JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1977, 28, 243-251 NUMBER 3 (NOVEMBER)

CONTROL OF RESPONDING BY LOCATION OF AUDITORY STIMULI: ADJACENCY OF SOUND AND RESPONSE[1]

J. M. HARRISON, S. D. IVERSEN, AND S. R. PRATT

BOSTON UNIVERSITY, NEW ENGLAND REGIONAL PRIMATE RESEARCH CENTER, AND CAMBRIDGE UNIVERSITY

Four rhesus monkeys were trained to respond on one key when a one-second noise burst was presented through one speaker and to respond on a second key when the noise burst was presented through a second speaker. The acquisition of stimulus control was studied under three conditions, in each of which the relationship between the sound source and the response-key positions varied: an adjacent condition in which the noise burst was presented through the key and a response on this key was reinforced; a reversed-adjacent condition in which the noise burst was presented through one key and responding on the other key was reinforced; and a nonadjacent condition in which responding on the key nearer the sound was reinforced. Under adjacent conditions, stimulus control developed within one or two sessions. Under reversed and nonadjacent conditions, 10 sessions were required for the development of control. The asymptote of correct responding was the same under each condition in all animals.

Key words: auditory discrimination, localization, asymptotic level of stimulus control, development of stimulus control, rhesus monkey

---

The present experiment, as well as other experiments of this series, investigated the control of responding by the location of auditory stimuli under conditions in which this might naturally occur (Beecher and Harrison, 1971; Downey and Harrison, 1972; Harrison and Beecher, 1969; Harrison, Downey, Segal, and Howe, 1971). Under natural conditions, the animal is free to move with respect to sources of sound, its behavior is not usually instrumental in producing the majority of sounds in its acoustic environment and, finally, the sound fields produced by sounding objects in the animal's environment are complex, including standing waves, sound shadows, and spectral differences from point to point. In these experiments, the animal is free to move with respect to the sound sources and no attempt is made to create artificially a free sound field. Furthermore, the occurrence of the stimuli is not dependent on the behavior of the animal; the animal can be in any position or anywhere in the enclosure when the sound is presented. It was not the purpose of these experiments to measure mechanisms of sound localization *per se* (for example, the relative influences of binaural intensity or time differences, the extent to which the control is based on monaural as against binaural stimulation, or the extent to which movements contribute to appropriate responding). The features of the sounds on which control depends remain unknown, and it is not our purpose to investigate them.

There is already some indication in the literature of the variables likely to determine the speed with which behavior comes under the control of the position of a sound source. First, in squirrel and owl monkeys it has been reported that the relation of a sound source to the manipulandum (degree of spatial contiguity) is a significant factor (Downey and Harrison, 1972, 1975; Harrison, *et al.*, 1971). When the sound was adjacent to (spatially contiguous with) the manipulandum, stimulus control developed within a single session, but when the sound was not adjacent the development of control required 10 to 15 sessions (Downey and Harrison, 1972). In these experiments, not only was adjacency varied, but the sound field under adjacent and nonadja-

[1]This work was carried out while the first author was visiting the Department of Experimental Psychology, Cambridge University, England. The work was supported in part by NSF grant GB. 043302. Reprints may be obtained from J. M. Harrison, Department of Psychology, Boston University, 64 Cummington Street, Boston, Massachusetts 02215.

cent conditions was also different. One purpose of the present experiment was to control for these differences in the sound fields.

Second, the rate at which stimulus control develops under adjacent and nonadjacent conditions might be related to the asymptote of correct responding under the two conditions. A second purpose of the present experiment was to investigate the asymptote of correct responding under the two conditions.

Third, there is a general impression in the literature on the genus *Macaca* that the development of stimulus control by various aspects of auditory stimuli (including sound position) typically requires a large number of sessions (see Cowey, 1968 and Wegener, 1964, for reviews of the literature relevant to this point). We were, therefore, interested in comparing the absolute rate of acquisition of stimulus control in the *Macaca* with that observed in other species.

Finally, the influence of food deprivation on asymptotic levels of correct responding under adjacent and nonadjacent conditions was investigated. The difficulty in obtaining rapid or high levels of percentage-correct responses in *Macaca* might be related to this variable. For example, Wegener, who used adjacent conditions in which the monkey was required to approach the sound source, reported only 78% correct responses when the two possible locations of the speaker were separated by an angle of 10 degrees (Wegener, 1964). Since this was an auditory position discrimination, in which response and sound-source sites were contiguous, rapid acquisition and a high asymptotic level of correct responses would have been expected.

