The Schwalbe Lab

Jeremy Levin
Lake Forest College
Lake Forest, Illinois 60045

Assistant Professor of Biology Margot Schwalbe's interest was initially sparked while studying fish sensory systems during her undergraduate years at the University of Minnesota Duluth, where she majored in Biology with a focus on animal diversity. A pivotal moment occurred during her senior year when she enrolled in an Animal Physiology course, which ultimately steered her toward research focused on fish sensory systems, including how fish localize sound. This research led her to unravel differences in sensory abilities between three local and one invasive fish species from Lake Superior by comparing their abilities to locate and capture prey with vision and their lateral line systems. Subsequent years were dedicated to in-depth exploration, including her doctoral at the University of Rhode Island, where she delved into the structure-function relationships of different patterns of lateral line systems by studying the feeding behavior of two African cichlid species with different lateral line patterns. During her postdoctoral work at Tufts University, she studied how sensory systems contribute to how fish swim, as well as the neural control behind fish swimming behavior.

As an important part of Dr. Schwalbe's research, she has sought to understand how vision and the lateral line system collaboratively influence fish swimming in turbulent conditions. This research has involved the meticulous digitization and analysis of videos from experiments studying lateral line system-related experiments and imaging. Importantly, the lab's work extended beyond academia, holding significant potential for real-world applications. Notably, the similarity between the sensory structures of the lateral line system and the human ear hair cells (cilia of the cochlear hair cells) presented opportunities for treating human ear diseases and advancing our comprehension of hearing mechanisms. The lateral line system's integration into remote vehicles promised improved precision in engineering applications, linking biological research to broader technological advancements. Additionally, Professor Schwalbe's work applies to over 33,000 of the existing species of fish in the oceans, all with uniquely different lateral line systems.

With labs back in full swing post-COVID, the Schwalbe lab is making numerous advances in the world of fish sensory systems by focusing on the study of fish hair cell functionality, physiology, and biomechanics. The lab's research uses a combination of microscopy techniques and high-speed cameras coupled with multiple computer-based programs (i.e. Matlab) to analyze behavioral experiments on kinematics and feeding behavior. Of particular interest was the examination of one of the fish's major sensory complexes, known as the lateral line system.

