CONTROL OF RESPONDING BY SOUND LOCATION IN MONKEYS: RAPID ACQUISITION IN DARKNESS¹

PAUL DOWNEY² AND J. M. HARRISON

BOSTON UNIVERSITY AND NEW ENGLAND REGIONAL PRIMATE
RESEARCH CENTER, HARVARD MEDICAL SCHOOL

Rapid control of responding by sound location is obtained in squirrel monkeys when sound stimuli are presented from one of two loudspeakers, each one adjacent to a response key. With this arrangement of loudspeakers and response keys, squirrel monkeys quickly learn to respond on the key near the source of the sound stimulus, and this pattern is the same whether or not responses near the sound source are differentially reinforced. This result may depend on a pre-experimental tendency in squirrel monkeys to orient head and eyes toward a sound, which would lead the animal to look at the response key in front of the loudspeaker producing the sound. The present experiment sought to determine whether visual stimuli are necessary for rapid control of responding by sound location. Two monkeys were trained in darkness in a sound-localization task similar to that described above. Results were similar to those obtained from animals trained in light, indicating that visual stimuli are not required for rapid acquisition of sound-localization behavior in monkeys.

Control of responding by sound location is acquired rapidly in squirrel monkeys when sound stimuli are presented from locations near response manipulanda. In one experiment with squirrel monkeys, (Harrison, Downey, Segal, and Howe, 1971), sound stimuli were presented in random order from one of two loudspeakers, each located behind one of two response keys. When a sound stimulus was presented from one loudspeaker, a response on the key in front of that loudspeaker was followed by food. A response on the other key produced timeout. Within 50 trials (stimulus presentations) under these conditions, the monkeys responded in nine of 10 trials on the key in front of the sounding loudspeaker.

Rapid acquisition of sound-localization behavior has also been obtained in monkeys in the absence of differential reinforcement of responses (Downey and Harrison, 1972). The arrangement of loudspeakers and response keys described above was used but food was de-

livered following responses on either key in the presence of sound stimuli from either loudspeaker. Again, within 50 trials responding occurred on the key in front of the sound source in over 90% of the trials. This pattern of behavior occurred only when loudspeakers were adjacent to response manipulanda. When loudspeakers and response keys were spatially separate, responding remained independent of sound location.

The development of control by sound location in the absence of differential reinforcement may result from a tendency in squirrel monkeys to orient head and eyes in the direction of a sound (Downey, 1971; Downey and Harrison, 1972; Harrison *et al.*, 1971). When sound sources are adjacent to response manipulanda, orientation to a presented sound brings the response key in front of the sound source into the visual field of the animal. This could bias the animal toward responding on that key. Such a bias could not develop when response keys and loudspeakers are separate. Orientation to sound under this condition could not predispose the animal either to look at or to press one response key or the other.

In the present study, monkeys were trained in a differential reinforcement procedure to locate sound stimuli in total darkness. The purpose was to determine whether stimuli associated with orientation to an auditory sig-

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²Now at the Department of Psychology, St. John's University, Jamaica, New York 11439.

nal are necessary for the rapid control of responding by sound location observed in previous experiments. Results indicate that visual stimuli are not necessary for the acquisition of this behavior.

METHOD

Subjects

Two naive adult male squirrel monkeys (*Saimiri sciureus*) were reduced to 80% of their free-feeding weights before training.

Apparatus

The experimental room was a 2 by 3.4 m light-proof room containing a cubicle wire-mesh cage measuring 51 cm on each side. The wire-mesh construction was designed to minimize sound-reflecting surfaces near the cage. Other parts of the experimental room were made of sound-reflecting materials that provided an acoustically complex environment. Centered on one wall of the wire-mesh cage was a Gerbrands feeder that delivered 0.1 cc of a liquid reinforcer to a feed cup. The reinforcer was a mixture of two parts monkey diet (Nutritional Biochemicals Co.) to one part water and 0.1 part vegetable oil. The food cup was flanked on either side by a Gerbrands monkey key (R1 and R2 in Figure 1), and behind each key was a University Sphericon (T202) loudspeaker (S1 and S2 in Figure 1). The response keys were modified by cutting a 6-cm diameter hole in the response area of each key, covering the hole with a fine screen mesh, and attaching a 28-V lamp behind the screen. Opening the response area in this manner allowed sound from the loudspeakers to pass into the cage through the response keys.

