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CONTROL OF RESPONDING BY LOCATION OF AUDITORY STIMULI: ROLE OF DIFFERENTIAL AND NON-DIFFERENTIAL REINFORCEMENT[1]

PAUL DOWNEY AND J. M. HARRISON

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

Sound was presented to monkeys through one of two loudspeakers, each adjacent to a response key. A response on the key adjacent to the sound source was reinforced (correct response). A response on the other key produced a timeout (incorrect response). Under these conditions, over 90% of responses were correct within one or two sessions. When the procedure was changed so that a response on either key was reinforced independently of which speaker was sounding, similar control by location developed within one or two sessions. When conditions were modified by moving the keys away from the immediate vicinity of the speakers, the animals required about 20 sessions to reach a stable level of greater than 90% correct responses under differential reinforcement conditions. No control by location developed under nondifferential reinforcement conditions.

In experiments using squirrel monkeys when speakers were placed so that sound could emanate from either of two keys, the animals learned to respond to whichever key was sounding within one or two sessions (Harrison, Downey, Segal, and Howe, 1971). The procedure was as follows: when either speaker sounded, a response on the lever adjacent to the speaker was reinforced (correct response) and the sound was terminated. A response on the other lever (not adjacent to the speaker) produced a timeout (incorrect response) and terminated the sound. In this procedure, there was differential reinforcement of responding on the correct levers. Inspection of cumulative records during the first acquisition session showed that the number of correct responses immediately increased in number. This increase sometimes occurred during the first few presentations of the sound without any incorrect responses occurring; that is, without the animal being exposed to the differential reinforcement of correct responses. This suggested that differential reinforcement of responses on the two levers may be unnecessary for the acquisition of control by the auditory stimuli. The major purpose of the present experiment was to examine this possibility.

It was also found that when the speakers were not in the immediate vicinity of the levers, a stable, high lever of correct responses was not reached for about 15 sessions. Inspection of cumulative records suggested that differential reinforcement of responding was necessary for the development of control by the location of the acoustic stimuli. A second purpose of the experiment was to compare the acquisition of the control of responding, in the absence of differential reinforcement, under these conditions with acquisition under conditions where the speakers were adjacent to the levers.

Repeated noise and tone bursts and single clicks were used as the stimuli in these experiments to demonstrate that the effects apply to acoustic stimuli in general and are not restricted to special types of sounds, nor to a special type of dynamic relation to the sound sources as might occur with repeated or continuous stimuli.

METHOD

Subjects

Sixteen experimentally naive adult male squirrel monkeys were used.

Apparatus

The experimental chamber was a wire-mesh enclosure 20 in. square and 20 in. high (51 by

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51 by 51 cm) suspended on wires and aluminum rods 0.7 m above the floor of a 2 by 2 by 3.4 m room. The wire-mesh cage was designed to minimize sound-reflecting surfaces near the animal. No such precautions were taken with the surrounding room. The floor of the room was concrete and the interior walls were fiberboard with a 10 in. by 10 in. (25 by 25 cm) glass observation window cut into one wall. On the front wall of the mesh enclosure was a Gerbrands liquid food dispenser centered between two Gerbrands monkey keys. The keys were 18 in. (45 cm) apart center to center, and 8 in. (21 cm) above the cage floor. An identical pair of keys was attached at the same height to the side walls. Each key had a circular response area 3.25 in. (8 cm) in diameter made of white translucent plastic. A 2.5 in. (6 cm) hole was cut in the response area, covered with a fine mesh wire screen and illuminated at the center with a 28-v pilot light. Two loudspeakers (University Sphericon, T-202) were placed 1.25 in. (3 cm) behind keys A1 and A2 or behind keys B1 and B2 at the sides. On the roof of the cage was a 100-w, 110-v houselight connected to a 40-v supply. Attached below the cage floor was a 28-v relay connected to one of the two pairs of response keys. The relay clicked open and closed with each break in the contacts of either key.

Events in the experimental chamber were controlled by relay circuits and timers and recorded on magnetic counters and cumulative recorders located in a separate room.

Three sound stimuli were used: 10-kHz tone bursts of 0.2-sec duration, occurring at a rate of two per second, and having a rise-decay time of 0.2 msec; broad-band noise bursts (4 kHz to 50 kHz) having the same duration and rise-decay time as the tone bursts; 0.1-sec single noise bursts (clicks). Signals from a noise generator or oscillator (General Radio 1210C) were fed to an electronic switch (Grason Stadler 829D), which was used to turn the signal on and off and to control its duration.

A constant background noise of 56 dB was produced in the experimental chamber by a noise generator, amplifier and loudspeaker (University Tweeter 4401). The speaker was positioned on the vertical plane halfway between the two signal-producing speakers.

Sound levels were measured at a standard position 8.75 in. (22 cm) above the cage floor and halfway between speakers S1 and S2 positioned behind keys B1 and B2, respectively. Sound intensities were measured with a sound level meter (General Radio 1551C) using weighting scale A. The meter was connected through an extension lead to a microphone placed in the standard position. The noise and tone signals were set to intensities of 74 dB to 76 dB from each speaker.

Procedure

Differential reinforcement. The animals were reduced to approximately 80% of their body weight under free-feeding conditions and the liquid food (powdered monkey diet and water, mixed in ratio of 2:1) used as the reinforcer was substituted for the regular monkey chow in the home cage. When the monkeys consumed the reinforcer in their cages, training was begun.

