OPERANT CONDITIONING IN THE BAT *PHYLLOSTOMUS HASTATUS*^{1, 2}

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Bats of the species *Phyllostomus hastatus* were trained to press a pigeon key with food as the reinforcer. Patterns of responding under fixed-ratio, fixed-interval, and variable-interval schedules of reinforcement were similar to those typically shown by other species. In a simple auditory discrimination, responding readily came under stimulus control. It is suggested that the behavioral method could be applied to various problem areas of bat behavior.

Operant conditioning in bats has not been investigated, despite the fact that bats constitute a major mammalian Order (Order Chiroptera). This paper describes a method devised for studying operant conditioning in bats of the species *Phyllostomus hastatus*. The method has two particular advantages. First, it is similar to the methods used with species currently popular in this line of research (e.g., pigeon, rat, squirrel monkey). Thus the method is conventional, though the species may be exotic. Second, it places no restrictions on the frequency with which the measured response can occur, making possible analysis of response rate and temporal patterning. While various discrete-trial conditioning methods have been used effectively with bats to study their hearing and sonar (Bradbury, 1970; Dalland, 1965; Dijkgraaf, 1957; Simmons, 1968, 1969), these would not be considered free operant methods, as the rate of response is not free to vary (Ferster, 1953). This paper describes responding under four schedules of reinforcement: fixed-ratio, fixed-interval, variable-interval, and a simple discrimination.

Many species of bats prove difficult to maintain in captivity (Barbour and Davis, 1969; Orr, 1958). To maximize success a large, hardy bat with relatively non-specific food requirements was chosen. *Phyllostomus hastatus* is the second largest neotropical bat, weighing 60 to 100 g and averaging 4 to 5 in. (10-13 cm) in length. In addition, it is omnivorous and in captivity readily accepts fruits, meat, or prepared diets.

Although the experimental situation used

with the bats was conventional, it took into account several unique features of bats. First, bats cannot operate conventional operanda with either their forelimbs or hindlimbs, which are adapted for flying and roosting respectively. It was found, however, that *P. hastatus* could operate a conventional pigeon key by nosing or licking it.

Second, few species of bats will maintain a horizontal position on the ground (vampire bats being the most notable exception): a bat placed on a horizontal surface will either fly or back up to a vertical surface and pull itself up by its feet. The feet are modified for this purpose, being rotated 180° relative to the normal mammalian position and having strong curved claws. These considerations suggested a wire mesh cage that enabled a bat to hang head down from the wall above the response and feeder mechanisms. These were arranged so that a bat could move its body from one to the other without shifting its purchase.

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METHOD

Subjects

Four *P. hastatus*, taken from Guanapo cave, Trinidad, W.I., on October 5, 1967, were maintained on a blend of ripe banana, raw hamburger, a complete powdered diet (Sustagen, Mead Johnson), and apricot nectar. Water was continuously available. The weight of each animal was gradually reduced over a period of approximately four weeks. Attempts to shape key pressing were begun during the course of deprivation when 90% of the original body weight was attained. The critical weight at which shaping was possible and at which behavior could be maintained was 70 to 75 g for males, regardless of the animal's free-feeding weight. The single female bat (PH 14) was maintained at 60 to 62 g throughout the experiment.

Consistent behavior was maintained only by running the animals on a regular 24-hr schedule. This effect was independent of the level of deprivation, and casual observation suggested that it was related to an activity cycle developed by the animals.

Heavy gloves were worn when handling the bats, which can deliver a nasty bite. It should be emphasized that since bats can carry rabies, those coming into contact with them should be inoculated with the duck embryo rabies vaccine (Peck, Powell, and Culbertson, 1955).

Apparatus

The experimental chamber (Fig. 1) was a wire cage, 8 in. high by 8 in. long by 11 in. wide (20 by 20 by 28 cm). A Gerbrands pigeon key was mounted in one wall, 1.75 in. (4 cm) above the floor. A minimum force of 12 g (0.12 N) was required to operate the key. Effective key presses produced a click from a "feedback" relay. A Gerbrands dipper feeder was mounted to the left of the key. The dipper cup when raised was level with and 2.5 in. (6 cm) from the key.

Reinforcer presentations lasted 5 sec and consisted of a blend of Sustagen and frozen melon balls and their juice. The reinforcer was delivered in a 0.025-ml cup; the actual amount delivered was somewhat greater as the viscous blend adhered to the cup. Smaller amounts could not reliably be delivered with this equipment, and as the delivered amount is large for these animals, overfeeding was

Fig. 1. Bat in experimental chamber. The animal is eating at the feeder. The key further from the feeder was inoperative in this experiment.

avoided by limiting the number of reinforcers to 45 per session. Animals were given supplemental food after a session when needed to maintain their weight.

Procedure

The animals were first trained to approach the feeder following the sound of the solenoid operation. Shaping the key-pressing response, which took several sessions, was begun by smearing some of the food on the key. The bat would then lick the key, licks of sufficient pressure operating the feeder. The ultimate topography of the response was variable from animal to animal: some bats continued to lick the key, others pushed it with their snouts.

Bats typically learned to hang upside down over the area of the key and feeder, so that the head could be moved from one to the other with little or no shifting of the feet.

