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Sound Production by the Satinfin Shiner, Notropis analostanus, and Related Fishes

Abstract. Several sounds are produced by minnows. Only one is not of purely mechanical origin, and it is classed as a "biological" sound. This sound is variously produced by males when fighting and chasing as well as during courtship. Females emit a similar sound. Testosterone injections and elevated temperatures result in an increased rate of biological sound emission.

In recent years it has been demonstrated that marine fishes produce a wide variety of sounds, some of which must have a biological function (*1–3*). Little work has been done on fresh-water fishes, although aquarists and several European investigators have occasionally heard their sounds (*4, 5*). *Phoxinus laevis*, a cyprinid of Europe, has been studied in detail, but the only reported sound produced by this fish was one caused by the emission of a bubble of air (*5*).

Several kinds of sounds have been recorded from *Notropis analostanus* (*6, 7*). These were a scratchy sound produced when the fish hit the bottom gravel under various conditions, a high-pitched noise when air bubbles were released from the mouth, occasional chewing sounds, and finally one or more sharp knocks produced most frequently during reproductive activities. All except the latter are mechanical sounds, and superficially they do not appear to have any biological function, although they cannot be overlooked as potential stimuli to the fish. The knocks (similar to the sound made when one strikes wood with his knuckle) appeared under conditions that identified them as "biological" sounds. They were produced when the males fought and when the males and females courted, and appeared not to be a sound primarily associated with necessary movements. We follow the use of the terms "biological" and "mechanical" sounds as proposed by M. P. Fish (*1*), although there is reason to believe that the two categories grade into each other on an evolutionary basis, and may soon outlive their usefulness.

The single knocks, made when a male chased and fought with a male, contained frequencies from below 85 cy/sec up to between 2000 and at least 11,000 cy/sec, and lasted between 11 and 60 msec with greater intensities in the lower frequencies, as analyzed with a Kay Sonagraph model recorder. These single knocks were produced rapidly and intensely (40 to 60 msec, tapering to below 12 msec at highest frequencies) when a male chased another male, but they could be united into a very close series (11 to 24 msec, tapering very slightly to below 12 msec at highest frequencies) when two males fought each other. Similarly a purring sound occurred when a male actively courted a female. This appeared to be basically the same sound, but it was emitted more rapidly and less intensely. In all cases the male made these sounds (isolated, fighting a mirror image, and so forth), but isolated females also produced fainter, less frequent knocks than males, so that it was impossible to know which sex made the sound during courtship.

Biological sounds similar to the knocks of *N. analostanus* have been heard in other species of minnows. Occasional knocks were heard when a male chased another male of *Gila* (Clinostomus) *vandoisula* and *Notropis spilopterus*, and a large series of knocks were heard when several to many males chased a female of *Semotilus* (Margariscus) *margarita*.

The structure that produced the "biological" knocks has not been located. The sound was still produced, seemingly unaltered, when various organs were experimentally manipulated as follows: angle of jaws, base of pectoral girdle, pharyngeal arches cut through; operculum, pelvic fins, pectoral fins, anal fin, dorsal fin cut off; the air bladder punctured and removed; and the body cavity injected with petrolatum.

A series of males of *Notropis analostanus*, at the beginning of the breeding season (June and early July), were placed in water at different temperatures (Table 1). The production of sound decreased significantly at the lower temperatures. This fish breeds in water of 20° to 30°C. Individuals injected with testosterone at 25° to 27°C with a 10-hour photoperiod produced many more sounds than fish injected with sesame oil and normal control fish from 5 to 10 days after injection. The activity of those injected with testosterone was considerably greater than that of the control group.

Over the past 30 years many German and Dutch workers have demonstrated that *Phoxinus laevis* and other fresh-water fishes are able to hear and that this ability extends into frequencies not heard by nonostariophysid species of fish (*4, 8*). This ability to hear sounds of frequencies up to as high as 7000 cy/sec or more is enhanced by the weberian apparatus which connects the air bladder to the inner ear. However, the only sounds that have been heard from minnows are "nonbiological" sounds such as the chewing sounds made by goldfish and the emission of air from the air bladder of *P. laevis*. This suggested to the German and Dutch workers that the acuity of hear-

Table 1. The range and average number of sounds produced by males of *Notropis analostanus*, kept in 15-gal aquaria with an 18-hour photoperiod at various temperatures, during 5-minute listening periods, in June and July 1959. Three recordings were taken for each of three experiments (average usually based on nine readings), each with four males except for day one where data were available for only two experiments (average based on six readings). Some deaths occurred in one experiment at the highest temperature.

Temp. (°C)	Days after beginning of experiment									
	1		2		3		4		5	
	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.
29–30	109–280	231	35–328	176	8–207	102	101–191	157	64–161	121
23–24	27–206	70	12–43	23	14–193	69	18–101	41	11–49	25
18–19	10–69	27	14–213	82	18–129	60	6–100	37	4–96	43
13–14	3–13	5	1–7	4	0–23	6	4–18	9	2–24	11
7–9	0–5	1	0	0	0–3	1	1–6	2	0–3	1

ing in minnows need not be associated with the actual production of behaviorally significant and controllable sounds by the fish. On this basis they concluded that it has developed in response to mechanical and incidental sounds produced by the fish and the environment. From our data, however, it appears that many minnows produce "biological" sounds that can act as stimuli in reproductive activities, although the actual nature of the function of the sound has not been experimentally tested. The sound's association with reproductive activities, and its increase in rate with temperature elevation and injections of testosterone, seem to place the knocks and purrs of *Notropis analostanus* in the class of "biological" sounds. It might be hypothesized that the sound repulses under some conditions (as when two males of *N. analostanus* fight) and attracts under others (as when males of *Gila margarita* follow females to spawn). Hypotheses like these are numerous in the literature. Tavolga's experiments (*2*), which demonstrate that the grunts of the goby attract, and Moulton's playback (*3*) of sea robin calls to sea robins, which resulted in answering back, are the only experiments demonstrating the functions of sounds for fishes, except for occasional startle responses reported by various authors.