The experimental chamber was illuminated by a 100-W, 110-V houselight, connected to a 40-V power supply. Events in the experimental chamber were controlled by timers and relay circuits and recorded on magnetic counters and cumulative recorders located in a separate room. Sounds originating outside the experimental chamber were masked by constant noise from a third loudspeaker (University Tweeter 4401) located outside the cage and equi-distant from loudspeakers S1 and S2.

Sound stimuli were broad-band noise bursts (4 kHz to 50 kHz) of 0.2-sec duration, repeating twice per second, and with rise-decay time of 0.2 msec. The stimuli were produced by

Fig. 1. Schematic diagram (overhead view showing the spatial arrangement of response keys (R1 and R2), loudspeakers (S1 and S2), and food cup (F) in the wire-mesh enclosure.

feeding the output of a noise generator through an electronic switch (Grason Stadler 829D) and an amplifier (General Radio 1210 C), and then to the loudspeakers via a matching transformer (Krohn-Hite MT 56). Rise-decay time of the signals was controlled by the electronic switch, and the rate and duration of pulses were determined by electronic timers (Grason Stadler E 1100H) used to trigger the electronic switch. Nominal sound levels were measured using scale A on a General Radio sound-level meter (Type 1551C) placed in a standard position in the center of the cage. The intensity of the noise-burst stimuli was 70 dB, and that of the background noise was 56 dB (relative to 20 $\mu\text{N}/\text{m}^2$).

Procedure

(a) *Preliminary training in the absence of auditory stimuli.* The animals were placed in the wire cage for about 45 min each day and trained to press keys R1 and R2. Responses on either key produced food on a *tand* FI 25-sec DRL 5-sec schedule. Following the DRL component, a 7.5-sec limited-hold period began in which responses produced 7.5-sec access to food and initiated the next FI component.

When the rate of responding was approximately stable, the schedule was changed so

that at the end of each DRL component, food was available on only one of the two response keys. The order in which food was available on the R1 and R2 keys was R2R2R1R1R2R1R1R2R2R1. A response on the other key produced a 7.5-sec timeout (key illumination turned off).

During the above procedures, general illumination was provided throughout each session by the houselight. Other light sources included the pilot lights on the response keys, and a lamp that illuminated the food cup during operation of the feeder. When the above training procedures were completed, illumination from the houselight and keylights was faded out (to zero illumination) over a series of sessions by reducing the voltage across these lights. The size and number of steps for fading the illumination differed for the two animals. In general, the houselight was turned off first in a few steps, and the keylights were faded more gradually in increasingly smaller steps. The number of steps varied between seven and 12 for the two animals.

(b) *Auditory discrimination training.* The presentation of sound stimuli began immediately after the fading of houselight and keylights to zero illumination. The sound stimulus was a 14-pulse train of noise bursts presented for 7.5 sec after each DRL component. The pulse train came from either the S1 or S2 loudspeakers in the order S2S2S1S1S2S1S1S2S2S1. A response in the presence of the sound turned off the sound, began the next fixed interval, and produced either food or timeout for 7.5 sec. The reinforcer followed responses on the key in front of the pulsing loudspeaker, and timeout followed responses on the key near the silent loudspeaker.

Acquisition was measured by the increase in per cent of correct responses over successive blocks of 50 trials. A trial was recorded when a response occurred in the presence of a sound stimulus. Per cent of correct responses was calculated from the proportion of correct (reinforced) responses out of the total number of correct and incorrect (unreinforced) responses.

RESULTS

At low or zero levels of illumination, both monkeys tended to stop key pressing. This behavior developed as illumination was reduced near the end of preliminary training, and

persisted in early acquisition sessions in which all lights were out and sound stimuli were presented. To restore key pressing, key lights were turned on, or turned up slightly, and then gradually faded out—always in the absence of sound stimuli. For both animals, it was necessary to repeat this procedure several times before key pressing was maintained in the dark.

