AN EXPERIMENT ON VISUAL DISCRIMINATION IN THE LARGEMOUTH BASS, *MICROPTERUS SALMOIDES*

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Eighteen largemouth bass were run through a training procedure designed to determine whether they could use visual cues (hue, opacity, fluorescence) associated with different monofilament fishing lines in solving a discrimination problem leading to a food reward (an earthworm). Each fish was fed a worm attached to one ("reward line") of two different-colored monofilament lines presented six times per day for several days, then was given an additional worm for taking a very small piece attached to the reward line. When the feeding response to a tiny attached piece of worm was swift and unhesitating, the first test phase began: the fish was required to bite the empty snap-swivel on the reward line before it was given an allochthonous worm. When the fish bit the reward line in 5 of 6 trials (criterion) it was tested with single-strand monofilament lines (versus 3-strand braided in the first test phase) until it either reached criterion or clearly demonstrated an inability to selectively respond to the reward line. At least one fish was able to discriminate between each line combination tested (3-strand) and the majority of the fish tested were able to reach criterion in the one-strand test as well. Some line combinations proved to be more easily discriminable than others.

INTRODUCTION

Despite the fact that the largemouth bass (*Micropterus salmoides*) is one of the most important game fishes of North America, relatively little is known of its sensory capabilities (1). The largemouth is generally recognized to be primarily a visual feeder (2), but aside from a paper by Shafer (3) on cone patterns in the retina and Brown's (4) study of responses to color, there is virtually no direct information available on bass vision. Reports by Jester (5) and Jester et al., (6) on variations in catch rates of fish in different-colored gill nets suggested that bass may have difficulty perceiving yellow wavelengths, but their results are open to alternative explanations. McCoy (7) found that bass were capable of discriminating among cues varying in color and brightness, but he encountered some methodological difficulties in his study. Thus, at the present time we find that enormous sums of money are spent each year for the purchase of specially colored or constructed fishing lures and terminal tackle designed to capture a species about whose sensory mechanisms and behavioral organization we know virtually nothing.

One aspect of this situation that has proved to be a challenging area of investigation deals with the largemouth bass' ability to perceive and react to monofilament nylon fishing line. The fishing tackle industry's traditional view that the most invisible line (either transparent or pigmented to match water color) would be the most desirable from the angler's view was challenged when a fluorescent yellow line was marketed a few years ago. One support for the decision to depart from conventional thinking apparently was derived partly from Brown's (4) work, which showed that largemouth bass had difficulty discriminating between yellow and light gray objects, and his conclusion that bass, like some other fishes (8), appear to respond visually as if they were viewing the world through a yellowish screen. Since many fishes are known to have photostable yellow pigments in their corneas, lenses, and retinas (9), the possibility that bass are relatively yellow-blind seems to have appreciable circumstantial support. However, Brown did not have adequate intensity controls to demonstrate unequivocally the color-vision system he proposed. Jester (5) and his colleagues could have been measuring many factors beside (or instead of) response to color, and no one has yet demonstrated the presence of yellow filtering pigments in the largemouth eye (we

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are presently investigating the latter in this laboratory).

Thus, when we were challenged by representatives of the Berkley Corp. to determine whether bass could discriminate between different-colored fishing lines, we were faced with a serious methodological problem. Should we try to demonstrate unequivocally the presence of true color vision in bass, then generalize to the problem of line visibility; or should we attack the problem of responses to monofilament lines directly? We chose the latter, despite the acknowledged difficulty of devising a technique which would focus on the fishes responses to such an unobstrusive stimulus. The technique we finally developed was based on the premise that we could establish an association between a particular kind of monofilament and a positive reinforcer, food. The training method does not fit precisely either a classical or operant conditioning paradigm, but it has produced positive results which are of potential interest to both fishery scientists and the sport-fishing community.

MATERIALS AND METHODS

Monofilament Line Used

The Berkley Corp., Spirit Lake, Iowa, provided us with fresh rolls of 8-pound test lines identified only with code numbers. Absorption and emission peaks for the lines were determined by Stearns Midwestern Labs and provided to us after completion of the study. Since pigmented, unpigmented, and fluorescing lines were used, the possible visual characteristics of the 5 lines were undoubtedly complex. The lines, characterized by our subjective perception of color traits, were coded as follows:

(W) D-45-4;	white (clear); no pigment
(FW) D-45-3;	fluorescent white; absorption peak 400 nm, emission peak 430 nm
(Y) D-45-1;	fluorescent yellow; absorption peaks 350, 455 nm, emission peak 558 nm
(OBG) D-45-5;	optically brightened green; absorption peaks 400, 425 nm, emission peak 455 nm
(G) D-45-2;	blue-green; absorption peak for dye used 525-530 nm

All of the lines were easily discriminable to the human eye under both fluorescent and incandescent lighting, though the fluorescing lines were more strikingly different under natural light.