METHOD

Subjects

Four experimentally naive male adolescent rhesus monkeys served; they weighed between 3 kg and 3.7 kg at the start of the experiments.

Apparatus

A top view of the animal enclosure is shown in Figure 1. The apparatus consisted of an animal enclosure, 90 cm wide, 55 cm deep, and 100 cm high, standing 71 cm above the floor on four legs. The enclosure was a modified animal cage made of the same heavy wire mesh on all six sides. Two modified Gerbrands monkey keys, R1 and R2, were placed on opposite sides of the enclosure and 23 cm above its floor. Each key had a circular response area 8 cm in diameter made of translucent plastic. A 6-cm hole was cut in the response area, covered with a fine wire mesh and illuminated in the center with a 28-V, 1-W "Lilliput" lamp. A loud speaker (TTC, Model K 2006), S1 and S2, was placed behind each key as shown in Figure 1 so that the sound entered the animal enclosure through the fine wire mesh, that is, effectively through the key. Two other speakers, S3 and S4, were mounted in the positions shown in Figure 1. A food magazine was mounted 8 cm above the enclosure floor in the middle of the back wall of the enclosure. The feeder dispensed 190-mg banana pellets into a food cup placed 4 cm above the enclosure floor. The animal enclosure was in a plaster-walled room 5 m by 3.4 m by 3.2 m high.

The auditory stimulus consisted of a 1-sec pulse of white noise. The output of a Grason-Stadler noise generator (Model 1285) was fed to a power amplifier (Leak Stereo 70) via a Grason-Stadler electronic switch (Model 829 E). The electronic switch was operated by a timer to give a 1-sec pulse at the beginning of each trial. The rise-decay time of the pulse was approximately 0.2 msec. The signal was set at a nominal intensity of 76 dB (re. 20 N/m^2) using a Dawe sound-level meter (Type 1408 E) set to the A scale and placed in the center of the animal enclosure. The background noise level in the room was approx-

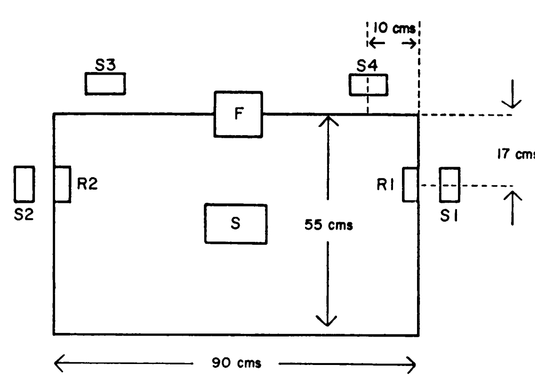

Fig. 1. Top view of the animal enclosure showing the positions of the two keys, R1 and R2 and the four speakers S1, S2, S3, and S4. F, food magazine. S, the position of the sound meter for taking nominal sound-level measurements. Speakers S1 and S2 were used in adjacent and reversed-adjacent training and S3 and S4 in nonadjacent training. See also Table 1.

imately 64 dB, measured with the meter in the same position.

Illumination during the session was provided by the two 28-V lamps mounted on the keys; no other houselight was present. These lights were extinguished and a pilot light (28 V, 1 W) over the food cup lit during operation of the magazine. The two keylights were extinguished at the end of the session.

Procedure

A trial-by-trial method was used and the relationship of the sound source to the keys was varied for different subjects. The procedure involved two steps: (1) preliminary training, in which the animal was trained to operate the two keys in the absence of sound; (2) training to respond to the position of the sound.

Preliminary training was carried out as follows. The animals were placed on a restricted feeding schedule until body weight was 80% of that under free-feeding conditions, then trained to press the two keys using food as the reinforcer. A 30-sec variable-interval schedule was then arranged on either one or other of the two keys according to the following sequence: LLRLRRRLRLLLRR (repeated), where R stands for R1 and L for R2. A response on the scheduled key (correct response) at the end of each interval on the VI 30-sec tape produced a 190-mg pellet and switched the programming equipment to the next item of the left-right sequence. If at the time reinforcement was available on, say, the left key, a response was made on the right key (incorrect response) the animal received an 8-sec timeout, during which the keylights were extinguished. A response that produced a timeout also switched the programming equipment to the next item of the left-right sequence. This procedure was continued for three to four sessions (depending on the animal), by which time the animals were operating the keys at approximately similar rates. Animals were routinely allowed 50 reinforcements per session. From time to time, this number was varied when details of behavior were being examined. Responding before reinforcement availability postponed reinforcement for 3 sec. The behavior of the animals was measured in terms of the percentage of reinforcements as follows:

$$\text{Per cent reinforcement} = \frac{\text{Number of reinforcements}}{\text{Sum of number of reinforcements and number of timeouts}}$$

