Effects of a Varied of Pectoral fin movement in Visual Looming Stimulus for Pacific staghorn sculpin (Leptocottus armatus) and shiner perch (Cymatogaster aggregata)

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Abstract

When startled, fish perform an escape response to flee from predators. Looming, a technique to visually stimulate a fish, has been extensively studied; however, studies have focused on a simplified loom that approximates the silhouette of an approaching predator as an expanding disk. We hypothesize that more detailed silhouettes of species-specific predators may have different effects on fish of different ecology. To this end, we look at the effect of adding flapping fins to the loom, simulating a seal attack, which adds both spatial and temporal detail to the loom. We use this to startle two different species of fish: staghorn sculpin (*Leptocottus armatus*), a benthic and cryptic species, and shiner perch (*Cymatogaster aggregata*), a benthopelagic species active in the water column, both of which are commonly preyed upon by local harbor seals. Four loom treatments were used: a black disk with flapping fins (additional spatio-temporal detail), a black disk with stationary fins (additional spatial detail), a black disk without fins (control), and a pair of flapping fins with no disk (control).

1 Introduction

Fish escape responses have been extensively studied [1], [2]. For most fish, a typical response is triggered by the Mauthner cells (M-cell), two giant neurons on either side of the head. Each M-cell, when triggering, cause a sudden contraction of the contralateral muscles such the fish turns away from the stimulus, and also inhibit the other M-cell to avoid conflicting actions occuring. Each M-cell receives sensory inputs from the ipsilateral inner ear (acoustic), lateral line (motion), and eye (visual) [3]. Escape responses can differ significantly depending on the sensory input the stimulus acts on [4], [5, Section 7].

Responses to visual stimuli have been studied of so-called "looming" effects. There have been extensive studies of escape responses to looming stimuli in lab settings, typically by exposing the prey fish to a computer-generated visualization of an expanding disk [6], [7]. The expanding disk is meant to simulate the silhouette of an approaching predator; given ecological parameters such as average predator size and speed, the disk *rate of expansion* (how quickly it 'grows') can be computed to follow a realistic profile. The rate of expansion of this stimulus on the prey retina has been identified as a key response trigger, though the disk size, relative angle between stimulus and fish orientation, and fish

behavior all also have an effect [8]. Cade, Carey, Domenici, Potvin, and Goldbogen [6] show that predators such as whales can take advantage of this sensitivity during hunting, by opening their mouths (a movement that would increase the silhouette size and thus rate of expansion) to the last moment. To model this predation strategy required using a more nuanced profile for the rate of expansion.

The importance of detail of the loom silhouette has, to the best of our knowledge, not been previously studied. Fish visual acuity is sufficient [9] that we can expect that silhouette details specific to a predator (or non-predator) may be recognizable and thus affect the fish escape response.

2 Hypotheses

Hypothesis 1. *Adding spatial and/or temporal detail to the looming stimulus will increase reaction distance in fish.*

Hypothesis 2. *Adding spatio-temporal detail will have a stronger effect than just spatial detail.*

Hypothesis 3. *The bentho-pelagic shiner perch will be more sensitive to added detail than the benthic/cryptic staghorn sculpin.*

3 Methodology

3.1 Experiment Overview and Silhouette

Escape responses of two species, staghorn sculpin and Shinner Perch, was tested with four different looming stimuli, as shown in Fig. 1 were tested.

1. **Flapping fins** a black disk with flapping ins
2. **Stationary fins** a black disk with non-moving fins at a fixed downwards angle
3. **Disk – control** a standard expanding disk
4. **Ghost fins – control** a pair of flapping fins with the disk removed

The stimuli simulate a predator approaching at constant speed from a given initial distance; parameters were chosen to be representative of Harbor Seals, which are known to prey on both sculpin and shiners locally. The circle diameter is 24 cm, starting from an initial distance of 2 meters and approaching at a speed of 2 meters per second. The fins are visualized as ellipses with a length and width of 1/3rd and 1/8th the circle diameter, that is 8 and 3 cm respectively. When flapping, the fins are flapping at a frequency of 3 Hz. While the silhouette is relatively abstract, the parameters are rough estimates of a harbor seal. The stimulus videos were generated with Python code (should be in the supplementary material in Abyss, if not feel free to contact Steve Heim, at `heim.steve@gmail.com`).