Each monkey was trained to press either keys A1 and A2 or B1 and B2 using 0.1 cc of liquid food as a reinforcer. The loudspeakers were located either directly behind the keys used for training (the adjacent condition) or behind the alternate pair of keys (the non-adjacent condition). Table 1 designates the response keys, relative speaker positions (adjacent and non-adjacent) and type of stimulus employed for each animal during acquisition.

The four training conditions are shown in Figure 1. The two adjacent conditions are shown in the left-hand column and the two non-adjacent conditions in the right-hand column. That is, both positions of the speakers were used for adjacent and non-adjacent conditions.

After initial key-press training, the rein-

Table 1

Experimental conditions during acquisition: differential reinforcement: position relative to response keys, type of sound stimulus, and response keys employed for each squirrel monkey.

Relative Loudspeaker Position	*Animal*	*Stimulus*	*Response Keys*
Adjacent	SM3	noise	A1-A2
	SM15	10 kHz	A1-A2
	SM12	10 kHz	B1-B2
	SM18	10 kHz	B1-B2
	SM41	Click	B1-B2
Non-adjacent	SM4	noise	A1-A2
	SM19	noise	B1-B2
	SM13	10 kHz	B1-B2
	SM11	10 kHz	B1-B2

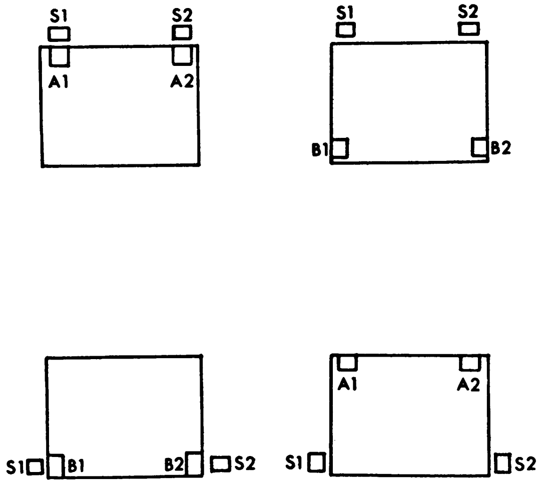

Fig. 1. The four conditions used in training the animals. The left column shows the two adjacent conditions and the right column the two non-adjacent conditions. The top row shows adjacent and non-adjacent conditions in which the speakers were in the A position for both conditions. The bottom row shows the same thing for speakers in the B position.

forcer was delivered following responses on either key on a fixed-interval schedule that was lengthened in 7.5-sec steps until the duration reached 30 sec. The total number of reinforcements that occurred as the fixed interval was increased varied between 100 and 200, depending on the time required to obtain stable responding after each increment in the fixed interval. Responses occurring in the last 5 sec of each interval prolonged that interval until 5 sec had elapsed without a response. At the end of each fixed interval there was a 7.5-sec period during which a single response on either key was reinforced and started the next 30-sec interval. If there was no response in the 7.5-sec interval the next fixed interval started at the end of the 7.5-sec period. When stable responding was established, reinforcement was made available on only one of the two keys. The order of availability of reinforcement was R2 R2 R1 R1 R2 R1 R1 R2 R2 R1, the sequence repeating. A response on this key at the end of the interval was reinforced as described above, while a response on the other key during the 7.5-sec period produced a 7.5-sec timeout in which the key lights were extinguished. The particular response key associated with reinforcement or timeout alternated in an irregular order with the 30-sec intervals. Keylights were on at all other times.

When responding was stable and about equal on both keys, training on the auditory discrimination was started. For the first discrimination training session, the animal was run for 15 min without the sound to give a baseline from which the effects of the introduction of the sound could be judged. Sound was then introduced in the 7.5-sec period at the end of each fixed interval during which reinforcement was available. All other aspects of the schedule remain unchanged.

The stimulus was a 14-pulse train of noise bursts, 10-kHz bursts, or a single click, presented alternately from speakers S1 and S2 in the order: S2 S2 S1 S1 S2 S1 S1 S2 S2 S1. The first response in a trial turned off the sound, started the next 30-sec interval and produced either reinforcement or timeout. Reinforcement followed a response on the key nearest the speaker through which the sound was presented and timeout followed a response on the key remote from the speaker. For animals trained on the A keys, for example, A1 responses produced reinforcement and A2 responses produced timeout in the presence of auditory stimuli from speaker S1.

Non-differential reinforcement. These procedures were identical to those described above except that responses were never followed by timeout during pretraining, and there was no differential reinforcement of correct responses and errors in the presence of sound stimuli. As in the differential reinforcement procedure, a response on the one of two keys nearest a sound producing speaker was called correct, and those on the key distal to the sound source were called errors. But here, both errors and correct responses produced reinforcement.

Table 2 lists the conditions in effect during acquisition including relative loudspeaker position (adjacent or non-adjacent), the type of sound stimulus, and the response keys used for each animal.

Animals were changed from the condition used for acquisition (adjacent, for example) to the second condition (non-adjacent, for example) when the percentage of correct responses appeared to be stable.

RESULTS

The results are presented as the percentage of correct responses made in each session.

Table 2

Experimental conditions during acquisition: non-differential reinforcement: loudspeaker positions relative to response keys, type of sound stimulus and response keys employed for each squirrel monkey.