Animals Used in the Conditioning Experiments

Bass ranging in size from 20 to 26 cm TL were captured by angling from ponds and lakes surrounding Stillwater, Payne County, Oklahoma. Prior to being used in experiments, these fish were maintained in 3 × 3.5 m outdoor holding tanks and fed a diet of minnows and worms. Fish were then brought into the laboratory and placed in individual aquaria and fed only worms for several days before the initiation of experimental procedures. No attempt was made to select fish on the basis of sex.

Experimental Apparatus

Five experimental tanks, measuring 42 × 58 × 85 cm, were constructed of metal with a large glass window at one end. Each tank was divided into two areas, a residence area and a feeding area (see Figure 1), which were separated by a clear Plexiglas sliding door. The feeding area was equipped with an aquarium reflector containing a 15-W cool white fluorescent bulb (Westinghouse) and controlled by a time switch set to provide a 10-hr light/14-hr dark photoperiod.

Spring-controlled feeding cups were provided at the front corners of the feeding area. Each tank was enclosed within a framework covered with black polypropylene plastic to shield the fish from outside disturbances. Each tank was observed through a viewing screen consisting of three layers of metal screen situated approximately 0.6 m in front of the tank. This permitted observers to monitor activity within the tank while essentially being invisible to the fish.

Monofilament lines used in the conditioning tests were attached to metal eyelets 31 cm apart on a 2.5 × 5 × 36 cm piece of wood that could be lowered to permit the lines to drop into the water in the feeding area. All the moving parts were controlled by lines extending to the area outside the plastic covering, where they could be manipulated without being observed by the fish.