Acquisition curves in Figure 2 show the increase in per cent correct responses (closed circles) over blocks of 50 trials for Monkeys SM22 and SM29. The experiment was divided into blocks of 50 trials, rather than sessions, because of the tendency in both animals to cease responding in the dark for

Fig. 2. Acquisition curves for Animal SM29 (upper graph) and SM22 (lower graph). The development of stimulus control by sound location is represented by the increase in per cent of correct responses over blocks of 50 trials (closed circles). The lower curve in each graph (crosses) shows the decrease over blocks of 50 trials in the number of responses between stimulus presentations (intertrial responses shown on the right-hand ordinate).

periods of time. These periods are excluded from the measurement of acquisition rate when behavior is plotted over blocks of 50 trials. Moreover, this method facilitates comparison of acquisition in the present experiment with that of animals trained in previous experiments in 50-trial sessions, and in normal illumination (Downey, 1971; Downey and Harrison, 1972; Harrison *et al.*, 1971).

The discrimination of sound location developed rapidly in both animals. Figure 2 shows that performance reached 90% correct in the second block of 50 trials for SM22, and in the third block of trials for SM29. Both animals eventually produced near-errorless behavior.

The two graphs in Figure 2 show the decline in number of intertrial responses (crosses) over sessions in both animals. This decline in

responses occurred after discrimination performance reached maximum levels of 90 to 100% correct, and in this respect, acquisition in these animals was similar to that obtained from animals trained in light (Downey, 1971; Downey and Harrison, 1972; Harrison *et al.*, 1971).

Most discrimination was acquired in the early sessions. Figure 3 shows cumulative records from the first two sessions of SM22 and SM29. Each paired record represents responding on two keys in a single session. Correct responses are marked by downward deflections of the curve and errors by dots above the curve. The discrimination was acquired rapidly, with per cent of correct responses for SM22 increasing from 25% in Session 1 to 90% in Session 2. For SM29, the proportion of correct responses increased between the first and

Fig. 3. Cumulative records from Sessions 1 and 2 of Monkeys SM22 and SM29. Each paired record represents responding on two keys in a single session. Correct responses are marked by downward deflections of the curve and errors by dots above the curve.

second half of Session 1. Figure 3 also illustrates the tendency of both animals to cease responding for periods of time during early sessions. For example, in Session 1 of SM22 there were no responses on one key and frequent pauses in responding on the second key. For SM29, pauses developed in the latter portion of Session 1 and responding ceased at the end of Session 2.

DISCUSSION

The present results show that visual stimuli are not necessary for the rapid development of control by sound location. When animals are trained in light, rapid control may be aided by visual stimuli that result from orientation to a sound, but such stimuli are not necessary. This conclusion is supported by several similarities between the present results and those obtained previously in animals trained under similar conditions but in a lighted environment (Downey, 1971; Downey and Harrison, 1972; Harrison *et al.*, 1971). In both light and dark conditions, acquisition of the discrimination is rapid. In addition, the decline in responses between sound presentations (inter-trial responses) is similar under both light and dark conditions. In both cases, responses always continue to decrease after the sound discrimination has been acquired.

The possibility that discrimination behavior in the present experiment could be based on vibratory rather than auditory cues was considered in the design of apparatus. Loudspeakers with a low frequency cutoff of 4 kHz were used to eliminate the low frequencies

that were likely to produce discriminable vibrations in the experimental cage. Moreover, the loudspeakers were not in physical contact with any part of the cage, but were mounted on metal standards outside the cage. Under these conditions, it is unlikely that vibratory cues could account for the discrimination behavior observed here.

The fading out of illumination in the present experiment did not retard acquisition of the discrimination, but all key pressing in both animals was disrupted temporarily on several occasions. This effect may have resulted from a transfer of control by visual stimuli to stimuli of other modalities as lights were faded, and may indicate that light stimuli, when available, are an important source of control in squirrel monkeys. However, the present results clearly show that in the absence of visual cues, squirrel monkeys rapidly come to use sound stimuli to orient.

REFERENCES

- Downey, P. *Stimulus control of responding by sound location: a comparative study of monkey, rat, and cat*. Ph.D. dissertation. Boston University, Department of Psychology, 1971.
- Downey, P. and Harrison, J. M. Control of responding by location of auditory stimuli: role of differential and non-differential reinforcement. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 453-463.
- Harrison, J. M., Downey, P., Segal, M., and Howe, M. Control of responding by location of auditory stimuli: rapid acquisition in monkeys and rats. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 379-386.

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