In discrimination training, each time reinforcement set up on say R1 (the right key), the 1-sec pulse of noise was presented to the animal through one speaker. When reinforcement set up on the other key, the noise burst was presented through a second speaker. Which speakers were used varied with different animals, as shown in Table 1. With introduction of the sound, a limited hold was placed on the availability of reinforcement. For the first few trials, the limited hold was 10 sec. This value was reduced to 5 sec by the end of the first sound session. Sessions were 50 reinforcements long unless details of behavior were being examined. All other aspects of the schedule were the same as those of the later sessions of preliminary training.

The development of stimulus control was examined under different spatial relationships of the sound source to the keys. As can be seen from Table 1, three relationships were used; adjacent, nonadjacent, and reversed adjacent.

When it was judged that each animal had reached its asymptote of percentage of reinforcements (percentage of correct responses), relationships between the sounds and the keys were changed and the asymptote under the

Table 1

Relation of the sounds to the two response keys during the sound-training sessions.

Animal No.	*Condition*	*Relation of Speakers to Keys**
M1	Adjacent	S1; R1 S2; R2
M2	Adjacent	S1; R1 S2; R2
M3	Nonadjacent	S3; R1 S4; R2
M4	Reversed adjacent	S1; R2 S2; R1

*S1; R1 means that when sound was presented through S1 a response on R1 was reinforced. A similar meaning holds for the other relations.