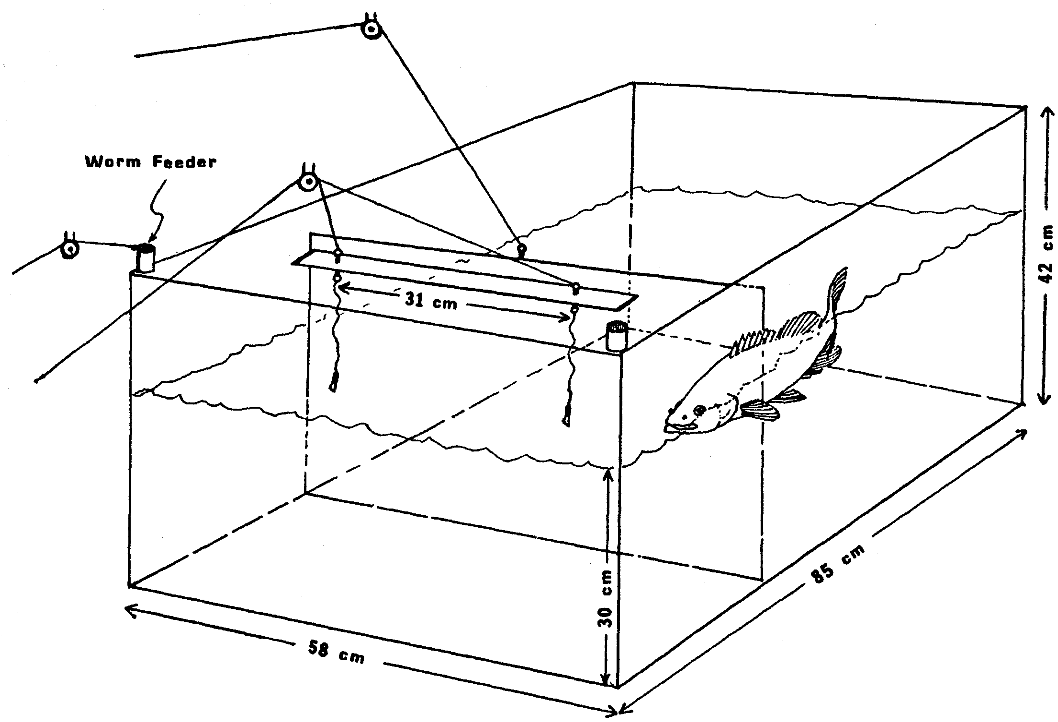

FIGURE 1. Experimental Tank

Training Procedure

The procedure used to train fish consisted of the following steps: after being brought into the laboratory, fish were placed into their several tanks and permitted to acclimate to the new environment for a period of 1 to 2 days. Following this period, daily rations of 4-6 worms were supplied to each fish in the feeding area until feeding occurred with regularity. When this was accomplished, a whole worm was hooked on a fishing snap-swivel attached to a braided 3-strand monofilament line ("reward line") suspended from one end of the lowering board. At the opposite end, a different-colored braided line and empty snap-swivel were attached; then the lines were lowered into the feeding area of the tank.* At this point, the fish was given 30 seconds to view the lines before the Plexiglas door was drawn. When the door was raised, the fish was permitted access to the feeding area until it removed the worm from the clip.

Once a fish was feeding off the snap-swivel regularly, the size of the attached worm was reduced to a small piece. Thereafter the fish was rewarded with a worm supplied via the feeding cup immediately after the fish had approached and bitten the swivel with the piece of worm attached. This "shaping" period required between 4 and 15 days in different fish until performance of the task was accomplished without hesitation. When immediate response was achieved, pieces of worm were no longer attached to the reward monofilament; the fish were thus required to discriminate between lines on the basis of visual qualities, and had to approach and bite the snap-swivel on the reward line before a worm was dropped from a cup into the tank.

At this point, the observer recorded the following data during each of six daily trial runs: time to orientation on the correct line (while in the home area), approach time (from raising of barrier to contact with line), whether the choice of line was correct or incorrect, and whether the fish ingested the clip.** In order for a fish to progress to the next step, a criterion

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*Position cues were eliminated by randomized left-right positioning of the reward line.

**Both clips were carefully washed after each trial.

of five correct choices in six trials had to be met. Subsequent to reaching this criterion, the line size was reduced to a single strand and the training procedure repeated until either criterion was reached or it became apparent that the fish was not able to achieve this goal.

Qualitative data on the behavior of each individual were also recorded at the time of testing.

RESULTS

Because of the tendency of some of the fish tested to swim rapidly back and forth in front of the clear partition prior to its raising, data on orientation time were not available for all individuals and were not considered in the analysis. The remaining data, however, are included in Table 1, which summarizes information on how long it took (in days) for fish to reach criterion (5 correct line choices out of 6) after the lines and snap-swivels were presented without attached worms, the average duration (in seconds) of the interval between raising of the barrier and contact with either of the snap-swivels (approach duration), and the overall proportion of choices that were successful in producing worms (per cent correct choices). Since the different measures of discrimination

TABLE 1. *Summary of laboratory results for individual fish.*

Fish No.	Monofilament Pairing	Days to Criterion	3-Strand Approach duration (sec)	Correct choices (%)	Days to Criterion	1-Strand Approach duration (sec)	Correct choices (%)
1	D45-1,[a] (Y) D45-5 (OBG)	NC[c]	15.54[b]	49[b]	---	---	---
2	D45-1 (Y) D45-5[a] (OBG)	4	3.01	71	1	1.45[b]	100[b]
3	D45-1[a], (Y) D45-5 (OBG)	1	1.10	100	2	30.58	67
4	D45-1, (Y) D45-3[a] (FW)	7	3.91	84	1	0.78	83
5	D-45-1[a], Y D45-3 (FW)	1	1.48	100	2	1.21	83
6	D45-1, (Y) D45-4[a] (W)	1	4.42	100	1	1.38	83
7	D45-1[a], (Y) D45-4 (W)	2	1.80	92	2	12.81	83
8	D45-2[a], (G) D45-3 (FW)	1	1.72	100	1	1.84	83
9	D45-2, (G) D45-3[a] (FW)	NC[c]	64.78	50	---	---	---
10	D45-2, (G) D45-4[a] (W)	2	14.54	67	2	21.04	75
11	D45-2[a], (G) D45-4 (W)	2	9.09	83	NC[c]	20.67	29
12	D45-2, (G) D45-5[a] (OBG)	2	5.42	75	1	2.44	83
13	D45-2[a] (G) D45-5 (OBG)	NC[c]	39.69	42	---	---	---
14	D45-3[a], (FW) D45-4 (W)	NC[c]	37.03	45	---	---	---
15	D45-3 (FW) D45-4[a] (W)	2	2.89	75	NC[c]	3.65	61
16	D45-3[a] (FW) D45-4 (W)	NC[c]					
17	D45-3[a], (FW) D45-5 (OBG)	2	52.97	46	3	10.62	61
18	D45-3, (FW) D45-5[a] (OBG)	5	1.55	67	NC[c]	19.37	49

[a]Indicates this was the "reward line"
[b]Values in these columns are mean responses for the individual
[c]Criterion not reached

success may be related to different aspects of the training paradigm, they are discussed separately below.