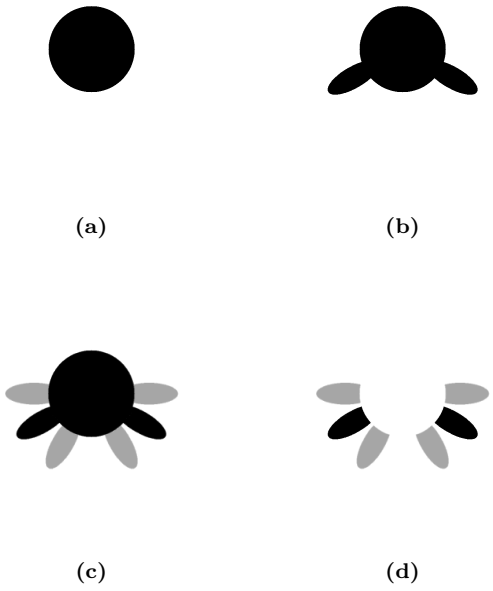


Figure 1: The four silhouettes used: a) is a simple disk used as the primary control, b) adds spatial detail in the form of stationary fins, c) adds spatio-temporal detail in the form of flapping fins, and d) is a second control consisting of only the fins flapping at the same frequency as in c). The shaded fins in c) and d) show the maximum and minimum range of the flapping.

3.2 Ethics Statement and Housing Conditions

The species of fish look towards in this study are Pacific staghorn sculpin (Leptocottus armatus) [N] and Shinner Perch (Cymatogaster aggregata) [N] which were obtained at Jackson Beach via beach seining in July and August 2025, and kept over the span of at most 5 weeks at Friday Harbor Laboratories under AUMS guidelines of the University of Washington. Fish were housed in various acrylic tanks, all of roughly $90 \times 60 \times 70$ centimeters, with flow-through seawater which ranged between 12.2 and 14.5 degrees Celsius over the course of five weeks. Sculpin were fed store-bought frozen shrimp (thawed) every third day.

3.3 Setup Details

Experiments were conducted in two separate, nearly identical tanks of dimensions width$\times$ length $\times$ height $= 59 \times 90 \times 30$ cm, as visualized in Fig. 2.

Water was filled to a depth of 25 cm, and a netting was used to wall off the back-half of the tank, such that the reachable area for the fish was $59 \times 44 \times 25$ and $59 \times 30 \times 25$ cm for the two tanks. Two sides of the tank were rendered opaque with pieces of white plastic to avoid the fish being distracted with people moving outside; the fourth side was left exposed and a display (Dell P2412H, 24", resolution of 1920×1080) was placed against this side to expose the fish to the looming stimulus. A piece of paper was placed in the corner of tank where this fourth side, such that the top-left corner of the display would not be visible to the fish; the stimulus videos included a colored box in the top-left corner on the first, middle, and last frame of the video, to help identify the stimulus (by color) and mark the start of the video from high-speed video recordings. A high-speed camera (GoPro 9, 240 frames/second) was placed above the tank at 69 cm as measured from the

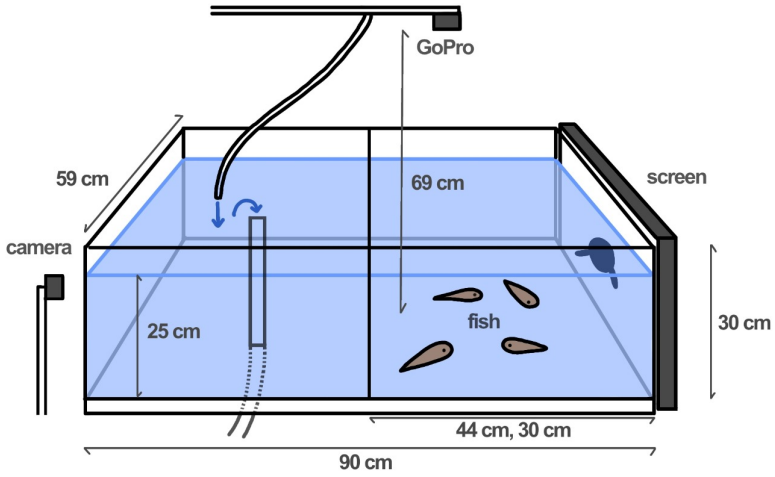


Figure 2: A visualization of the experimental setup.

bottom of the tank, to provide an overhead view of the fish as well as the display with the looming stimulus. A webcam (1080p Webcam, Trausi) with a live feed was placed at the back of the tank such that the fish height of the fish could be observed. Videos from these webcams was not used for data analysis.