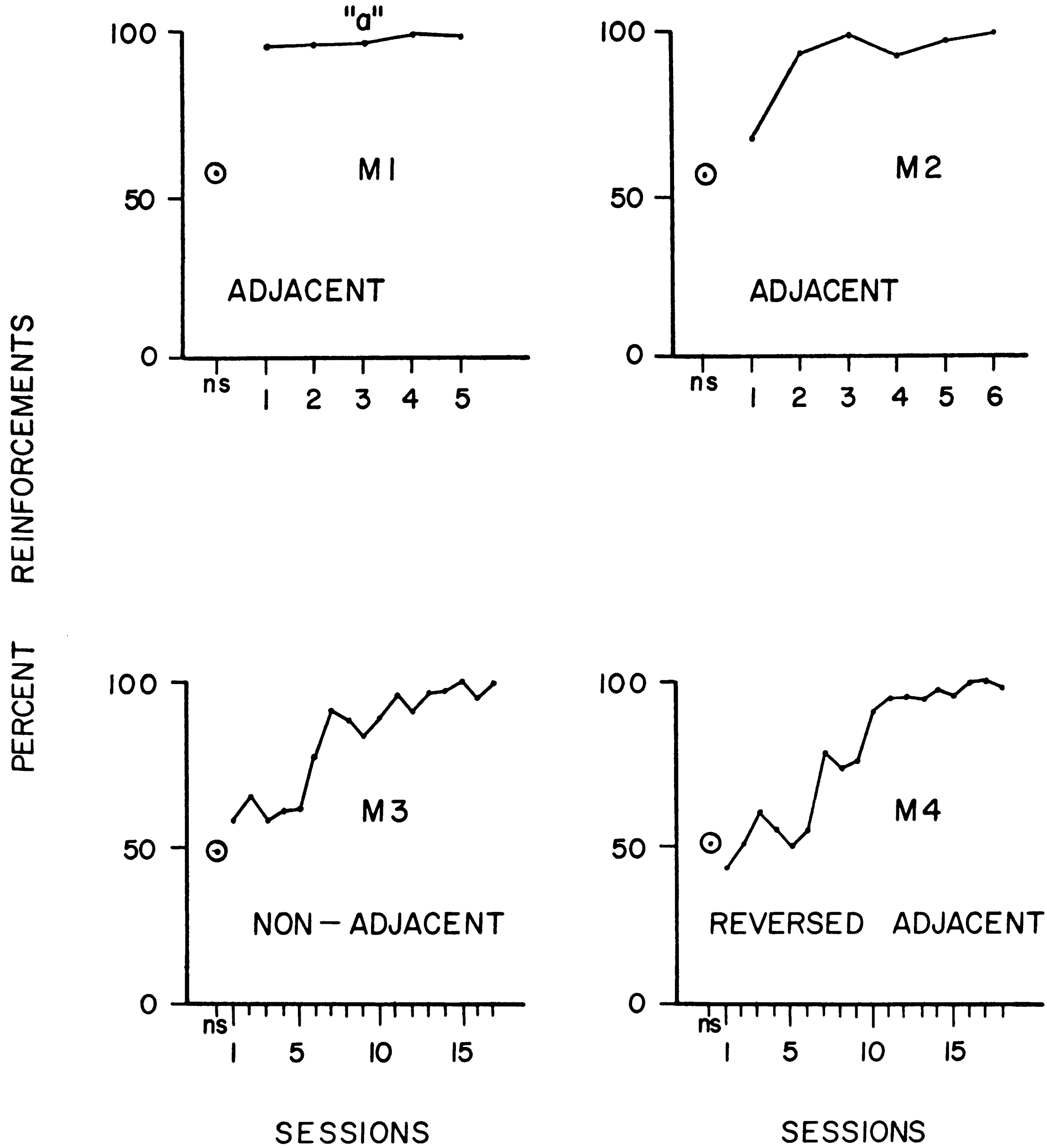

Fig. 2. Session-by-session development of stimulus control. The two speakers, S1 and S2 were interchanged at "a" to control for qualitative differences in the sounds. M1, M2, M3, and M4 are the four monkeys. No sound (ns) refers to the percentage of reinforcements obtained during the last session before sound was introduced.

new condition was obtained. Each animal was exposed to each relationship.

At the conclusion of this series, three animals were studied under simultaneous adjacent and nonadjacent conditions. For this, the sound could be presented through any one of the four speakers on any trial. If the sound was presented through S1 or S3, then a response on R1 was reinforced; if the sound was presented through either S2 or S4, a response on R2 was reinforced. All other conditions remained the same. The percentage of correct responses was calculated separately for the adjacent and nonadjacent sounds. For this series of observations the animals received 50 trials per session.

RESULTS

Development of Stimulus Control

Adjacent condition. The development of stimulus control, session by session, is shown in Figure 2, and the details of the development of control during the first sound session for blocks of reinforcements is shown in Figure 3. Since it was uncertain how the monkeys would behave when the sound was first introduced, data were recorded initially by hand, the number of reinforcements forming the blocks being a matter of convenience for the experimenter for the first two monkeys (M1 and M2). For later monkeys, data for blocks of 10 reinforcements were automatically collected. It can be seen from Figure 2 that on a session-by-session basis, responding of the two monkeys studied