Time (days) to Criterion

Table 1 shows that at least one fish achieved criterion for every possible combination of monofilaments used. In line pairs Y-FW and Y-W all fish achieved criterion under both 3-strand and 1-strand conditions. One of three fish trained on the Y-OBG combination failed to reach criterion, but this individual was the first tested in the study and was subjected to some procedural flaws that were eliminated in subsequent trials. At least one fish reached criterion on both 3-strand and 1-strand lines in line combinations G-W, FW-OBG, G-FW, and G-OBG. With line combination FW-W, one of three fish reached criterion on the three-strand lines and none on the one-strand.

Approach Duration

Approach durations listed in Table 1 represent the average length of approaches for all trials subsequent to complete removal of a worm from the snap-swivel, up to and including the trials demonstrating achievement of criterion. Approach durations vary considerably for both 3-and 1-strand lines. Some fish obviously solved the discrimination problem, moving immediately to the line and biting the snap-swivel. It is doubtful whether the observer's reflex time was sufficient to record such trials as anything more precise than < 1 second. Thus, average durations of less than or close to 1 s probably represent virtually unhesitating responses over the series of trials and indicate individuals that had acquired the "correct" response mode and were highly motivated to obtain food. Generally speaking, the lowest approach durations were exhibited by fish with line combinations Y-FW, Y-OBG, and G-FW, if fish that did not reach criterion are omitted from consideration. Fish on the other line combinations generally had longer approach durations, though one fish on the FW-OBG pair averaged less than two seconds on the 3-strand line. In most cases where approach durations were low on the 3-strand lines, average durations tended to decrease on the 1-strand lines. Where approach durations were longer for the 3-strand discriminations, they tended to increase or at least remain high in subsequent 1-strand tests, though exceptions to this and the previous statement can be found in several cases.

Percent Correct Choices

Because it was possible for a fish to achieve criterion by making 5 or 6 correct choices in 6 trials, or to fail by making 4 or fewer correct choices, data on the overall proportion of correct choices were included in Table 1 under this heading. Most of the fish that did not achieve criterion selected the correct line as if they were responding randomly — i.e.: values range from 42 to 61 percent correct. Fish that did reach criterion tended to have a relatively high percentage of correct responses, particularly for line combinations Y-FW, YW, Y-OBG, and G-FW. Fish trained on the other line combinations tended to make more unrewarded responses early in the test phase in both 3-strand and 1-strand situations.

DISCUSSION AND CONCLUSIONS

The methods used in this study were devised in the hope that frequent association of a "neutral" visual stimulus (monofilament line of a particular hue and brightness) with a reinforcing stimulus (worm attached to a snap-swivel) would produce an association between the neutral stimulus and an acquired feeding response (biting a snap-swivel). Essentially, the bass had to learn to take worms from a snap-swivel, then bite the snap-swivel tied to a line similar to the one that had produced food (first attached, then both attached and non-attached) in order to receive food in the test phase of the experiment. Because we felt that a single 8-lb. test strand of monofilament did not necessarily constitute a particularly obtrusive visual stimulus, we designed the experiment with the initial training period being performed with a 3-strand braided line, to enhance the probability that the fish would use color cues in learning how to identify the "proper" line to approach and feed on. We recognize the possibility that structural idiosyncracies (kinks, tightness of braid, etc.) could serve as discrimination cues in the 3-strand tests, and that opacity or brightness cues were available in all tests. Though the results raise questions about the nature of cues used by some of the fish in acquiring positive responses in the test situation, we believe the data provide some interesting insights into the visual discrimination capability of the largemouth bass.

First, the possibility exists that some fish achieved criterion (5 of 6 choices correct) on the basis of chance alone. Because fish in only four of 22 trials (both 1- and 2-strand) required more than 2 days to reach criterion, it appears that this possibility is an unlikely explanation of the results in general.

