory response to prey-simulating stimuli appears to be an innate ability, not a learned one; the target will be smaller, immature sharks of both species (60-80cm TL). Not only are smaller sharks easier to transport, but the cephalofoil of mature male bonnetheads also differs from that of mature females. This difference may have an unknown effect on electroreception, and can be avoided by using only immature male and female bonnetheads, and subsequently, similarly sized Atlantic sharpnose.

Animals will be placed in the Center for Shark Research (CSR) indoor tanks. The smaller tank will be set up for behavioral trials, and all captive sharks will be kept in the larger tank. By bringing the experiment into a laboratory setting, natural electrical interference is minimized. The sharks will be allowed a minimum of one week to acclimate to the tanks before trials begin i.e., once they appear to be able to navigate the walls of the tank and are eating regularly. Their diet will be chopped squid at all times, to condition them for the behavioral trials. Since it has been found that sharks will become unresponsive to trials of this nature over

time (Kajiura and Holland 2002, Kajiura 2003), individual animals will be tested no more than three times total, no more than twice in one week, and each trial separated by at least two days. After their trials have been completed, animals will be retained for head morphology analysis and pore counts (Kajiura, 2001).

The small tank will be set up for behavioral trials, following the protocol laid out by Kajiura and Holland (2002), and Kajiura (2003). Briefly, a removable acrylic plate will be placed on one end of the tank prior to testing. The plate will house four pairs of electric dipoles and an odor delivery tube in the center of the plate. The dipoles will be randomly activated to emit a prey-simulating electric field (initially one of $6.0 \mu\text{A} \times 1\text{cm}$, but able to range in $0.5 \mu\text{A}$ increments from $5.5\text{-}8.0 \mu\text{A}$). The current will be monitored during trials with a multimeter, and regulated to maintain the target intensity. The other three dipoles will remain off when one is on, and therefore serve as controls. One video camera will be mounted above the acrylic plate and another positioned in the tank window (see figure 1).

The individual to be tested will be starved 24 hours prior to testing, to help ensure a response. At the beginning of a trial, the individual to be tested will be transported to the trial tank. After a few minutes of re-acclimation time (strong, regular swimming throughout entire tank), a dipole will be activated, and squid rinse will be introduced via the odor delivery tube to stimulate the shark to begin searching for food. Should the shark bite at a dipole, it will be turned off and another one activated. Total time of testing will not exceed 10 minutes, and afterwards the shark will be fed to satiation with chopped squid, and returned to the larger tank. Squid remains will be cleaned from the trial tank, and the water allowed to recycle for $\frac{1}{2}$ hour before beginning another trial. Trials will be repeated for up to 5 individuals per day.

The observations and video footage will be analyzed to determine search area and maneuverability, using Kajiura and Holland's (2002) definition of each. The search area of a shark is defined as swath of substratum that passed directly under the head of the shark over time (Kajiura and Holland 2002). The prey stimulated search area is quantifiable by comparing it to the search area when sharks are not stimulated by odor, i.e. simply swimming around the tank. Special attention will also be paid to orientation pathways of the shark when approaching the active dipole, degree of torso flexibility (maneuverability), and general swimming behaviors leading up to a bite, such as turns, turning radii, and trajectory.

Significance of Study

The research proposed here will further knowledge on a relatively understudied sensory

system, and allow for more informed decisions to be made in affected industries. For example, Kim Holland at the Hawaii Institute of Marine Biology has been studying sharks and their behavior around hydrophone cables towed by commercial oil and Navy ships. He has found that the cables leak a weak electric field similar to prey fields, and hungry sharks bite at the cables, causing costly damage and potential injury to themselves. Holland is working on finding the threshold level at which sharks can detect the cables, so that companies may insulate their cables better (Holland, 2000). Studies such as the one proposed here will help us to further understand the electroreception of sharks and protect both humans and sharks from the destructive tendencies of the other.

Budget

Gillnet (200yds X 10ft. X 4.5 in), floats, anchors, and flags	\$1600
Tagging/measuring equipment	\$500
Tiburon II Boat rental	\$300/day - max of 14 total days - \$4200
Renting a truck from Mote	\$0.38/mi - max of 3000 mi - \$1140
YSI-85	\$1300
GPS	\$600
Renting a transport tank and truck from a local aquarium (including generator/gas/driver)	Variable – max of \$15,000
Oxygen tank/regulator/air-stone for live well on Tiburon II	\$300
Electrical equipment and apparatus	Variable – max of \$10,000
Video equipment and apparatus	Variable – max of \$5,000
Odor delivery apparatus	Variable – max of \$500
Food for captive animals	\$3,000
Personal Salary	\$36,000/year for 1 year
Staff Biologist Salary	\$20,000/year for 1 year
Volunteers/Interns	Free
Lodging and Food for Field Outings	Variable – max of \$5,000
TOTAL: \$104,140.00	
(extra money left over from variable categories will be used for areas where budget underestimates cost.)	