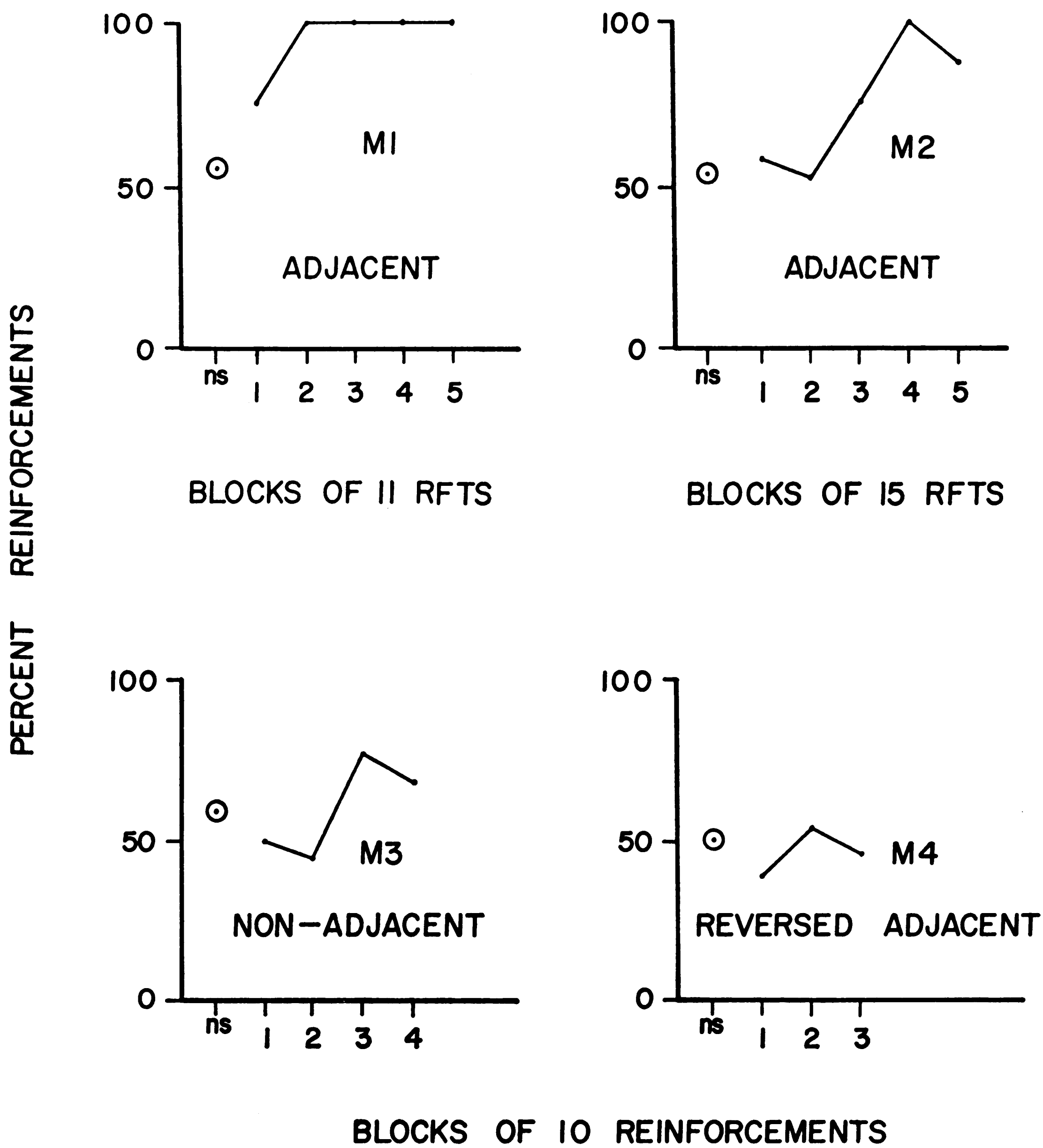

Fig. 3. The development of stimulus control during the first sound-training session by blocks of reinforcements during the session. "No Sound" refers to the percentage of reinforcements obtained during the last session before sound was introduced.

under adjacent conditions, M1 and M2, came under stimulus control rapidly. M1 exceeded the 95% reinforcement level during the first session, and M2 by the end of the second. At "a" (Figure 2), the speakers S1 and S2 were interchanged for control purposes. As can be seen, this had no effect on the behavior, indicating that responses were being controlled by position of the sound source, rather than by possible qualitative differences between the sounds. Speakers were also interchanged for the other animals at various times during the experiment without affecting behavior. The rapidity with which control developed can be more clearly seen in Figure 3. M1 reached the 100% reinforcement level after the first 11 reinforcements. During that time, only two incorrect responses were made. M2 reached the 100% reinforcement level after the fourth block of reinforcements, having made a total of 30 incorrect responses.

Nonadjacent and reversed adjacent conditions. Figure 2 shows that M3 (nonadjacent) and M4 (reversed adjacent) did not reach above a level of 95% correct responses until the eleventh session. The percentage of correct responses for the first session for each monkey is shown in the lower part of Figure 3. Comparison of results under adjacent conditions with those under nonadjacent and reversed-adjacent conditions shows that the relative positions of the sound to the keys is a significant variable in the development of stimulus control.

Asymptotic Level under Different Adjacency Conditions

The asymptotic level of the percentage of reinforcements under various conditions for the four monkeys is shown in Figure 4; there is no indication that the asymptote was different under the three conditions.

Asymptotic Level Under the Four-Speaker Condition

Three animals (M1, M2, and M4) were studied at asymptote under the four-speaker condition. The percentages of correct responses for adjacent and nonadjacent sounds were analyzed separately. The results are shown in the left-hand panel of each graph in Figure 5. As can be seen in the figure, there appears to be no difference in the asymptote of percentage of reinforcements for the two conditions. These data (under the four-speaker condition) are in agreement with the data shown in Figure 4, with respect to the lack of difference between adjacent and nonadjacent conditions.

