Bubble Netting as a Whale Feeding Strategy: Why does it Work?

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Introduction

One of the biggest challenges facing life on earth is finding food, and this has led to some amazing adaptations and behaviors. From a chameleon's tongue that can extend well beyond its body length to fish that hide in plain sight disguised as a rock nature is full of amazing and bizarre examples of animal ingenuity; one hunting strategy in particular is both brilliant and a puzzle. Humpback whales have been observed using bubbles to corral fish. The whales locate schools of small fish like herring or sardines and blow rings of bubbles around them which causes the fish to clump tightly together and move towards the surface, this makes them easy prey for the whales (Ardern 2012). Humpbacks are uniquely adapted to this hunting style because their flippers and flukes are proportionally larger than other whales which gives them the enhanced maneuverability needed to create the complex bubble nets (Wiley, 2011). A recent study was performed in which researchers attached sensors to the whales using suction cups to record their orientation and behavior underwater as they hunt the fish. The data revealed that groups of two or more whales blow bubbles in spiral patterns starting underneath the schools and continue upwards towards the surface until all of the fish are grouped tightly together (Brill, 2011). This new data reveals the intelligence and ingenuity of the whales to master such a sophisticated hunting strategy but in the research that has been done there have only been vague explanations and guesses as to why it works in the first place and why the fish seem unwilling to just swim through the bubbles to escape. The studies have been so focused on the whales' strange behavior that they do not stop to question why it works in the first place. This was the question that this research was geared towards; what factors prevent the fish from simply swimming through the bubbles.

Significance

This research could be applied to help us preserve the ocean in several ways. If we improve our understanding of how the whales hunt these fish then we can ensure that we don't do anything to interfere with their survival. Understanding why the fish behave this way could not only help us preserve their populations but could also lead to new fishing techniques that are less harmful on the marine ecosystem. Current fishing techniques such as bottom trawling involve dragging weighted nets along the seafloor to collect the fish in their path but in the process these nets tear up the bottom turning it into an inhospitable scar on the seafloor (Russell, 2015). Another popular technique is long lining, in which involves leaving a fishing line that can be ten kilometers long stretched across the surface with thousands of baited hooks to catch fish. This tactic is effective in catching the intended fish species, usually tuna or marlin, they also catch and can kill anything else that takes the bait such as sharks and whales that could get tangled in the lines (Russell, 2015). By studying why bubble nets are effective at catching fish we could potentially create a new form of fishing that doesn't have such a damaging impact on the oceans.

Materials and Methods

The first part of my research was analyzing video of humpbacks using this hunting behavior to try and understand how I could replicate it in a lab. To do this I used several videos given to me by Dr. Werth who received them from a colleague working in alaska at a fish hatchery. The whales had learned that they were releasing fish on a regular basis so they would come and hunt off of the dock of the hatchery, which was in a fjord about forty feet deep. After watching the videos I came up with several experiments to test fish behavior in response to bubbles in the lab. To conduct these experiments in a lab I used small freshwater fish that were easily obtained through local pet stores (zebrafish and two types of goldfish) and subjected them to bubbles created by aquarium air stones under various conditions. I tested the zebrafish (*Danio rerio*) first. In order to get numerical data for comparison I took a small tank (approx. ½ gallon) and put a line of tape down the middle widthwise to separate it into two halves. For the control I placed each fish in the small tank for twelve minutes (two minutes to acclimate to the change then ten minutes of experimental time) and counted the number of times each fish swam across the middle line of the tank. This data gave the base activity level for these fish under normal conditions. I would repeat this procedure in future experiments with the goldfish. The two breeds of goldfish I used were the fantail and the common goldfish (*Carassius auratus*). I also put them into the small tank in groups of five to gauge how they behaved as a school as opposed to individuals. The second part of the experiment involved placing aquarium air stones which create a steady stream of bubbles along the centerline of the tank and counting how many times each fish crossed the bubbles, both as an individual and as a group, and observing how their behavior may or may not change. To try and determine the cause of their behavior I ran additional experiments, one to test if it was purely a visual response and two to test if they were responding to physical changes in the water. The visual experiment involved the same procedure as the others but with the addition of decorative beads being draped down the middle of the tank to create a loose barrier that the fish could swim through if they wanted. The other experiments used small aquarium fans designed to create a current in a tank placed along the centerline like the air stones were to test their response. Finally to get a sense of how the fish would respond in a larger body of water I performed two experiments in the five hundred gallon bubble tank down in the physics department. For one of them I used a small ring of tubing that sat on the bottom and pumped bubbles into the tank and for the other I used a bed of hypodermic needles that had air pumped through to create bubbles.

Results

For the zebrafish control experiment they crossed the middle of the tank an average of 72.4 times with a standard deviation of 26.2, with the bubbles the average was 16.7 crossings with a standard deviation of 11.7 (see Table 1.1). For the zebrafish school control experiment the average was 157.7 crossings with a standard deviation of 21.6 and for the bubbles it was 63.3 with a standard deviation of 2.5 (see Table 1.2). Please note that the fish were randomly selected for each experiment so the fish number does not correspond from one experiment to the next.

For the visual barrier experiment the zebrafish crossed an average of 122.7 times with a standard deviation of 1.5 (see Table 1.3).

For the first batch of goldfish the average number of crossings for the control was 26 and the standard deviation was 4.3, with the bubbles the average was 1 with a standard deviation of 0.7 (see Table 1.4). These goldfish were more expensive so only 5 were purchased which limited the number of trials that could be done.

For the second batch of goldfish the average for the control was 22 with a standard deviation of 9.2, and for the bubbles the average was 4.5 with a standard deviation of 5.9 (see Table 1.5). These fish were less expensive so more could be purchased for experimenting.