Relative Loudspeaker Position	*Animal*	*Stimulus*	*Response Keys*
Adjacent	SM21	noise	A1-A2
	SM23	noise	B1-B2
	SM28	10 kHz	B1-B2
	SM43	click	B1-B2
Non-adjacent	SM31	noise	A1-A2
	SM34	noise	A1-A2
	SM27	noise	B1-B2

There were 50 reinforcements a day per animal and performance in each daily session was calculated by summing all correct responses on both keys, and dividing this number by the total number of correct and incorrect responses (that is, by the total number of responses made in the presence of the stimuli).

Differential Reinforcement

The development of control of responding by the auditory stimuli under adjacent and non-adjacent conditions is shown in Figure 2 (A and B, respectively) and Figure 5 (SM41). Four of the five monkeys (SM3, SM12, SM18, and SM41) run under adjacent conditions reached a level of 90% correct responses after one session or less (SM41) (Figures 2A and Figure 5). The other monkey (SM15) required two sessions before reaching this level. Under non-adjacent conditions, monkeys required from seven to 16 sessions to reach a stable percentage of correct responses (Figure 2B). Rates of acquisition were independent of the nature of the stimulus (noise bursts, 10-kHz tone bursts).

Figure 3 shows the cumulative response records of one monkey in the adjacent condition and one in the non-adjacent condition. All responses on each key (R1 and R2) were recorded on separate cumulative recorders, responses on R1 being shown in the top of each pair of records in Figure 3 and responses on R2 on the lower of the two records. Hash marks indicate reinforcements (correct responses) and the dots over responses indicate timeouts (incorrect responses). The sound was first introduced in Session 1 at the resetting of both recorders. It can be seen that under adjacent conditions (Monkey SM12) the percentage of reinforcements (correct responses) immediately increased with the introduction of the sound at the resetting of the recorders. This suggests, as indicated in the introduction, that differential reinforcement is not necessary for the development of control. During the second session, the animal made no incorrect responses (timeout). This behavior may be compared with that of the non-adjacent animal (SM13). This animal continued to make incorrect responses during the sixth session.

The discriminability of the availability of reinforcement was acquired more slowly than the differential discrimination of the auditory stimuli under adjacent conditions. It can be seen from Figure 3 that the rate of responding during the fixed interval declined at a slower rate than the percentage of correct responses increased. The records of SM12 are typical in this respect. During Session 1, the introduction of the sound increased the number of correct responses (reinforced responses) but had little effect on the response rate during the fixed interval. By the second session, the percentage of correct responses reached a high value, but responding on one key (R1) continued at a moderate rate. By the fourteenth session the response rate had dropped to a low value. Under non-adjacent conditions there was also a reduction in response rate, the rate falling to a low value by the fourteenth session in SM13 (Figure 3).

Responding during the fixed interval (an S^{Δ} for the availability of reinforcement) was probably not maintained by the adventitious occurrence of the immediate onset of the stimuli, or food since 5 sec had to elapse between a response and the onset of a trial, preventing this adventitious relationship.

Non-Differential Reinforcement

Adjacent conditions. The results obtained under these conditions are shown in Figure 4 (for noise and tone bursts) and in Figure 5 (SM43) (for single clicks). Comparison of these data with data obtained under differential reinforcement conditions (Figures 2 and 5) shows that the rate of acquisition and degree of control of responding in the presence of the stimuli is similar under the two conditions.

These results indicate that differential reinforcement of responding on the two keys is