At the conclusion of this experiment, the animals were fed freely for 19 to 24 days and then studied (free-feeding continued) for further sessions on the four-speaker arrangement. These data are presented in the right-hand panels of each graph of Figure 5. As can be seen, the percentages of reinforcements for both adjacent and nonadjacent conditions were clearly different from those under deprivation conditions. The average weights of each animal during the deprivation and free-feeding sessions are shown in the figure. Free-feeding appears to have no consistently different effect on behavior under adjacent and nonadjacent conditions. Shown in Table 2 are the total number of R1 and R2 responses that each animal made in the last three deprived and the last three free-feeding sessions. As can be seen from the table, there was little change in the number of responses for M4. Animals M1 and M2 show some signs of responding principally on R1.

Table 2

Number of responses on the two keys under food-deprived and free-feeding conditions. The last three sessions under each condition are shown.

	Deprived			*Ad Libitum*		
Animal	*R1*	*R2*	*Total*	*R1*	*R2*	*Total*
	24	27	51	34	24	58
M1	27	25	52	79	9	88
	29	27	56	69	11	80
	25	26	51	49	7	56
M2	28	52	80	38	12	50
	26	25	51	50	4	54
	27	28	55	24	39	63
M4	34	29	63	27	28	55
	29	25	54	27	29	56

DISCUSSION

It is clear from the data presented in Figures 2 and 3 that adjacency of sound to manipulandum is a significant variable in the rate of development of stimulus control. Two kinds of nonadjacency were used in this experiment: the speakers in the S3 and S4 positions and the reversed-adjacent arrangement. Under the

