Tipsy Fishy: disabling Bluegill visual system in turbulent water results in unstable swimming patterns

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Introduction

The lateral line system is a sensory system that is essential for the detection of movement, vibration, and pressure gradients in surrounding water (Jiang, 2019). It consists of receptor organs that contain mechanosensory hair cells that connect to the surrounding water, called neuromasts, which are distributed across the entire body (Bleckmann, 2009).

Many past studies have observed how fish swimming mechanics may change when vision is disabled, leading to a heavier reliance on the lateral line system (Stinson et al., 2020). In one study, it was found that disabling the vision system reduces the fish's distance from the flapper, and that manipulating the turbulence of the water also impacted the way the fish swims (Stinson et al., 2020). Previous research shows that turbulent flows create instabilities that can negatively impact the fish's swimming abilities. This includes increased oxygen intake and reduced swimming speed, which can be detrimental to fish in predator-prey situations. However, through the use of their lateral line system, fish use turbulence to their advantage and save energy when their body movements are in accordance with turbulence (Liao, 2007).

When swimming, fish are able to move in three dimensions. One of these dimensions is pitch, which is the quantitative measurement of the up and down movement of the fish's body (Schwalbe, 2022). There has been very little research done on the relationship between the vision system and pitch, hence why our study aims to determine how disabling vision systems can affect fish's swimming mechanics. We hypothesize that if we manipulate the fish's vision system, it will impact the stability of the fish in terms of its distance and pitch. By disabling the vision system in turbulent water, the fish will have a decreased distance from the flapper and increased pitch compared to less turbulent water.

Methods

The experiment started by gathering the necessary materials. This included a fish tank with flappers to create turbulence, bluegill sunfish, a net, a ruler and cameras. The fish were placed in a tank, the lights were turned off to impair the visual system and videos were taken to record the fish's movements in varying conditions when relying solely on the lateral line system. All trials contained a consistent flapper speed of 3Hz, an intact lateral line system, but the flow tank speed varied from low to high for different trials. All of the aforementioned aspects of the experiment were conducted by Dr. Margot Schwalbe independently beforehand. We were provided with all of the data relevant to our hypothesis to analyze. We used a software called ImageJ to analyze the photos taken of the bluegill through measurements of pitch and distance. There were a total of 14 trials that we examined; for each trial, ventral and lateral videos were taken, and images from 0 seconds, 2.5 seconds, 5 seconds, 10 seconds and 15 seconds were extracted. These images are what we conducted our measurements of pitch and distance on. To measure pitch, the angle tool was utilized to draw a straight line from the end of the fish's upper jaw to the point where the peduncle meets the caudal fin and then in the opposite direction to the end of the flapper (Figure 1). To measure distance, the line tool was utilized to draw a straight line from the tip of the fish's mouth to the bottom flapper blade (Figure 2). Image J generated a quantification for the angle in degrees or length in centimeters. Values for pitch were negative if the fish was pointing downwards and positive if the fish was pointing upwards. For each image, we replicated the measurement three times and took the average of the three measurements. The data was then recorded in an Excel spreadsheet to keep all aspects of our measurements organized.

Results

On average, when placed in high flow tank speed, fish were closer to the flapper compared to low flow tank speed, where they had an increased distance from the flapper, 19.93 and 22.64 centimeters, respectively (Figure 3). A two-way ANOVA was conducted to see whether there was a significant effect of flow speed on distance. A main effect was found between flapper speed and distance [$F(1,2) = 6.733$, $p = .012$] (Table 1), demonstrating that as the flapper speed increased, the distance decreased. Additionally, over time the fish got further away from the flapper, regardless of the flow tank speed (Figure 4). Through a two-way ANOVA, a main effect of time on distance was also found. The effect of time on distance from the flapper was found to be significant, [$F(4,2) = 63.760$, $p = 0.000$] (Table 1), demonstrating that over time the fish were further away from the flapper. The interaction between flow speed and time on distance was not found to be significant, [$F(4, 2) = 0.676$, $p = 0.612$] (Table 1).