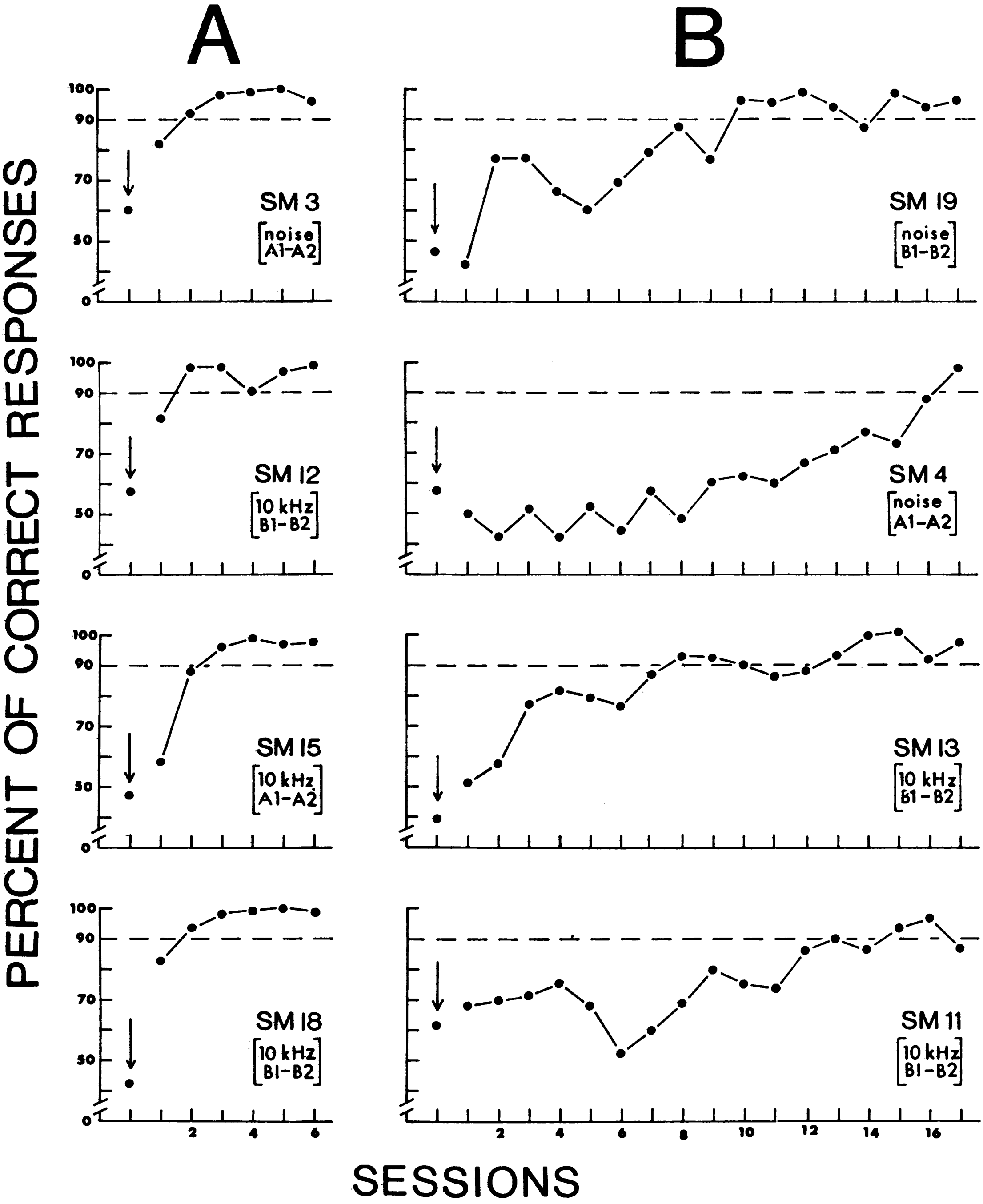

Fig. 2. Acquisition of stimulus control of responding in monkeys as per cent of correct responses in daily sessions obtained with loudspeakers adjacent to response keys (A), and with loudspeakers in a non-adjacent position relative to the response keys (B). The type of sound stimulus (noise bursts or 10-kHz tone bursts) and the response keys (A1 and A2 or B1 and B2) employed for each animal are indicated in brackets below each curve. The data points marked with an arrow represent behavior prior to the introduction of sound stimuli. Note the difference between adjacent and non-adjacent conditions in the number of sessions required to reach the 90% correct level.

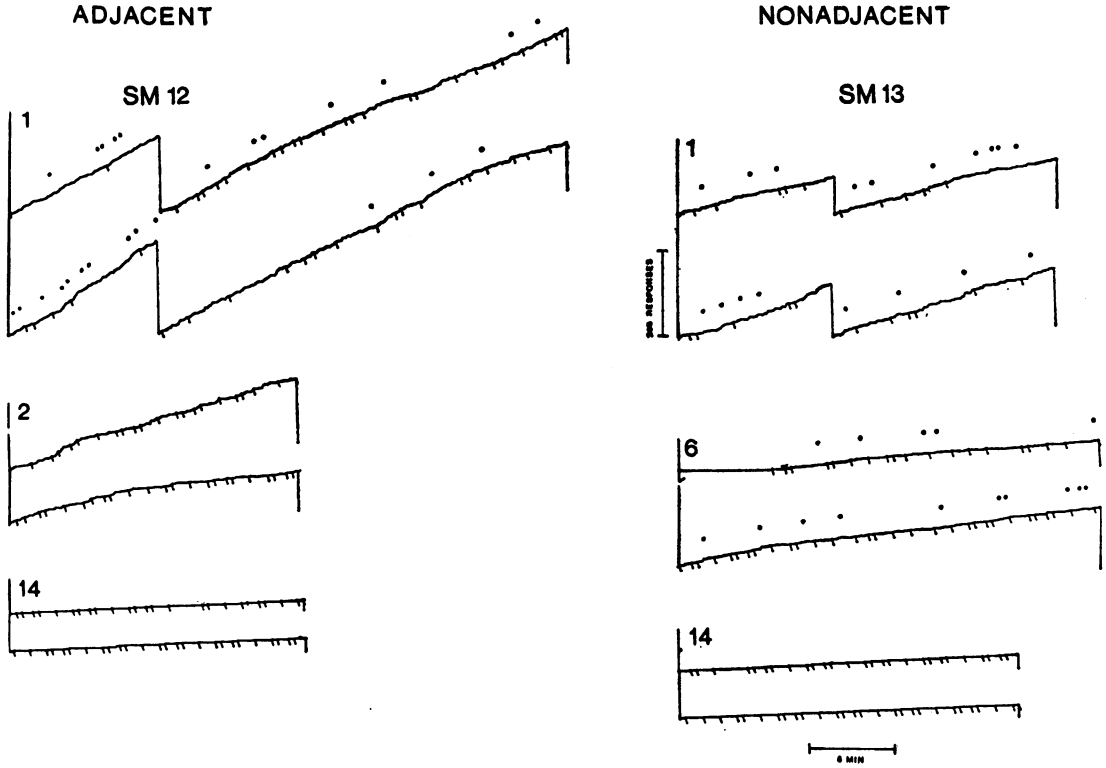

Fig. 3. Cumulative response records from adjacent and non-adjacent acquisition sessions of monkeys. The record of responding on two keys is shown separately in paired curves from individual sessions (numbered at the left). Reinforcements (or correct responses) are marked by deflections of the event pen, timeouts (or errors) by dots above the curves, and all responses on each key stepped the pen of the appropriate recorder. The reset of Session 1 of each animal marks the introduction of sound stimuli. These records illustrate the decline in response rate and number of incorrect responses (timeouts) that occurred during acquisition. Incorrect responses dropped out faster in the adjacent condition than in the non-adjacent condition.

not necessary for the development of control by the two auditory stimuli.