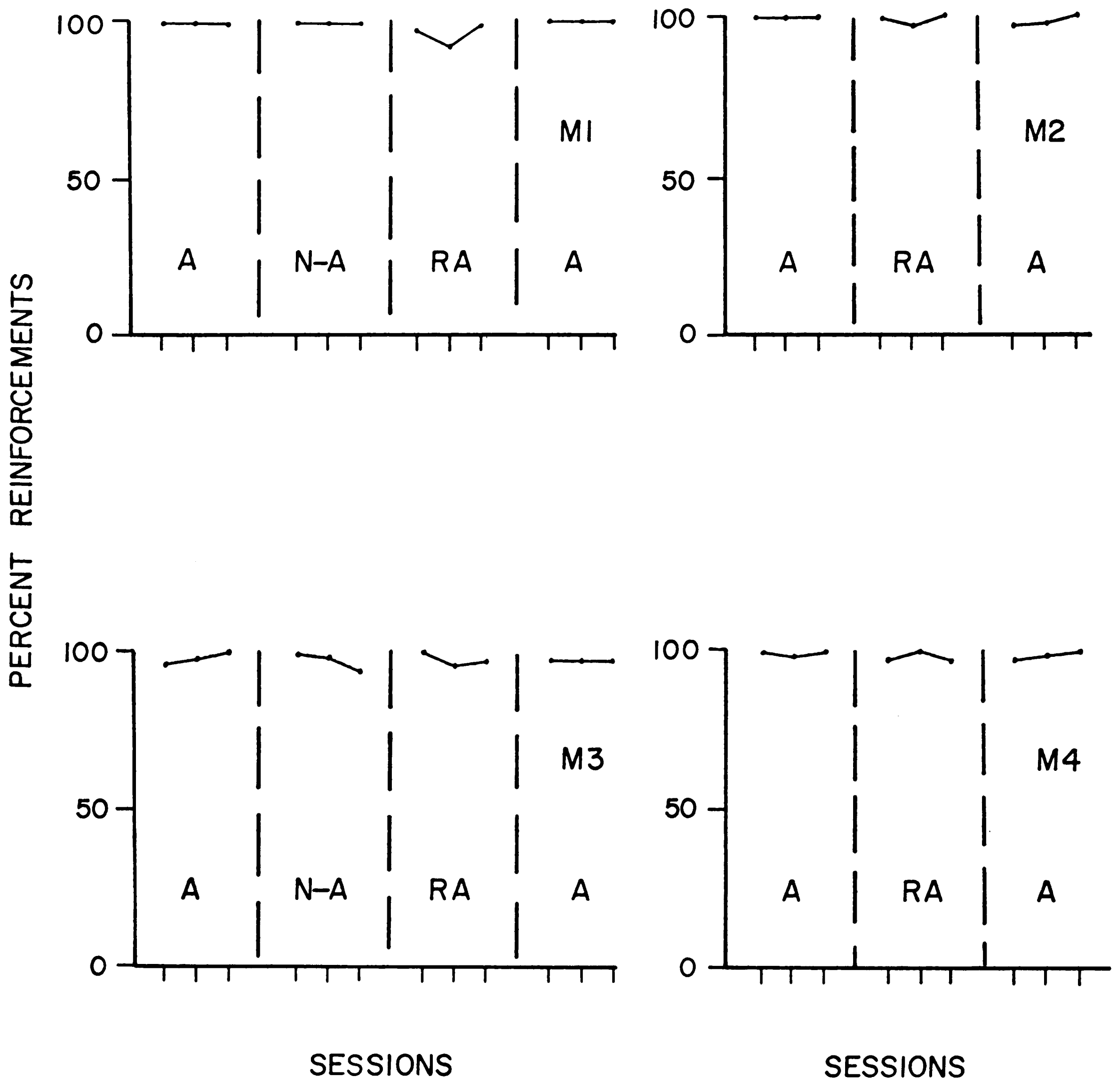

Fig. 4. Asymptotic level of percentage of reinforcements under adjacent (A), nonadjacent (N-A) and reversed-adjacent (R-A) training. The last three sessions under each condition are plotted.

reversed-adjacent arrangement, the sound fields produced in the animal's enclosure were identical to those produced under adjacent conditions (since the speakers are in identical positions), hence the difference in rate of development of the discrimination cannot be attributed to differences in the sound field. Under both conditions, the animal was likely to be in any position in the enclosure when the sound was presented. While the sound field produced by the speakers in positions S3 and S4 (nonadjacent) are different from those produced by the speakers in positions S1 and S2, the rate of development of control for the S3 and S4 positions was the same as for the reversed-adjacent condition.

In a similar situation in which squirrel and owl monkeys were the subjects, stimulus control developed rapidly under adjacent conditions and slowly under nonadjacent conditions (Downey and Harrison, 1972, 1975; Harrison, Downey, Segal, and Howe, 1971). While the outcome of those experiments strongly suggested adjacency to be the significant variable, it was possible that sound-field differences contributed to the results since the reversed-adjacent condition was not studied. The fact that, in the present experiment, development