Two tanks were used to be able to conduct tests in parallel; all experiments for shiner perch were conducted in the first ($59 \times 44 \times 25$ cm reachable area) tank, experiments for staghorn sculpin were conducted in both (after all shiner perch experiments were completed). The experimental tanks were in the same room and within a few meters of the holding tanks, such that external conditions did not change, and transfer of fish could be performed with a net with the fish being out of water for only a few seconds at a time.

3.4 Protocol

Before each experiment, a fish species and looming stimulus were chosen. The experimental tank was prepared by starting the looming video and making it full-screen, such that the initial frame of the stimulus is already visible before the fish were introduced to the testing tank. Four fish of the given species and of approximately the same size were transferred from a holding tank to an experimental tank. The fish were then allowed to acclimate for at least 15 minutes, after which the position of the fish was checked using the live feed of the overhead camera. As long as at least one fish was in a position that would allow it a good view of the stimulus, the camera high-speed recording was started and then the stimulus was played. After the stimulus finished playing, the recording was stopped. The fish were then removed one at a time and measured for total length (tip of the snout to tip of the tail), and finally transferred to a separate holding tank. For the sculpin, if the all 4 fish in a given group were unresponsive, the whole testing group would be transferred to a holding tank for unresponsive fish. After a minimum resting period of 24 hours, new groups of 4 sculpin were selected from the unresponsive tank and tested a second time.

4 Results

We have two types of results at the time of writing: *response rate*, and *reaction time*.

Response Rate

The response rate is simply the number of trials in which at least one fish exhibits an escape response, over the total number of trials, and is shown for both species and for each stimulus in Table 1. Because some sculpins were exposed to the stimulus a second time if they did not respond the first time, the table shows two sets of response rates for the sculpin.

	Shiner perch		Staghorn sculpin		without re-used sculpin	
Stimulus	resp./trials	p	resp./trials	p	resp./trials	p
Flapping fins	14/17	0.82	9/19	0.47	4/11	0.36
Stationary fins	15/18	0.83	9/17	0.53	5/10	0.50
Disk	15/17	0.88	9/11	0.82	8/9	0.89
Ghost fins	1/15	0.07	—	—	—	—

Table 1: Response rates by stimulus and species; note, we have reported two sets of trials for staghorn sculpin: the first results reported include all fish tested. The second set tested (without re-used fish) exclude trials 36 to 48, which had already been used in a previous trial but where the entire trial was unresponsive; in these cases, the fish were stored separately and allowed at least 24 hours rest before being used again.

Reaction Time

We have analyzed the videos to determine reaction time from the onset of the looming stimulus to the start of an escape response; we only consider the first fish to react, as the other fish may be reacting to the first fish rather than the loom. Note, the reaction time gives us only a coarse indication of the desired information, reaction distance: the *reaction distance* is the (virtual) distance of the predator from the prey at the time of reaction. While clearly a shorter reaction time corresponds to a larger reaction distance, the exact correspondance also depends on the relative position of the fish to the screen. We are in the process of further analyzing the videos to include this data, but at the time of writing only have the timing. Nonetheless, the results show a large enough change in reaction time that we can confidently expect to make useful conclusions regarding reaction distance as well.

5 Discussion

We re-iterate here our three hypotheses and discuss them.

Hypothesis 4. *Adding spatial and/or temporal detail to the looming stimulus will increase reaction distance in fish.*

Hypothesis 5. *Adding spatio-temporal detail will have a stronger effect than just spatial detail.*

Hypothesis 6. *The bentho-pelagic shiner perch will be more sensitive to added detail than the benthic/cryptic staghorn sculpin.*

We note first of all that hypotheses 2 and 2 are centered around *reaction distance*. However, we have so far only recovered from our recordings the response rate and the *reaction time*; we can nonetheless make some conclusions based on these.

