Conversation with a Colleague: Joseph A. Sisneros: The Soniferous Life of Midshipman Fish

Joseph A. Sisneros
Conversation with a Colleague Editor: Micheal L. Dent

Figure 1. *Joe Sisneros with a plainfin midshipman.*

Meet Joseph A. Sisneros

Joseph A. (Joe) Sisneros is the first subject of our new "Sound Perspectives" essay series "Conversation with a Colleague." Joe is currently a professor in the Psychology Department at the University of Washington, Seattle (see sisneroslab.org). He received bachelor's and master's degrees from California State University, Long Beach, California, and his PhD from the Florida Institute of Technology (FIT), Melbourne. He completed his postdoctoral training at Cornell University, Ithaca, New York. Joe is a Fellow of the Acoustical Society of America and serves as an associate editor for *The Journal of the Acoustical Society of America*. We asked Joe to give us his elevator pitch and then to elaborate on his inspirations, contributions, and hopes for the future.

Give your "elevator speech" about the thrust(s) of your scholarly work over your career.

How well can you hear? If you are like me, a middle-aged person, you may have trouble hearing high-frequency sounds or have difficulty being able to discriminate certain sounds in a loud room. What if I told you that the fish that I study may "hold the key" to improving hearing in older humans? My lab is interested in how steroid hormones such as testosterone and estrogen enhance hearing sensitivity to high frequencies within an animal's hearing range.

We study the plainfin midshipman (*Porichthys notatus*), a vocal fish that is highly dependent on the production and reception of acoustic signals for its social behaviors (**Figure 1**). Thus, it has become a good model species to investigate the neural basis of acoustic communication. Female midshipman rely on their auditory sense to detect and locate calling males during the breeding season. Work from our lab has shown that females exhibit reproductive-state and hormone-dependent changes in the auditory sensitivity of the saccule, the main organ of hearing in the midshipman and most other fishes, such that reproductive females are better able to hear the advertisement calls of potential mates than nonreproductive females. The primary mechanism for this reproductive state-dependent change in hearing sensitivity is estrogen. In support of these findings, studies of human and rodent females with Turner's syndrome, a genetic aberration that results in the loss of ovarian estrogen production and decreased estrogen-receptor expression in the cochlea, show that females with this syndrome exhibit a progressive loss in high-frequency hearing with development. These mammalian studies support the link between estrogen and high-frequency hearing sensitivity. Might circulating levels of estrogen

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and testosterone be involved in the maintenance of high-frequency hearing sensitivity in humans? Studies of the effects of estrogen on midshipman hearing might provide the answer someday.

What inspired you to work in this area of scholarship?

I became inspired to work in the research area of hormones and behavior during my PhD working in the lab of Timothy "Tim" Tricas at FIT. I had the opportunity to travel to Mexico with Tim to investigate the role of electroreception during mating in the round stingray (*Urobatis halleri*).

We found that male stingrays use their extremely sensitive electric sense to detect and locate reproductive females buried in the shallow lagoons, which were the breeding grounds for this species. Females emit a complex weak bioelectric field from their gills that is modulated during ventilation by the rhythmic movements of their gill slits and spiracles (a muscular valve that intakes water into the gill chamber). We discovered that the electroreceptor system of male stingrays was "tuned" to 1-2 Hz, which matched the low-frequency "signature" signal produced by buried females during ventilation. This matched filter of the male's electroreceptor system with the female's electrical signal only occurs during the mating season when androgen levels are elevated. These studies that combined animal behavior and electrophysiology piqued my interest in learning more about the neural basis of behavior and initiated my career path on becoming trained as a neuroethologist.

Of all your contributions during your career, which are you most proud of and why?

Perhaps I am most proud of the research that was performed during my postdoc training in the laboratory of Andrew "Andy" Bass at Cornell University, Ithaca, New York. What started as an "odd observation" eventually led to an important discovery of the mechanism that is responsible for seasonal changes in hearing sensitivity in the plainfin midshipman.

The purpose of my postdoc was to work on the auditory system of the plainfin midshipman fish. My initial interests were to examine how the auditory sensitivity of the midshipman changes during development from early juvenile to adult stages.

During my first full summer in the Bass lab, I traveled to the University of California, Davis, Bodega Marine Laboratory in Bodega Bay to collect juvenile midshipman and characterize ontogenetic changes in the auditory sensitivity of the midshipman saccule. Unfortunately, I arrived too early in the summer season to collect fish that were large enough to obtain recordings from. This enabled an alternative fortunate opportunity. Instead of waiting around for my fish to grow large enough to record from, Andy suggested that I try to characterize the sensitivity of the saccule in adult females that had recently spawned and from females that were still gravid (full of eggs) to determine if the presence of eggs affected the auditory sensitivity of the saccule.

Earlier, Andy had shown in midshipman behavioral experiments that reproductive gravid females perform phonotaxis to the playback and sound source of a synthetic male midshipman advertisement (mate) call because gravid females are highly motivated to spawn. However, females that had recently spawned showed no interest in the call. Could it be that "spent" females (void of eggs) are just no longer motivated to respond to the call or could there be a change in their auditory sensitivity to the call?

As I started collecting data on the auditory sensitivity of saccule in reproductive females, I noticed something odd. The auditory tuning profiles of the saccule in reproductive females did not match the saccular tuning profiles that the Bass lab had obtained in a previous study on midshipman fish that had been housed over the winter back at Cornell. The saccule of reproductive females (whether gravid or not) appeared to have a greater sensitivity to higher frequencies within their hearing range compared with previous recordings of "winterized" fish. After many calibration checks and the retesting of my equipment, we concluded that it wasn't the equipment but something different about the fish!