The sounds with frequency components as high as 11,000 cy/sec, produced by the cyprinid we studied, contain frequencies which are well fitted to the sensitive hearing ability of ostariophysid fishes. Perhaps this more sensitive hearing has been one of the causes for their success in the fresh waters of the world (over 70 percent of the primary fresh-water fishes of the world are ostariophysids). The statement by Moore and Newman (*9*) that natural noises in fresh waters are so great as to make unlikely the use of any sounds for attraction or repulsion of fish seems unjustified, or at least premature, although it may be true for the salmonids with which they worked. *Notropis analostanus* produces these sounds in fairly rapid and noisy water of small streams where they spawn, but, the sounds are made when the fish are close to each other.

The fresh-water minnows' "biological" sounds, their ease of handling, and the fact that they will go through normal behavior, especially spawning, in the laboratory, make these fish excellent subjects for the study of sound. This is less true for most marine fishes at this time.

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Avoidance Conditioning and Alcohol Consumption in Rhesus Monkeys

Abstract. Measures of intake of water and of a solution of 20-percent alcohol in water were determined in rhesus monkeys before, during, and after avoidance training. Alcohol consumption increased during, and decreased after, avoidance sessions. Water intake remained the same or decreased during avoidance sessions and stayed at this level after the sessions.

Masserman and Yum (*1*) reported that cats often develop a definite preference for a solution of alcohol in milk, if they are given alcohol during a conflict conditioning procedure. Aside from these data, little is known about the effects of various conditioning procedures on alcohol intake.

In the experiment reported here we investigated the effects of an avoidance conditioning procedure (*2*) on the alcohol consumption of rhesus monkeys. Avoidance conditioning can cause gastrointestinal lesions, ulcers, and elevations in plasma levels of 17-hydroxycorticosteroids and norepinephrine in monkeys (*3*). Since analogous forms of behavioral stress are thought to play an important part in the development and maintenance of human addiction to alcohol, it seemed reasonable to inquire whether avoidance conditioning would have similar effects upon the monkey's alcohol consumption.

The subjects were two 6-lb rhesus monkeys (male and female) maintained in restraining chairs (*4*). Crackers and water were available to the animals for 1 hour each day.

The first, or "preavoidance," phase of the experiment lasted 43 days, during which time base-line measurements of alcohol and water intake were made. During each 23-hour period between feedings one of three conditions was in effect: (i) an alcohol bottle alone was present (20-percent solution of 95-percent grain alcohol in water); or (ii) a water bottle alone was present; or (iii) both an alcohol and a water bottle were present. The order of presentation of conditions on successive days was as follows: alcohol, alcohol-and-water, alcohol, water, alcohol, alcohol-and-water, water.

In the second, or "avoidance," phase, which lasted 54 days, the animals were trained to press a lever to avoid electric shocks. The response-shock and shock-shock intervals were gradually decreased over a period of approximately 2 weeks to final values of 1 second each. That is, the monkey was shocked once each second as long as it failed to press the lever, but every time it pressed the lever it postponed the electric shock for 1 second. If the animal pressed the lever more frequently than once each second

Table 1. Mean alcohol and water intake. Preav., the last 3 preavoidance weeks; Av., the last 3 avoidance weeks; Postav. I, the first 3 postavoidance weeks; and Postav. II, the last 3 postavoidance weeks. The following *t*-test comparisons were significant at the .05 level or beyond. Monkey No. 1: *a* compared with *b* or *c*, *d* with *b* or *c*, *a* with *d; e* with *f*, *g* or *h; i* with *j*, *j* with *l*, *m* with *n*, *o*, or *p*. Monkey No. 2: *a* compared with *b* or *c*, *d* with *b* or *c*; *i* with *j* or *k*, *l* with *j* or *k*.

Monkey No.	Intake (ml/23 hr)			
	Preav.	Av.	Postav. I	Postav. II
	Alcohol intake: only alcohol available			
M1	48.0 (*a*)	113.8 (*b*)	113.7 (*c*)	80.1 (*d*)
M2	53.9 (*a*)	85.6 (*b*)	70.6 (*c*)	57.2 (*d*)
	Water intake: only water available			
M1	295.9 (*e*)	115.2 (*f*)	114.0 (*g*)	119.8 (*h*)
M2	232.9 (*e*)	237.5 (*f*)	233.8 (*g*)	253.3 (*h*)
	Alcohol intake: alcohol and water available			
M1	27.5 (*i*)	49.8 (*j*)	39.2 (*k*)	22.4 (*l*)
M2	33.3 (*i*)	76.4 (*j*)	70.6 (*k*)	40.6 (*l*)
	Water intake: alcohol and water available			
M1	295.0 (*m*)	90.8 (*n*)	75.8 (*o*)	85.2 (*p*)
M2	212.5 (*m*)	208.6 (*n*)	217.7 (*o*)	204.3 (*p*)