We also note that the control treatment "ghost fins" elicited only a single response from a total of 15 trials in the shiner perch, and due to this not tested on the sculpin. We can conclude from this result that high-frequency movement alone is not perceived as a threat, and do not consider it further

We see from figure 3 that, for both shiner perch and staghorn sculpin, the reaction time to added spatial detail (fixed fins) is not significantly different than the control treatment of a simple disk. On the other hand, the reaction time to added spatio-temporal detail is different in both species in a similar way: there is a wider range of reaction times. Further analysis will be needed to verify if there is structure to this range (e.g. is it dependent on the relative orientation of the fish to the loom), but we can nonetheless conclude that hypothesis 2 is true, while hypothesis 2 is false but also poorly formulated; it is true for spatio-temporal detail, but false for spatial detail only.

The response rates in Table 1 reveal a difference between the two species that is less expected, and not directly visible in the histograms of Fig 3. The shiner perch response rate was similar for the flapping fins (14/17), stationary fins (15/18), and disk silhouettes (15/17); the staghorn sculpin, on the other hand, showed a similarly high response rate to the disk silhouette (9/11), but significantly lower response rates to both flapping fins (9/19) and stationary fins (9/17). This result shows that the staghorn sculpin are indeed sensitive to not only added spatial-temporal detail, but also to added spatial detail, even though it does not manifest in a change of reaction distance. While the significantly lower response rate of the staghorn sculpin to silhouettes of higher detail may seem counterintuitive, it does not necessarily imply that the sculpin interpret these stimuli as a lower threat. Since staghorn sculpin are cryptic, it is possible that this result is a reflection of a different type of response; whether due to differentiating the type of predator, noticing the predator earlier, or for other reasons is not possible to tell from our current results.

5.1 Outlook

Further analysis of the gathered data is needed. In particular, it is important to determine the fish initial position and orientation with respect to the loom in order to convert our results from reaction time to reaction distance, and also verify the rate of expansion of the loom. Considering the wide spread of reaction time to the flapping movement, it will also be interesting to see if there is relationship between rate of expansion and relative orientation of the fish, which we see is absent without the temporal detail in both species. In a few trials, the fish moved multiple times, and occasionally the first movement happened almost immediately which makes us suspect it may not be a response to the looming stimulus. We also have videos of routine turns which will need to be analyzed to be able to determine if these should be considered routine movements or actual escape responses.

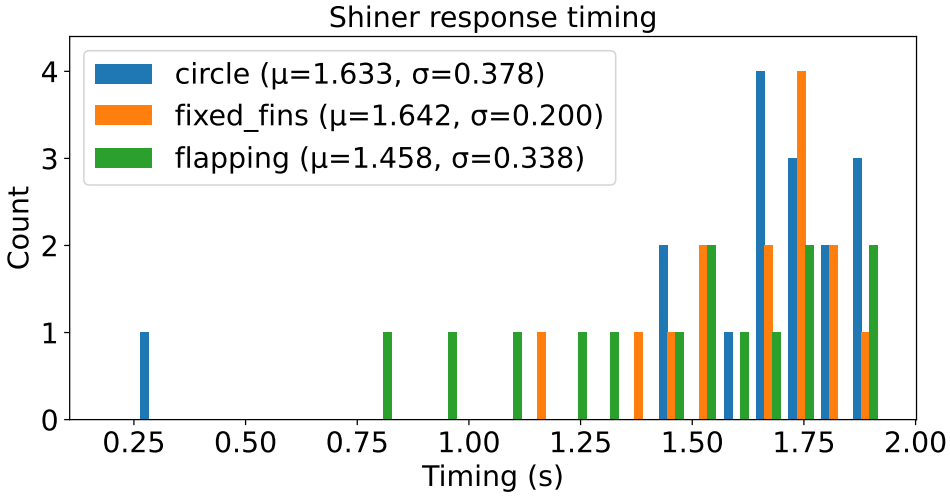
5.2 Lessons Learned

The experimental setup and all data presented are from the last two weeks of the five-week course; we initially had a different set up focusing just on Sculpin, which resulted in extremely low response rates (roughly 10%). For posterity, here are some lessons learned.