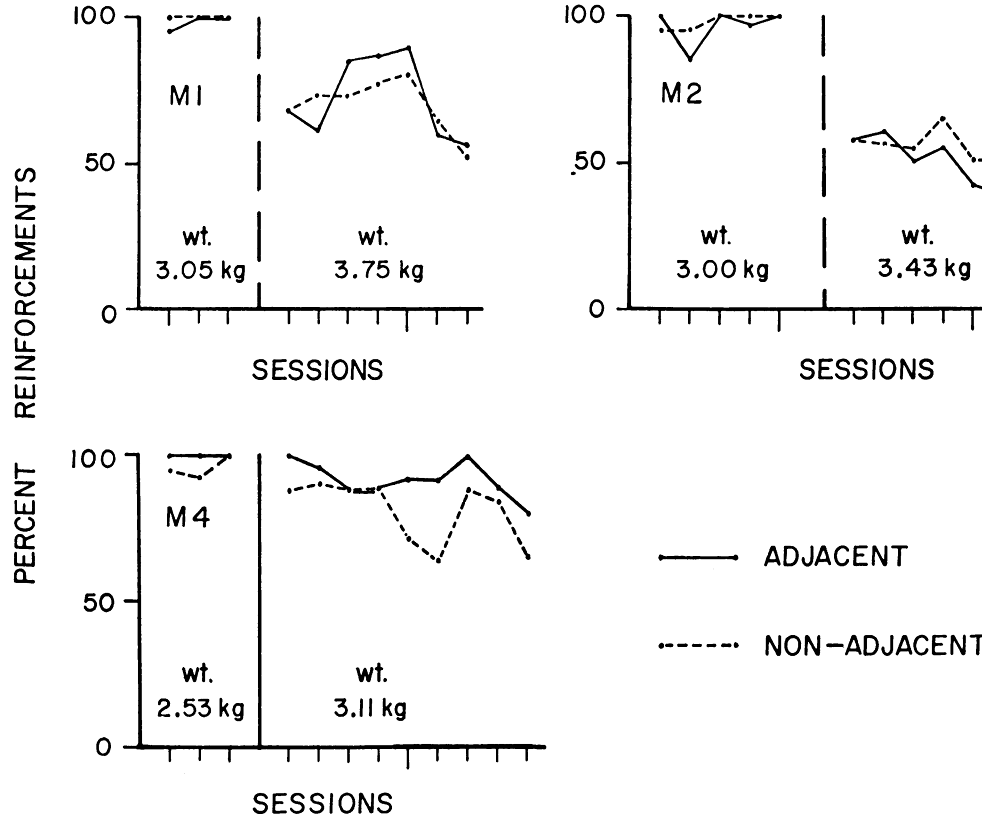

Fig. 5. The percentage of reinforcements for adjacent and nonadjacent sounds with the sounds presented through the four speakers. For the sessions to the left of the vertical dashed line in each graph, the animal was food deprived. The animal's average weight for the three sessions is shown. At the dashed line, each animal was fed freely for 19 to 24 days. Data to the right of the line were collected under free-feeding conditions. The average weight for the sessions is shown.

of control in the reversed-adjacent condition also occurred slowly suggests that adjacency is the critical variable in the experiments cited above.

It has been suggested (Downey and Harrison, 1972) that head orientation to the sounding speaker may be significant in accounting for the difference in the rate of development of control under adjacent and nonadjacent conditions. Under adjacent conditions, orientation to the sounding speaker could be considered a necessary intermediate response in a chain that includes approach to the sounding speaker and pressing of the correct key. Under nonadjacent conditions, orientation to the sounding speaker would lead to approaching the sounding speaker, but since there is no key at that speaker, reinforcement of the chain would never occur. For the animal to respond correctly under nonadjacent conditions, it would be necessary for orientation to the correct key to replace orientation to the sounding speaker. However, studies of head orientation to sounds in squirrel monkeys have shown that under both adjacent and nonadjacent conditions, head orientation was to the sounding speaker (Harrison and Briggs, 1977). Thus, changes in head orientation cannot account for the differences in the rate of development of stimulus control under the two conditions.

The majority of experiments on the discrimination of stimulus position in monkeys have been carried out on the genus *Macaca* (see Cowey, 1968, and Wegener, 1964, for reviews of these experiments). In none of these experiments did stimulus control develop rapidly. It should be noted that in Wegener's experiments, not only did control of behavior by position develop slowly, but the animals took more than twice as many trials to learn the "adjacent" than the "reversed-adjacent" condition. Wegener concluded that this occurred because the auditory stimuli used were aversive. There is no indication, however, that the buzzer he used was materially more intense than our stimuli, and it is not easy to account for the different results obtained by Wegener by stimulus parameters or response requirement differences.

Wegener does not report any food deprivation of the animals; during acquisition, our subjects were at about 80% of their free-feeding weights. It would appear that differences in food deprivation, rather than in the relative aversiveness of the stimuli used, accounts for the discrepancy between our results and Wegener's. That body weight is a significant variable in the asymptote of percentage reinforcements is shown in Figure 5. It can be seen from Table 2 that in animals M2 and M4 there was no effect on the total number of responses in a session as the result of raising body weight. The occurrence of a sound (from either speaker) still controlled responding, since there was no increase in the number of intertrial responses. However, control of response location in the presence of either stimulus was partially lost. In the case of M1, there was some loss of control of responding since the total number of responses (and hence the number of intertrial responses) increased. These data clearly point to the need for studying monkeys at a lowered body weight if a high asymptote of reinforced responses is required.

The present experiment, and other experiments in this series, were carried out in different rooms, with different-sized animal enclosures and with different stimulus-producing equipment. Various kinds of stimuli, from repeated tone bursts to single clicks, have also been used. In all these experiments, similar results have been obtained. This indicates that the results are not due to any idiosyncratic sound properties of the room, stimuli, equipment nor to any particular properties of the species of monkey used. The effects of adjacency are probably quite general for all species of monkey under a wide variety of conditions.

REFERENCES

Beecher, M. D. and Harrison, J. M. Rapid acquisition of auditory localization discrimination by rats. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 193-200.

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

Downey, P. and Harrison, J. M. Control of responding by location of auditory stimuli; role of differential and nondifferential reinforcement. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 453-463.

Downey, P. and Harrison, J. M. Control of responding by sound location in monkeys; rapid acquisition in darkness. *Journal of the Experimental Analysis of Behavior*, 1975, **23**, 265-276.

Harrison, J. M. and Beecher, M. D. 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. and Briggs, R. M. Orientation and responding in auditory discriminations in squirrel monkeys. *Journal of the Experimental Analysis of Behavior*, 1977.

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

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

Received 5 May 1976.
(Final acceptance 7 June 1977.)