After shaping, the animals were exposed to several schedules of reinforcement.

Schedules

Fixed ratio (FR). The twentieth response was reinforced (FR 20). FR 40 was also used.

Fixed interval (FI). The first response after 50 sec, timed from the previous reinforcement, was reinforced (FI 50-sec). FI 100-sec was also used.

Variable interval (VI). The first response

after a variable interval averaging 60 sec was reinforced (VI 60-sec).

Simple auditory discrimination. An auditory stimulus was added to the VI 60-sec schedule. The stimulus was presented when the variable-interval clock timed out, and terminated when a response (producing reinforcement) was made. The auditory stimulus was a 40-kHz tone burst, 100 msec long, repeated twice per second. The loudspeaker was mounted on top of the cage.

The order of exposure to these schedules, and the animals studied under each schedule were: FR (bats PH 5, PH 6), VI (bats PH 4, PH 5, PH 14), discrimination (PH 5, PH 14), FI (PH 5, PH 6). Animals received at least 20 sessions at each schedule value.

RESULTS

Representative fixed-ratio, variable-interval,

and fixed-interval cumulative records are shown in Fig. 2. Fixed-ratio records were characterized by high terminal rates of near 80 responses per minute. Post-reinforcement pauses were occasionally observed at FR 20 and were conspicuous at FR 40. Variable-interval records were characterized by steady, relatively low rates. They showed a rough grain due to the occurrence of bursting and pausing. The three animals represented in the VI records of Fig. 2 showed different rates, 20 to 30 responses per minute for PH 5, 10 to 20 responses per minute for PH 14, and slightly fewer than 10 responses per minute for PH 4. In all cases these rates were lower than rates under the FR schedules. Fixed-interval records were characterized by post-reinforcement pauses and acceleration into high terminal rate ("scalloping").

Behavior on the discrimination schedule is shown in Fig. 2 and 3. Addition of the audi-

Fig. 2. Representative cumulative records on VI, FI, FR, and discrimination schedules. Downward deflections of the pen indicate reinforcements. Discrimination records are from Sessions 1 (the first with the stimulus present), 10, and 25.

Fig. 3. Responses per minute, averaged over the session, on the discrimination schedule. Stimulus introduced in Session 1, removed after Session 50. Sessions 31 to 49 are omitted from the graph. Bats PH 5 and PH 14.

tory stimulus to the VI 60-sec schedule produced a decrease of responses in the absence of the stimulus with the overall response rate approaching the minimum level of about one response per minute by Sessions 10 to 20. In Session 51, the stimulus was removed: once a bat made one or two reinforced responses in the absence of sound it returned to its pre-discrimination pattern of steady responding.

DISCUSSION

The effects of standard schedules of reinforcement on the temporal patterning of a bat's key pressing were similar to those found with the species commonly studied in operant conditioning experiments. Fixed ratios produced the typical diphasic pattern of a post-reinforcement pause followed by a constant, high rate of responding. At the lower fixed ratio (FR 20), the pauses could be very short or absent, as is often found for low fixed-ratio values (Ferster and Skinner, 1957). The variable-interval 60-sec schedule produced a steady, lower rate of responding. Fixed intervals produced "scallop", that is, a post-reinforcement pause followed by acceleration into a relatively high terminal rate. The pauses were longer under FI 100-sec than under FI 50-sec.

In the auditory discrimination, responding

by the bats readily came under stimulus control. The bats compare favorably with rats and squirrel monkeys run on the same auditory discrimination in the same laboratory. With rats and squirrel monkeys, good stimulus control can be gained only with the added contingency that responses in the absence of the stimulus postpone the stimulus 5 sec or so. With bats, this contingency was not necessary for the development of the discrimination.

The behavior of *P. hastatus* in this free operant situation, then, is sensitive to schedule and stimulus manipulations, the effects of these manipulations being similar to those observed with other species.

The behavioral methods described in this paper can be applied to various problem areas of bat behavior. Three applications are mentioned here.

(1) It is a suitable method for auditory experiments, as the relative positions of the sound source and the animal's head can readily be controlled. With a two-key discrimination, as well as with the simple auditory discrimination, it has been possible to maintain performance generally superior to that exhibited by several other mammalian species under comparable conditions (Beecher, 1970).

(2) The functional properties of vocal behavior, in particular the susceptibility of vocalizations to operant conditioning, is a topic of some interest (e.g., Lane and Shinkman, 1963; Lieberman, 1968). It is of especial interest in bats, since ultrasonic vocalizations play such a prominent role in their instrumental behavior. The author is presently comparing operant conditioning of vocalizations and of key pressing by *P. hastatus*.

(3) There has been considerable interest recently in bat vision (e.g., Suthers, 1966; Williams, Williams, and Griffin, 1966). With the present method, the visual abilities of bats could be investigated according to the same procedures that have been used with pigeons and other animals (Blough, 1966).

For researchers in the United States, the only serious drawback with *P. hastatus* is that it is not found in this country. Probably the most suitable North American species for this sort of experiment would be *Eptesicus fuscus* (see Barbour and Davis, 1969; Simmons, 1969). Good sources of general information concerning bats are Barbour and Davis (1969), Griffin

(1958), Wimsatt (in preparation), and the newsletter *Bat Research News*.³

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