Three of the monkeys were changed to the non-adjacent condition (see below) and two of these (SM21 and SM23) were subsequently returned to the adjacent condition. Stimulus control was regained when the adjacent condition was reinstituted. The regaining of stimulus control was not prevented, in SM21, by the large number of incorrect responses reinforced during the first three sessions when the adjacent condition was reinstituted.

Cumulative records of two monkeys run under adjacent conditions are shown in Figure 7. The decline in rate during the fixed interval (an S^{Δ} for food) was slower than the acquisition of differential control of responding on the two keys by the auditory stimuli and in this regard, the non-differential reinforcement condition was similar to the differential reinforcement condition.

Non-adjacent conditions. Results obtained under these conditions are shown in Figure 6. There was no indication that stimulus control would develop in these three monkeys nor did the percentage of correct responses appear to differ from chance. The failure of these animals to develop stimulus control was not due to hearing impairment because all three, when changed to adjacent, differential reinforcement conditions, developed stimulus control to a level exceeding 90% correct responses.

Comparison of these data with the acquisition of control under differential reinforcement conditions shows that differential reinforcement of the responses in the presence of the auditory stimuli is necessary for the development of control under non-adjacent conditions in the naive monkey. Rate of responding during the fixed interval declined more slowly than under other conditions (Figure 7).

Change of conditions. Animals run initially

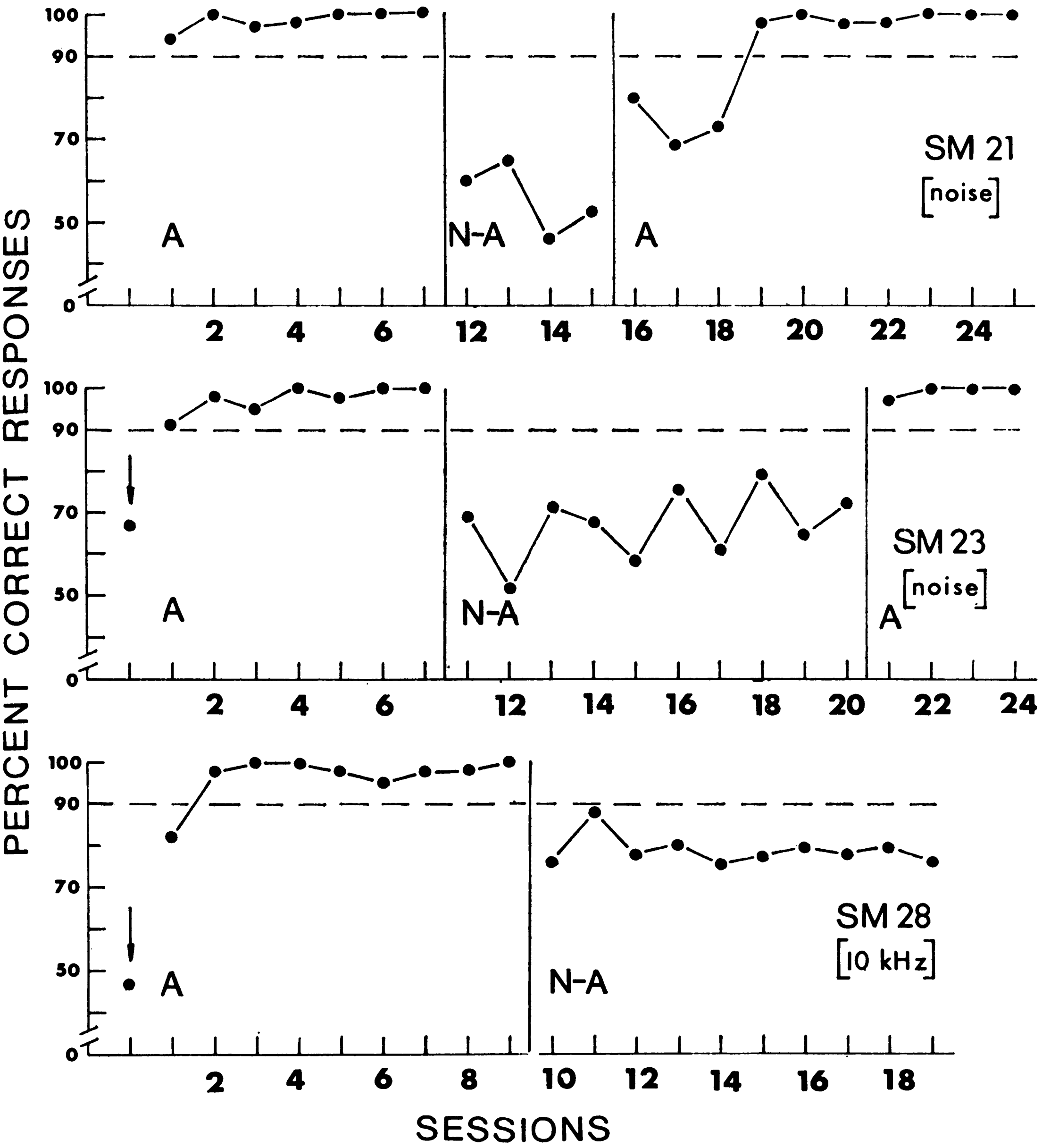

Fig. 4. Acquisition of stimulus control of responding of monkeys obtained with loudspeakers in the adjacent position (A), and the effects of a post-acquisition change to the non-adjacent position (N-A) followed by a return to the adjacent position (A). Non-differential reinforcement was used throughout. Stimuli were either noise or 10-kHz bursts (indicated for individual animals in brackets). The data points marked with an arrow (shown for SM23 and SM28) represent behavior before sound stimuli were introduced.

under adjacent conditions were changed to non-adjacent conditions (Figure 4) and animals run initially under non-adjacent conditions were changed to adjacent conditions (Figure 6).