The fish need to be relaxed, and everything is a possible stressor; especially for those with little fish-handling experience, this requires practice and ideally guidance/feedback from someone with more experience. Practice moving the fish from holding tanks to the test tank.

The likely culprit for the low reaction rate is that the tests were conducted in a separate room from the holding tanks, which was much brighter and quieter than the holding area. While we expected the quieter area to help keep the fish relaxed, we now hypothesize that a sudden change in environment is a significant stressor.

Include in the protocol a clear naming convention that links files and trial number.



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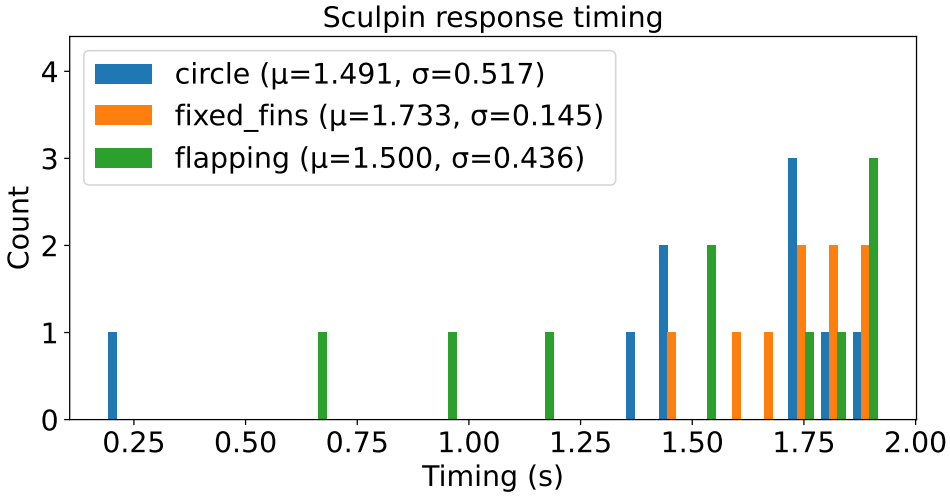

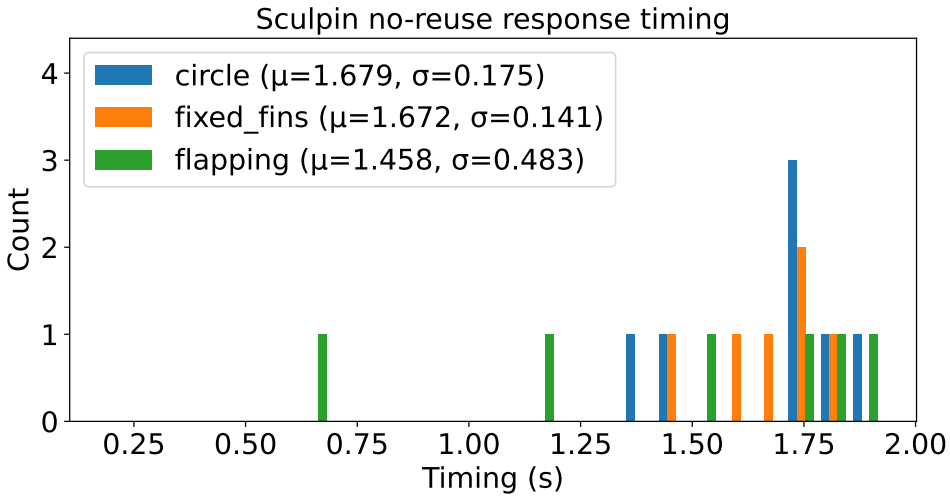

Figure 3: Histograms of the reaction timing for both perch and sculpin; again, we show two sets of results for the sculpin due to the re-use of some fish (see explanation in caption of Table 1).
The reaction time in shiners and sculpin show similar trends: for both circles and fixed fins silhouettes, the fish reaction time is clustered heavily around 1.75 seconds. For flapping silhouettes, there is a lot more variability in reaction time. In both shiners and sculpin there is a single outlier that reacted extremely quickly (less than 300 ms), which we believe is likely a spurious result; in both cases, the fish came to a rest, and then had a second reaction later during the stimulus.

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