The final batch of goldfish survived long enough to perform individual and school experiments. The average for the individual control experiment was 16.8 crossings with a standard deviation of 10, and the average for the bubbles was 14.5 crossings with a standard deviation of 11.7 (see Table 1.6). For the school experiments the average for the control was 51.7 with a standard deviation of 15.8, and the average for the bubbles was 46.7 with a standard deviation of 7 (see Table 1.7).

Finally, the average number of crossings for the current generator test was 14.1 for the vertical configuration, with a standard deviation of 5.1, and 12.2 for the horizontal configuration, with a standard deviation of 6.1 (see Table 1.8).

Control		**Bubble Treatment**	
Fish #	**# of crossings**	**Fish #**	**# of crossings**
1	106	1	25
2	95	2	8
3	33	3	10
4	89	4	1
5	43	5	0
6	98	6	26
7	61	7	35
8	88	8	28
9	44	9	24
10	67	10	10
Average	**72.4**	**Average**	**16.7**
STDEV	**26**	**STDEV**	**12**

Table 1: Zebrafish (individual)

Control		**Bubble Treatment**	
Group #	**# of crossings**	**Grouph #**	**# of crossings**
1	135	1	66
2	160	2	61
3	178	3	63
Average	**157**	**Average**	**63.3**
STDEV	**21.6**	**STDEV**	**2.51**

Table 2: Zebrafish (school)

Group #	# of crossings
1	121
2	123
3	124
Average	**122.7**
STDEV	**1.53**

Table 3: Zebrafish Visual Barrier Test

Control		**Bubble Treatment**	
Fish #	**# of crossings**	**Fish #**	**# of crossings**
1	25	1	1
2	32	2	2
3	20	3	0
4	27	4	1
5	26	5	1
Average	**26**	**Average**	**1**
STDEV	**4.3**	**STDEV**	**0.71**

Table 4: Goldfish Batch #1 (fantail)

Control		**Bubble Treatment**	
Fish #	**# of crossings**	**Fish #**	**# of crossings**
1	27	1	1
2	15	2	1
3	19	3	16
4	20	4	0
5	17	5	4
6	22	6	14
7	36	7	3
8	19	8	0
9	7	9	6
10	37	10	0
Average	**22**	**Average**	**4.5**
STDEV	**9.2**	**STDEV**	**5.9**

Table 5: Goldfish Batch #2 (common)

Control		**Bubble Treatment**	
Fish #	**# of crossings**	**Fish #**	**# of crossings**
1	3	1	30
2	14	2	11
3	33	3	14
4	17	4	36
5	15	5	8
6	11	6	22
7	3	7	6
8	30	8	15
9	20	9	2
10	22	10	1
Average	**17**	**Average**	**14.5**
STDEV	**10**	**STDEV**	**12**

Table 6: Goldfish Batch #3 (common; individual)

Control		**Bubble Treatment**	
Group #	**# of crossings**	**Group #**	**# of crossings**
1	69	1	46
2	38	2	54
3	48	3	40
Average	**52**	**Average**	**16**
STDEV	**47**	**STDEV**	**7.0**

Table 7: Goldfish Batch #3 (common; group)

Vertical		**Horizontal**	
Fish #	**# of crossings**	**Fish #**	**# of crossings**
1	8	1	4
2	22	2	18
3	18	3	10
4	21	4	13
5	8	5	17
6	13	6	17
7	17	7	7
8	10	8	18
9	12	9	16
10	12	10	2
Average	**14**	**Average**	**12**
STDEV	**5.1**	**STDEV**	**6.1**

Table 8: Goldfish Batch #3 (common)

Observations

All of the fish tested showed a few key responses to the bubbles. First, all of the fish started to swim away from the bubbles in a frenzy, trying to get as far away as they could. Second, the fish were constantly swimming hard away from the bubbles fighting the current that the bubbles generated. Third, when the fish did cross they looked for the gaps where the bubbles were thinnest (towards the surface of the tank, usually close to the sides where there were gaps between the bubbles and the side of the tank). Fourth, the fish often crossed by simply surrendering to the current instead of powering through it. And finally, when they were in groups the fish were more likely to cross if they could see a fish on the other side and tended to stay in groups.

Conclusion

From the observations and data from these experiments I believe I know why the fish avoid the bubbles. The first factor that repels the fish is the rising current generated by the bubbles that pushes the fish up and away from them. I first noticed this in the videos of the whales feeding when the fish can be seen separating to one side of the bubbles or another before the bubbles reached the surface. When I noticed the current created in my experiments and how it pushed the fish up and out I did the test with the current generators to confirm it. The data for the fish in these experiments does correspond with the data for this batch of fish when they were exposed to bubbles (14.5 average crossings for bubbles 14.1 and 12.2 for the current generators). On top of this the fish exhibited the same frantic swimming behavior when exposed to the current generators as they did when they were exposed to the bubbles. These results suggest that the current generated was the key factor in repelling the fish but it wasn't the only factor. The other major factor is the that the bubbles create a visual obstruction for the fish. Again this first came up by observing the recordings of the whales feeding. The bubbles that the whales create are so large and densely packed that they create a foaming white barrier, much more impressive than I could generate in any of my experiments. To test if the visual response of the fish I used strings of bead necklaces strung across the middle of the tank, and while the fish did swim through them they were held back (control average 157.7, bubble average 63.3, barrier average 122.3). This data suggests that there was a slight influence on how the fish behaved but not as much as the bubbles themselves. In addition the behavior of the fish was more similar to the control experiment, they appeared calm and swam normally instead of the frantic behavior when the bubbles were present. Putting these factors together, I believe that the fish are primarily corralled by the current and the fish stay within the bubbles because they see them as a visual barrier.

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