Stimulus control of responding, under adjacent conditions, did not develop in animals (SM31 and SM34) that were initially run under non-adjacent conditions, whereas control did develop in experimentally naive animals (SM21, SM23, and SM28, Figure 4). The development of stimulus control under differential reinforcement conditions (SM31, SM34 and SM27, Figure 6) was also affected

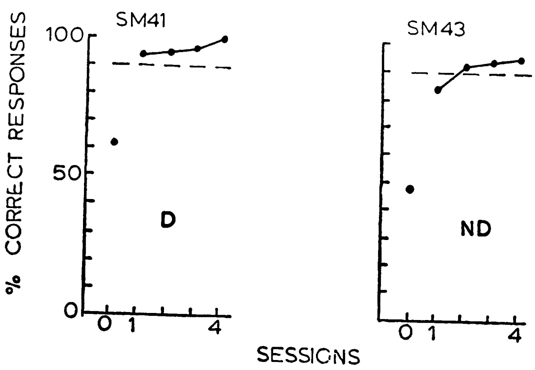

Fig. 5. Acquisition of stimulus control in animals run under adjacent conditions with differential and non-differential reinforcement. The sound stimulus was a single brief noise burst (click). The dots indicate the percentage of correct responses immediately before the introduction of the sound.

by a past history of non-adjacent conditions. Control of responding by the auditory stimuli developed more slowly in these animals than in those initially run under adjacent conditions.

Thus, stimulus control in monkeys is dependent upon the past experimental history of the animal with respect to auditory discriminations.

A corresponding (though smaller and less consistent) effect of past history can be seen in animals run under non-adjacent conditions after acquisition under adjacent conditions (SM21, SM23, and SM28, Figure 4). SM23 and SM28 both ran at a higher level of correct responses than was found in animals initially trained on the non-adjacent condition (SM31, SM34, and SM27, Figure 6).

DISCUSSION

Differential and Non-Differential Reinforcement

The major purpose of this experiment was to determine whether differential reinforcement of the two responses was necessary for the acquisition of correct responding. The results clearly show that under adjacent conditions, differential reinforcement was not necessary and that under non-adjacent conditions it was. These data strongly suggest that the animals brought to the experiment a response bias to go to the sounding key. Whether such a bias is inborn or the product of prior experience with sounds is not known. It is suggested that such a bias orients the animal's head and eyes in the direction of the sound and that such a response brings the image of the correct key into the animal's visual field (approximately at the fovea) and leads to correct responding. Such orienting responses are present in the cat (Thompson and Welker, 1963), and, from our observations, certainly appear to be present in the monkey. Under non-adjacent conditions, the orientation of the head and eyes to the sounding key would not bring the image of the correct key on the fovea.

Adjacent and Non-Adjacent Conditions

We conclude that the difference in rate of acquisition of the discrimination under adjacent and non-adjacent conditions is due to the adjacency of the speakers and keys. On the other hand, it is possible that sound location was more discriminable in the adjacent than in the non-adjacent condition. When the monkey's head is in the vicinity of the keys the effective angular separation of the speakers is greater in the adjacent than in the non-adjacent condition. It appears unlikely, however, that the effect of adjacency can be explained in this way. For two animals run under adjacent conditions the stimulus was a single click at the beginning of the trial. The animal was likely to be anywhere in the enclosure when the click occurred. Since the stimulus was no longer available when the response was made, the adjacency of speaker and key would not lead to an easier discrimination of sound location. Despite this, the discrimination was acquired as rapidly and maintained as well as in animals for which the stimulus was a repeated series of tone (or noise) bursts.

Stimulus Parameters

Under adjacent conditions, different animals were run using repeated noise bursts, repeated tone bursts and a single noise burst (click). With all these stimuli, control to a level exceeding 90% correct responses was obtained within two sessions (with the exception of SM15, which reached 89% by the second session). These data indicate that it is not necessary that the animal be repeatedly stimulated to achieve rapid control, and also, therefore, that movement relative to the