When examining the fish's pitch, there were no differences observed either between flapper speeds or over time (Figure 5). A Waston's U2 test was conducted to see whether there was an effect of flow speed on pitch. No main effect was found for flow speed on pitch [$U2=0.143$, $0.2>p>0.1$] (Table 2).

Discussion

Our findings partially support our initial hypothesis, as we saw that in turbulent water, in the dark, fish were closer to the flapper. However, their pitch was not significantly impacted by the turbulence. Several studies have demonstrated that the amount of light the fish received had the biggest impact on their overall swimming (Didrikas & Hansson, 2008; Neilson & Perry, 1990). Without the use of their visual system in unstable waters, the fish tended to stay close to the flapper compared to more stable waters which was supportive of what we found. We believe this is due to the fish being more comfortable closer to the flapper. The bluegill's body shape allows them to pierce through water fairly easily. Because of their body shape, when a high current is presented to them, they know how to handle it and stay stable in rough waters.

Additionally, a study done by Liao et al. showed that in high turbulence, fish swimming mechanisms became unstable, and had irregular pitching motions (Liao, 2007). However, our findings did not support this. When fish were placed in either high turbulence environments, or stable ones, they had no significant changes in their pitch. The fish were able to maintain stable swimming patterns regardless of the turbulence in the water. Our findings somewhat support the previous literature, as they followed what has been found regarding distance, but not for pitch.

This study helps researchers understand how sensory systems work together. Disabling the fish's visual system allows us to analyze if it works separately from the lateral line system. If this were the case, we would expect a change in the fish's pitch. However, because we don't see a shift in the fish's position in the water, we know that the fish is relying heavier on its lateral line system to navigate through turbulence. This highlights the connection between the visual and lateral line systems in fish, as one loses function, the other compensates to make up for the loss of the other.

Future Studies

This can be further studied in other species, and with other sensory systems to help us learn the extent to which sensory systems work together. We could conduct a study with the same conditions, but with other fish species to see if they have the same outcome as a bluegill sunfish with the distance measurements. This would allow us to analyze if the bluegill's body type is really what enabled them to stay close to the flapper, or if it is something else. Another study we think would be beneficial to conduct is performing the same experiment, but with a turbine instead of flappers to create a different turbulent water flow and analyze if the bluegill's distance and pitch will stay the same as we found in this experiment or if it would change.

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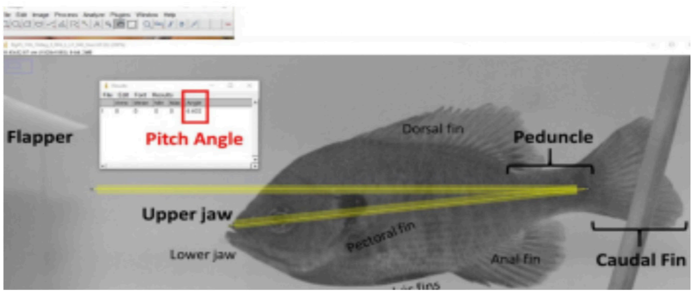

Figure 1. Screenshot of how Pitch was measured in Image J.

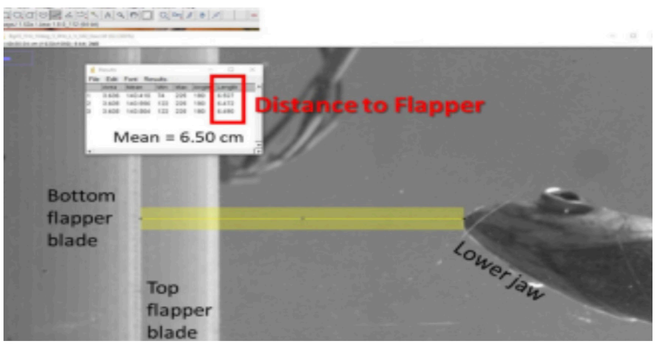

Figure 2. Screenshot of how Distance was measured in Image J.