The overall pattern of the results argues against the importance of chance in most trials. Half (5) of the fish that reached criterion on the 1-strand lines did so on the first day the single line was presented, and most of the rest (except fish 10 and 17) made four correct choices the first day. Since only 3 fish that reached criterion on the 3-strand lines failed to do so on the 1-strand lines, the data strongly suggest that most of the fish tested were able to discriminate between qualitatively different monofilaments and use visual cues in guiding acquired responses toward stimuli that would produce a food reward. The high percentage of responses to "reward lines" in the 1-strand phases argues further that these fish were using hue and brightness cues in making line choices. Although fish could have been using structural characteristics in the 3-strand trial most non-chromatic features would be likely to vary from one presentation to another; therefore we suggest that discrimination, when it occurred, was primarily based on hue and brightness cues, even in the 3-strand trials.

Table 1 shows that some line combinations produced apparently easier discrimination tasks than others. In all trials (fish 1-7) where the fluorescent yellow line was involved (except fish # 1, where procedural flaws vitiate the results), fish were able to achieve criterion on both 3-strand and 1-strand lines, approach durations were predominantly short, and percent correct choices were invariably high. Some unexpected observations were made during the training procedure for the 3 fish on the Y-OBG line combination. Both fish (#1, #3 Table 1) trained with fluorescent yellow as the reward line showed some reticence (slower approach time) to approach the worm on the Y line, and several times even ingested the bare swivel on the OBG line though an earthworm was attached to the swivel clip on the Y line. This behavior was not observed in any other line combinations, and while fish #3 did eventually achieve criterion on both 3- and 1-strand lines, we were struck by the obvious reluctance of the fish to approach the Y line. We do not believe the OBG line served as an attractant because of the absence of any similar behaviors where OBG was paired with other lines (in fact, fish seemed to have some trouble discriminating the OBG-G and OBG-FW combinations: Table 1).

The poorest success rate was observed in fish with the W-FW combination. Although these lines were discriminable to the human eye, the FW line showed relatively little fluorescence when submerged, and might not have provided a strong enough contrast with the W line to permit differentiation of the two. Fish #16 did not even approach the lines once earthworms were no longer attached to the reward line. Fish #14 did bite the snap-swivel on the 3-strand line, but had an extremely long approach duration and never reached criterion. Fish #15 learned to approach quickly and bite the snap-swivel, but performance was poor (75% correct over 2 days). This fish did reach criterion on the second day of the 3-strand trial, but was unable to do so with the 1-strand lines, though approach time remained fairly low. It is possible that #15 achieved criterion by chance; at the least, this line combination definitely produced the poorest discrimination results.

Performance scores for the other line combinations were intermediate between these extremes, though at least one fish was able to reach criterion in both 3-strand and 1-strand tests with every combination. Approach times and percent correct choices generally indicated that these discriminations were more difficult than those involving the Y lines.

We believe that the results reflect interaction of two or more factors that influenced the outcome of training procedure on fish. Some fish undoubtedly never made any association between line characteristics and worms on the swivel clip. Those that made an association of this sort were faced with dealing with different degrees of contrast between the visual charactersistics of the two lines, and apparently some were unable to perform the discriminations on the 1-strand lines. Finally, it is possible that some fish achieved criterion on the 3-strand lines on the basis of chance alone, though we do not believe this is a likely possibility.

We conclude that largemouth bass are capable of learning to discriminate between monofilament lines having different visual characteristics. Fluorescence, per se, does not seem to be the dominant visual characteristic being used, because fish evidenced some difficulty in discriminating between OBG or FW lines and nonfluorescing lines. Fluorescent yellow, in combination with OBG, FW or W lines, appeared to be most easily discriminable to the largemouth. While this experiment does not clarify the question of whether or not bass can subjectively perceive yellow as a distinct wavelength, the combination of pigment and fluorescence in the Y line was not only discriminable to bass, but may have provided them with a mildly aversive visual stimulus. The latter possibility is presently being tested in a visual experiment we are conducting in our laboratory and will be reported on at a later date.

Extinction of the response occurred within 1 to 4 days, with no obvious relationship between line combination and extinction rate. Some fish that were not run through an extinction procedure (presentation of test lines, but no reward for correct choice) retained their ability to respond "properly" for at least two weeks. On several occasions we were able to demonstrate to visitors the ability of such fish to approach and bite the correct swivel after they had spent more than a week without any training or food. These fish were invariably accurate and completely unhesitating in their response to line presentation. All individuals tested in this manner had been successful on both 1- and 3-strand combinations and were fish that we were certain had acquired the desired discrimination and response capabilities.

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