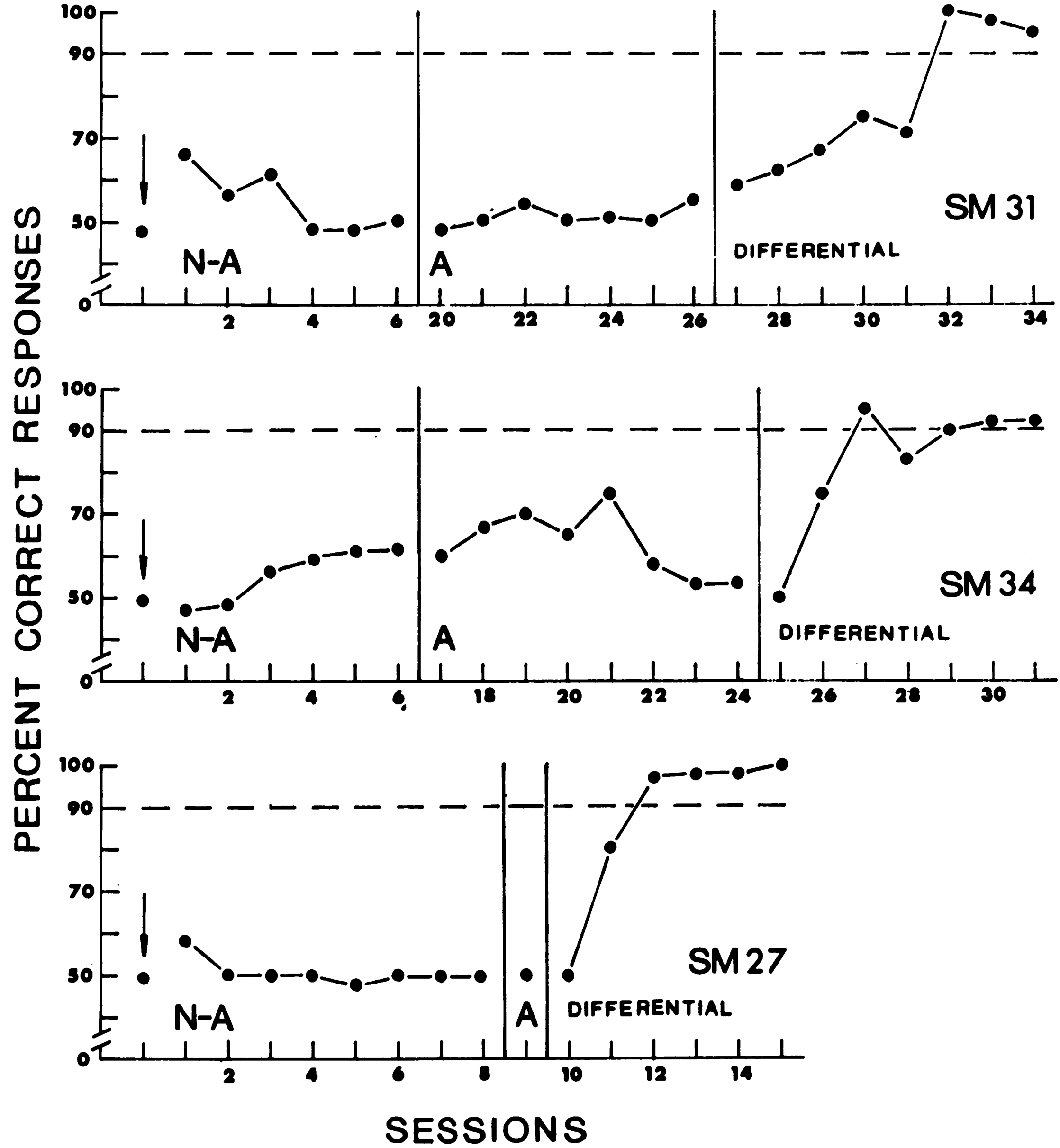

Fig. 6. Percentage of correct responses per session for animals run initially under non-adjacent conditions (N-A), then changed to adjacent conditions, non-differential reinforcement throughout. The animals were finally changed to adjacent, differential reinforcement conditions (differential). Data points marked with an arrow represent behavior in the absence of sound stimuli.

sound (moving towards a speaker, for example) is not an essential condition. All animals stabilized at between 98% and 100% correct responses. This indicates that whatever properties of the sound were supporting the behavior, they operated exceedingly reliably. This reliable control of responding took place in complex sound fields, which, in the case of the tones, included many standing wave patterns.

That the animal has auditory processes that permit orientation under complex acoustic conditions is not surprising from the biological viewpoint, since these are the conditions under which hearing is required to operate.