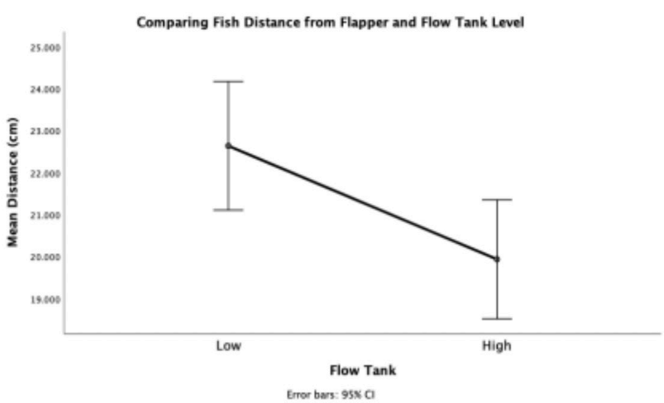

Figure 3. Line Graph Comparing Distance from Flapper and Flow Tank Level. Note: Fish in Low Flow Move Further than Fish in High Flow, $p < .001$.

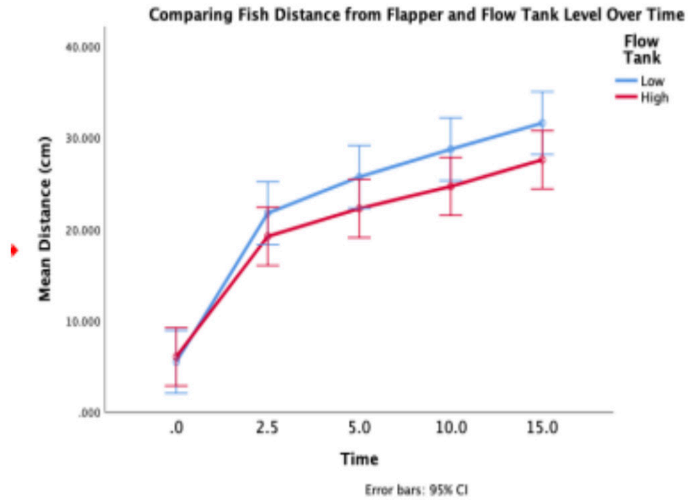

Figure 4. Line Graph Comparing Fish Distance from Flapper and Flow Tank Level Over Time.

Tests of Between-Subjects Effects

Dependent Variable: Distance (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4594.256[a]	9	510.473	29.109	.000
Intercept	29277.675	1	29277.675	1669.530	.000
Flow	118.075	1	118.075	6.733	.012
Time	4472.503	4	1118.126	63.760	.000
Flow * Time	47.388	4	11.847	.676	.612
Error	964.506	55	17.536		
Total	34723.664	65			
Corrected Total	5558.762	64			

a. R Squared = .826 (Adjusted R Squared = .798)

Table 1. Two Way ANOVA Comparing Distance from Flapper with Tank Flow and Time 9.

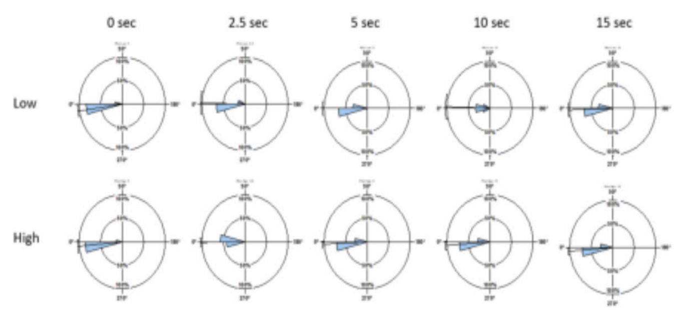

Figure 5. Circular Output Comparing Pitch and Flow Speed Over Time. Note: There was not a difference in pitch between flow speeds over time.

	Pitch High	Pitch Low
Pitch High	-----	0.2 > p > 0.1
Pitch Low	0.143	-----

Table 2. Watson's U2 Test Comparing Flow Speed and Pitch.