The lateral line is composed of tiny sensory organs called neuromasts, which can be separated into two distinct types: superficial (Fig. 1) and canal neuromasts (Fig. 2). Superficial neuromasts on the skin detect changes in water velocity and are more numerous, whereas canal neuromasts in canals sense changes in water pressure and are not as prevalent but are much larger in size. Located within the neuromasts are clumps of hair-like bundles that are made up of a single, long kinocilium and several, much shorter stereocilia. When the neuromast's kinocilium hair cells are moved by water flow, they stimulate the surrounding stereocilia, eliciting electrical impulses from changes in water pressure and velocity inherent to their respective neuromast. To communicate these electrical signals, efferent and afferent nerves are innervated between neuromasts. Efferent nerves serve for the transportation of electrical signals (action potentials) towards the central nervous system (CNS) and afferent towards the peripheral nervous system (PNS). Both act as connectors to transport electrical impulses back and forth between the CNS and PNS, which control communication between all the bodily components of an organism. By understanding these underlying processes that elicit the locomotion of fish, we are better able to understand the nuances in behavioral responses produced in a controlled setting. Furthermore, being a prominent sensory system in fish, the lateral line system is a vital component of a fish's physiology and sensory biology that mediates their prey and predator responses, schooling behavior, and survival in unforgiving environments. To study the organization and anatomy of neuromasts, Dr. Schwalbe's research team has employed a myriad of techniques. The most notable include fluorescent microscopy techniques using vital fluorescent stains revealing the underlying structures that integrate the sensory stimulus of water into electrical signals (Fig. 3). When under fluorescence, one may observe the large variation in lateral line distribution of both superficial and canal neuromasts. Another important technique known as clearing and staining (Fig. 4) has been utilized to reveal the cartilage, skeletal structure, and how skeletal structure coupled with lateral line physiology mediate fish movement. Additionally, the team is developing collaborations with a colleague of Dr. Schwalbe's to acquire micro-CT scans. In turn, this technology can generate high-definition 3-D renderings of the skeletal structure of the silver hatchetfish, one of their current model organisms. With both a clearing and staining protocol and CT scans, the Schwalbe lab will be able to contribute amid the absence of data on the underlying skeletal and muscular structures, as well as lateral line physiology. These methods facilitated the evaluation of the structural and organizational aspects of the sensory system and its regeneration. These efforts have allowed for the observation of anatomy and morphology at various levels of organization, ranging from the cellular to the tissue that composes the gross anatomy of the fish. The Schwalbe lab has effectively applied a range of skills to enhance their research efforts. This proficiency has enabled her research team to collect both qualitative and quantitative data from videos produced during behavioral experiments. The utilization of advanced recording technology is a key aspect of their studies, where they use a high-speed Panasonic camera. Through their experimental designs, the Schwalbe team has established the means to capture specific behaviors exhibited by fish in response to live prey or controlled stimuli. These behaviors are then meticulously recorded using the appropriate camera and frame rate settings. By scrutinizing these videos frame by frame, they can quantify various aspects of the fish's movements and behaviors, encompassing general body motion, specific fin movements, and their responses to particular stimuli. Their work extends further into mapping out the precise movement of the fish relative to well-defined points on their bodies (Fig. 5), as well as concerning the tank and prey, utilizing established grids to track their motion along the x and y axes, and eventually z. Recent endeavors by her team have focused on manipulating sensory systems to observe and quantify their influence on the feeding behavior of gobies and the ballistic jumping behavior of the silver hatchetfish. Fish possess six plus sensory systems, generally including vision, taste, hearing, olfaction, touch, and the lateral line. During the summer, her lab team conducted studies to investigate the impact of disabling the lateral line system and vision, both of which were found to be highly influential on swimming behavior. To manipulate the presence of the lateral line, the team developed various procedures that exposed the fish to a range of neurotoxins, such as gentamicin, streptomycin, neomycin, and cobalt chloride that are known for their hair cell-destructive properties (Fig. 6 & Fig. 7). Their rationale was that by destroying these hair cells, they could eliminate the medium responsible for integrating external sensory information. Consequently, their findings have unveiled distinct thresholds for ablating lateral line tissue, allowing for precise timing of treatments, although the dosage remains a subject of ongoing investigation. Currently, her lab continues to explore the exposure of the exact neurotoxin concentrations required for full lateral line ablation while preserving the behavior for testing purposes. Following their efforts to test and quantify the effects of disabling sensory systems, Professor Schwalbe's team conducted an analysis that calculated the averages of several variables, including jump duration, jump latency, tail beats per second, and jump height. This extensive data was subsequently correlated with the structural organization of the silver hatchetfish, a species under current investigation in her lab due to its noteworthy ballistic jumping behavior, which is believed to be an adaptation for predator evasion.

In the future, the Schwalbe lab envisions delving into the realm of muscle activation and its intricate relationship with fish swimming behavior. This exciting endeavor will harness electromyography (EMG) techniques, allowing the lab to record the precise activity of the abductor and adductor muscles responsible for propelling the silver hatchetfish out of the water. Additionally, they plan to apply digital particle image velocimetry (PIV) to uncover the dynamic water flows generated by the

silver hatchetfish during their startle responses. This groundbreaking research is not just a scientific pursuit; it holds profound implications for us and the world at large. Understanding how muscle activation influences fish swimming behavior can shed light on broader ecological and biological phenomena. By comprehending these intricate mechanisms, we can gain insights into the survival strategies of aquatic species, and their responses to environmental changes, and continue to inform the development of biomimetic technologies for various aquatic applications.

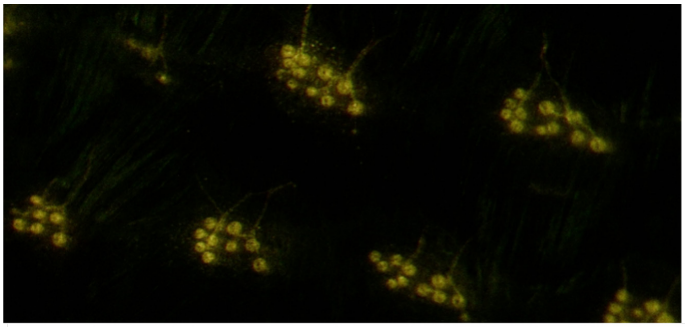

Figure 1: Silver hatchetfish superficial neuromasts via fluorescent microscopy (yellow dots) near pectoral girdle at