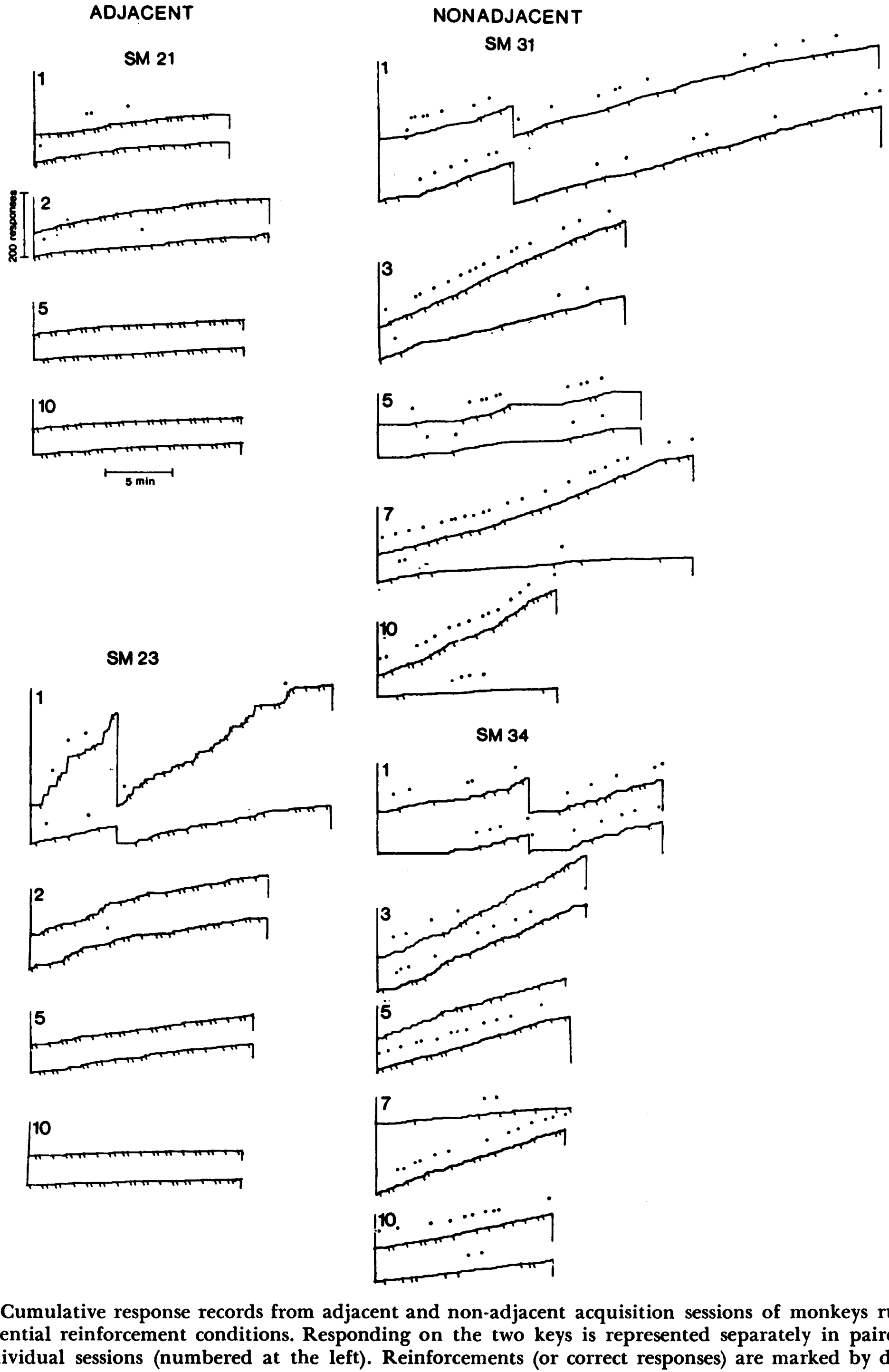

Fig. 7. Cumulative response records from adjacent and non-adjacent acquisition sessions of monkeys run under nondifferential reinforcement conditions. Responding on the two keys is represented separately in paired curves from individual sessions (numbered at the left). Reinforcements (or correct responses) are marked by deflections of the event pen, timeouts (or errors) by dots above the curves, and all responses on each key stepped the pen of the appropriate recorder. The reset in Session 1 of each animal (except SM21) marks the introduction of sound stimuli. Sound stimuli were present from the start of Session 1 of SM21. These records illustrate the decline in response rates during the fixed interval and in number of incorrect responses (timeouts) during acquisition under the adjacent condition (SM21 and SM23) and the absence of these changes under the non-adjacent condition (SM31 and SM34).

Species Differences

In some mammalian species, adjacency of speaker and manipulandum is of less significance in altering the rate of acquisition of stimulus control. In rats, acquisition of control was obtained within two sessions under non-adjacent conditions by Harrison and Beecher (1969). In a different apparatus and using a different non-adjacent arrangement of speakers and response levers, Beecher (1970) obtained stimulus control within two sessions in rats and also in bats (*Phyllostomus*). In the rat, Harrison, *et al.* (1971) showed that there is little difference in rate of acquisition in rats under the two conditions. From these data it is clear that rat and monkey are different in this regard. We speculate that this difference lies in the different head and eye orientating movements that are evoked by sounds in the two species.

It is well known that the acquisition of auditory discriminations by monkeys (including localization) is slower than in other species (particularly, rats and cats) (Dewsen, Wertheim, and Lynch, 1968; Wegener, 1964; Cowey, 1968). The present results and previous work on monkeys (Harrison, *et al.*, 1971) suggest that the difficulties of training monkeys in localization tasks was probably due to non-optimal arrangements used in the experiments. The monkeys in our experiments have come under stimulus control as rapidly as rats, bats, and cats (Beecher, 1970; Harrison and Beecher, 1969; Downey, 1971). Cowey (1968), on the basis of his analysis of the adjacency of visual cues and response manipulanda and its effect on rapidity of visual discriminations, concludes that adjacency of auditory stimuli and manipulanda may be a significant variable in auditory discrimination experiments. He appears to be correct with respect to localization.

REFERENCES

Beecher, M. D. *A comparative study of auditory localization*. Ph.D. dissertation. Boston University, Department of Psychology, 1970.

Cowey, A. Discrimination. In L. Weiskrantz (Ed.), *Analysis of behavioral change*. New York, Harper and Row, 1968. Pp. 189-238.

Dewsen, J. H., Wertheim, G. A., and Lynch, J. C. Acquisition of successive auditory discrimination in monkeys. *Journal of the Acoustic Society of America*, 1968, **43**, 162-163.

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.

Harrison, J. M. and Beecher, M. Control of responding by the location of an auditory stimulus: role of rise time of the stimulus. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 217-227.

Harrison, J. M., Downey, P., Segal, M., and Howe, M. Control of responding by location of auditory stimuli: rapid acquisition in monkey and rat. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 379-386.

Thompson, R. F. and Welker, W. Role of auditory cortex in reflex head orientation by cats to auditory stimuli. *Journal of Comparative and Physiological Psychology*, 1963, **56**, 996-1002.

Wegener, J. G. Auditory discrimination behavior of normal monkey. *Journal of Auditory Research*, 1964, **4**, 81-106.

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