Could there really be seasonal changes in midshipman auditory sensitivity related to the female's reproductive cycle? The observed seasonal changes in the electrosensitivity of adult elasmobranch fishes and in other fishes such as weakly electric fishes were one thing, but in the auditory system? Such changes in the auditory sensitivity of adult animals had never been documented before.

To test this, we would need to obtain female midshipman collected during the nonreproductive period and record from their saccules. I conspired with Paul Forlano, who was a graduate student at the time in Andy's lab and is now a professor at Brooklyn College, a campus of the City University of New York, and he helped me convince Andy to pay for a trip to collect winter, nonreproductive female midshipman in Monterey Bay, California.

The problem was that during the nonreproductive season, midshipman move offshore into deeper waters and can be found at about 80 to 100 meters deep. To collect midshipman at these depths, we needed to charter a boat and collect fish offshore using an otter trawl. We only managed to collect 22 nonreproductive females and sent them back to the Bass lab for auditory saccular recordings. After a few saccular recordings from those females, we arrived at that "Eureka" moment and realized that nonreproductive and reproductive females were tuned differently and that seasonal changes in the auditory sensitivity of adult animals did indeed exist!

Later, we found that the saccules of reproductive females were more sensitive to higher frequencies within the midshipman hearing range, which meant that summer reproductive females were better able to detect the higher harmonic components in the male advertisement call. This seasonal enhancement and plasticity of the auditory system likely enhanced the detection and location of potential mates by females during the breeding season.

The next big challenge was trying to determine the mechanism responsible for the observed changes in auditory sensitivity. Based on earlier work, including my dissertation research, we decided to investigate the role of gonadal steroids (androgens and estrogen) as potential modulators of auditory sensitivity. However, at the time, we had no idea about how gonadal steroid levels changed seasonally in the midshipman fish.

We decided to undertake a two-year study to document and characterize how androgen and estrogen levels changed during the midshipman reproductive cycle. This was not an easy task. It required us to collect blood samples and determine midshipman hormone levels at different time points throughout the year and correlate these changes with the seasonal development of the gonads in both males and females. We were able to characterize how androgen and estrogen levels changed during the annual reproductive cycle of both females and males. Interestingly, we noted that in females, both testosterone and estrogen levels were relatively low throughout the year except for one month prior to the breeding season, when females exhibited a spike in testosterone and estrogen levels. Could it be that these spikes in hormone levels were responsible for inducing the sensitivity changes in the saccule?

To determine if testosterone and estrogen were responsible for changes in auditory saccular sensitivity, we implanted winter nonreproductive female midshipman with either testosterone or estrogen to simulate the hormone levels that females naturally experience one month prior to the breeding season. Our results from the hormone implant experiments showed that nonreproductive females treated with testosterone or estrogen exhibited enhanced auditory saccular sensitivity to the dominant frequencies contained in the male advertisement calls. Furthermore, the saccular tuning profiles of the hormone-implanted females mimicked the saccular tuning profiles of summer reproductive females. This sensory plasticity observed in adult females was thought to provide an adaptable mechanism that enhances the coupling between sender and receiver in the midshipman communication system. Our work wound up being timely and was subsequently published in the journal *Science*. This study represents perhaps my most proud contribution to science and was truly a team effort in collaboration with Andrew Bass, Paul Forlano, and David Deitcher. Since the publication of this paper, the reported hormone-dependent mechanism appears to be evolutionary conserved with other studies reporting similar changes in sensory sensitivity due to gonadal steroids in adult animals from other taxa including amphibians, birds, and mammals.

What are some of the other areas in which you feel you made substantive contributions over your career?

These include the investigation of sound source localization by fishes, which was the topic of my first National Science Foundation grant as an assistant professor at the University of Washington. Previous evidence suggested that the capacity for sound source localization was common to mammals, birds, reptiles, and amphibians, but, surprisingly, it was not known whether fish locate sound sources in the same manner or what strategies they used for sound source localization.

Working with colleagues Richard Fay (see doi.org/10.1121/AT.2020.16.3.53) and David Zeddies, we showed that the midshipman use local particle motion sound cues to guide sound source localization behavior. All fishes are thought to be able to detect the particle motion cues of underwater sound using their inner ear otolithic end organs, which act as biological accelerometers to sense linear acceleration and respond to the direct displacement of water particles relative to the fish caused by sound. We showed that midshipman rely on their inner ear "accelerometers" to detect acoustic particle motion cues, which helps guide them to sound sources during localization behavior.

We also investigated the roles of the fish swim bladder and the lateral line system in midshipman sound localization behavior and showed that sound pressure reception via the swim bladder is likely required, whereas the use of the lateral line was likely not required for sound source localization. Currently, my lab is still very much interested in research on sound localization by fishes as well as the underlying neural mechanisms for these behaviors.

What do you think are the most pressing open questions that you would like to focus upon over the next 5-10 years?

As I think about the big unanswered research questions in the field, it is apparent that we know very little about the cellular, molecular, and genetic mechanisms that are influenced by gonadal steroids and how these mechanisms ultimately modulate the sensitivity of auditory and other sensory systems. Future studies that examine how steroids such as estrogen regulate gene expression in the midshipman inner ear may eventually provide insight to the mechanisms responsible for hormone-dependent changes in hearing and other senses. This area of research seems to be the next frontier that bridges genes and behavior. Research in the not-so-distant future promises to be exciting. Stay tuned!

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