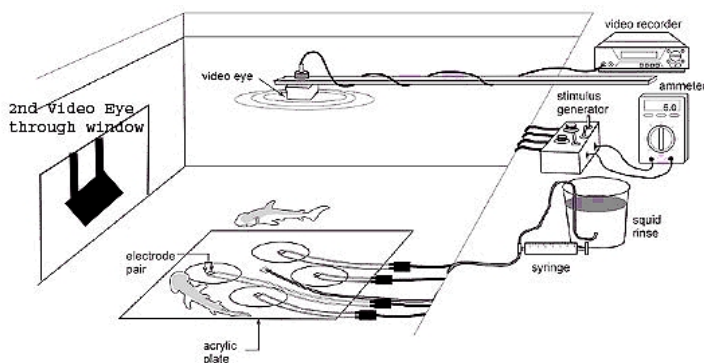


Figure 1: Experimental apparatus, adapted from Kajiura, 2003.

References

- Bennet, M.V.L. and W.T. Culsin. (1978). Physiology of the ampulla of Lorenzini, the electroreceptor of elasmobranchs. In Sensory Biology of Sharks, Skates and Rays (ed. E.S. Hodgson and R.F. Mathewson) pp. 483-505 Washington D.C. USA: Government Printing Office.
- Brown, B.R. (2002). Modeling an electrosensory landscape; behavioral and morphological optimization in elasmobranch prey capture. *Journal of Experimental Biology* 205: 999-1007.
- Cortes, E., C.A. Manire, and R.E. Hueter. (1996). Diet, feeding habits, and diel feeding chronology of the bonnethead shark *Sphyrna tiburo*, in Southwest Florida. *Bulletin of Marine Science* 58(2): 353-367.
- Gelsleichter, J., J.A. Musick, and S. Nichols. (1999). Food habits of the smooth dogfish *Mustelus canis*, dusky shark *Carcharhinus obscurus*, Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, and the sand tiger *Carcharias taurus*, from the northwest Atlantic Ocean. *Environmental Biology of Fishes* 54:205-217.
- Holland, K.N. (2000). KITV-ABC Movie Clip.
<[http://www.hawaii.edu/HIMB/sharklab/research/KITV\(long\).mov](http://www.hawaii.edu/HIMB/sharklab/research/KITV(long).mov)> Accessed 08/02/04.
- Kajiura, S.M. (2001). Head morphology and electrosensory pore distribution of carcharhinid and sphyrid sharks. *Environmental Biology of Fishes* 61: 125-133.
- Kajiura, S.M., and K.N. Holland. (2002). Electroreception in juvenile scalloped hammerhead and sandbar sharks. *Journal of Experimental Biology* 205: 3609-3621.
- Kajiura, S.M., J.B. Forni and A.P. Summers. (2003). Maneuvering in juvenile carcharhinid and sphyrid sharks: the role of the hammerhead shark cephalofoil. *Zoology* 106: 19-28.
- Kajiura, S.M. (2003). Electroreception in neonatal bonnethead sharks, *Sphyrna tiburo*. *Marine Biology* 143: 603-611.
- Kalmijn, A.J. (1966). Electro-perception in sharks and rays. *Nature* 212:1232-1233.
- Kalmijn, A.J. (1971). The electric sense of sharks and rays. *Journal of Experimental Biology* 55: 371-383.
- Kalmijn, A.J. (1978). Electric and magnetic sensory world of sharks, skates and rays. In Sensory Biology of Sharks, Skates and Rays (ed. E.S. Hodgson and R.F. Mathewson) pp. 507-528 Washington D.C. USA: Government Printing Office.
- Kalmijn, A.J. (1982). Electric and magnetic field detection in elasmobranch fishes. *Science* 218: 916-918.
- Naylor, G.J.P. (1992). The phylogenetic relationships among requiem and hammerhead sharks: inferring phylogeny when thousands of equally most parsimonious trees result. *Cladistics* 8: 295-318.
- Paulin, M.G. (1995). Electroreception and the compass sense of sharks. *Journal of Theoretical Biology* 174: 325-339.
- Tricas, T.C., S.W. Michael, and J.A. Sisneros (1995). Electrosensory optimization to conspecifics phase signals for mating. *Neuroscience Letters* 202:129-132.
- Tricas, T.C. (2001). The neuroecology of the elasmobranch electrosensory world: why peripheral morphology shapes behavior. *Environmental Biology of Fishes* 60: 77-92.