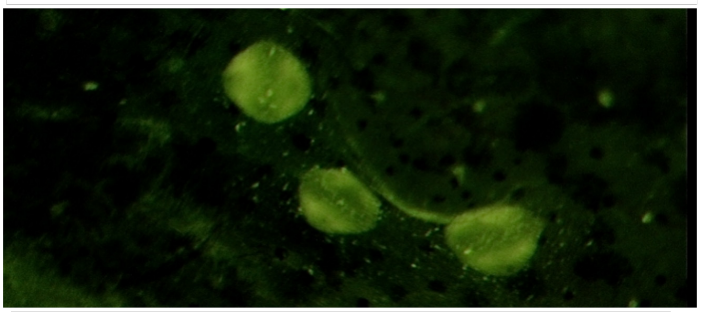

Figure 2: Guppy canal neuromasts visible via fluorescent microscopy (Green structures) on top of head 9.1x magnification.

Note: Dots in center of canal neuromast are active hair

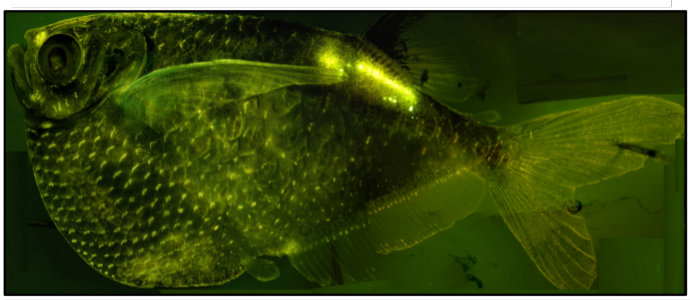

Figure 3: Silver hatchetfish lateral line system via fluorescent microscopy at 9.1x magnification.

Figure 4: Cleared and stained silver hatchetfish revealing skeletal structure and cartilage at 9.1x magnification.

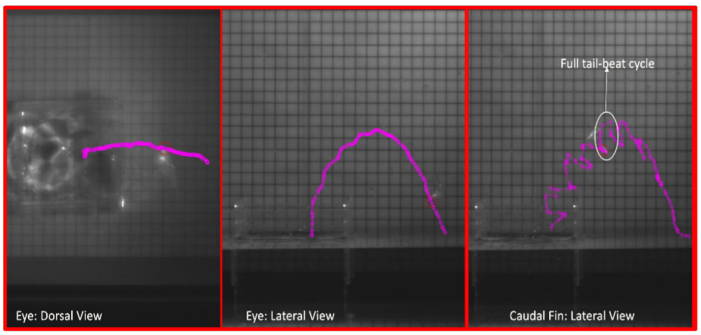

Figure 5: Digitized and quantified a ballistic jump of a silver hatchetfish in MATLAB.

Note: Grid is 1-by-1 centimeter. (Image by Kyle Lassen)

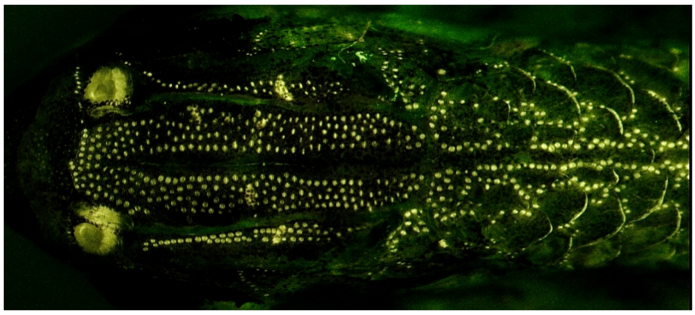

Figure 6: Silver hatchetfish dorsal view of the anterior lateral line system via fluorescent microscopy at 9.1x magnification.

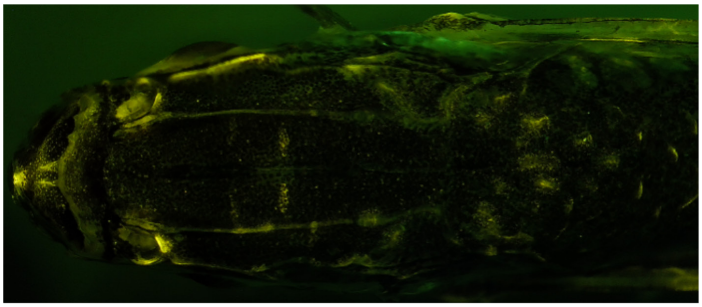

Figure 7: Silver hatchetfish dorsal view of an ablated anterior lateral line system via fluorescent microscopy at 9.1x