ANALYSIS OF DISCRIMINATIVE CONTROL
BY SOCIAL BEHAVIORAL STIMULI

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Visual discriminative control of the behavior of one rat by the behavior of another was studied in a two-compartment chamber. Each rat's compartment had a food cup and two response keys arranged vertically next to the clear partition that separated the two rats. Illumination of the leader's key lights signaled a "search" period when a response by the leader on the unsignaled and randomly selected correct key for that trial illuminated the follower's keys. Then, a response by the follower on the corresponding key was reinforced, or a response on the incorrect key terminated the trial without reinforcement. Accuracy of following the leader increased to 85% within 15 sessions. Blocking the view of the leader reduced accuracy but not to chance levels. Apparent control by visual behavioral stimuli was also affected by auditory stimuli and a correction procedure. When white noise eliminated auditory cues, social learning was not acquired as fast nor as completely. A reductionistic position holds that behavioral stimuli are the same as nonsocial stimuli; however, that does not mean that they do not require any separate treatment. Behavioral stimuli are usually more variable than nonsocial stimuli, and further study is required to disentangle behavioral and nonsocial contributions to the stimulus control of social interactions.
    Key words: behavioral stimulus, visual social stimulus, matched-dependent learning, social learning, following, imitation, auditory social stimulus, behavior as a discriminative stimulus, rats

One reason for using animals in social-learning experiments is that they provide a simplified framework for discovering the fundamental processes or building blocks of social interactions. Miller and Dollard (1941) stated the obvious advantage of animal subjects: Their social experiences both inside and outside the experiment can be controlled so that the acquisition of social behavior can be studied relatively uncomplicated by histories of social and verbal interactions. This approach assumes that at least a portion of human social behavior can be explained by the same learning principles that account for the behavior of infrahuman animals. The task then is to determine which learning principles are involved in a particular social interaction and how they combine to produce the complex social interaction.

One strategy is to start with simple instances of social behavior and then proceed to more complex cases. The simplest case is behavior that is under the discriminative control of the mere presence of another animal. For example, Husted and McKenna (1966) showed that rats could learn to bar press for food in the presence of another rat (S+) and not in its absence (S−).

The basic unit of analysis in social interactions such as cooperation, however, is discriminative control by a specific behavior of another animal, not the mere presence. For example, if moving an object requires simultaneous lifting responses by two individuals, lifting by one individual should serve as the discriminative stimulus for lifting by the other individual.

Miller and Dollard (1941) addressed the problem of discriminative control by a particular behavior of another animal in their matched-dependent learning procedure. The leader is provided nonsocial cues, and a correct response is reinforced regardless of what the follower does. The correct response for the follower, however, is cued by the leader's response. In their experiment, a food-deprived

follower rat learned to reach the baited arm of a T-maze by following a leader rat. The leader discriminated the correct arm on the basis of nonsocial cues (black vs. white card). A second experiment was necessary, however, to show that the followers had learned to follow the leader and not simply to discriminate the black and white cards, a nonsocial discrimination. The cards were removed and fresh leader rats trained to turn either right or left; followers were then tested with left- and right-going leader rats and followed both.

Their second experiment warned of artifactual sources of control in social-interaction experiments. Reviews of social-interaction experiments have discussed two sources of artifactual control—discriminative control by nonsocial stimuli and discriminative control by behavior of the other animal that is not appropriate to the procedure under investigation (Hake & Olvera, 1978; Hake & Vukelich, 1972).

Perhaps the problems of previous studies led Danson and Creed (1970) and Millard (1979) to focus on the acquisition of discriminative control by the behavior of another animal rather than advancing to the investigation of discriminative control in more complex social interactions (viz., imitation, cooperation, competition, etc.). A more general rationale for their research was the paucity of behavior-analytic research on social-interaction processes with animal subjects (e.g., Baron & Littman, 1961; Boren, 1966; Church, 1961; Grott & Neuringer, 1974; Hake & Laws, 1967) and the absence of any behavior-analytic studies specifically concerned with this fundamental process of the acquisition of discriminative control by the behavior of another animal (Millard, 1979). The behavioral stimulus in their studies was rate of responding; for example, a high response rate by the stimulus animal signaled a high-response-rate contingency for the subject, and a low rate by the stimulus animal signaled a low-response-rate contingency. Their results indicated acquisition of discriminative control, but their studies were complex. First, consider rate as a stimulus: It could involve patterns of operant responding, pausing, or doing something else. Second, measurement was automated but complex. High and low rates were on a continuum such that they were not necessarily correct or incorrect; the crucial analyses were ingenious but brief and involved (e.g., Millard's inter-bird inter-response times).

The present study had two objectives. The first was to provide data on an automated procedure that was simpler than previous ones with respect to the behavioral stimulus (visual location of a response) and analysis of discriminative control (responses on a correct operandum). The basic procedure was a version of one first suggested by Skinner (1953) in which leader and follower pigeons separated by a clear partition each had three keys arranged vertically next to the partition. When and where the leader responded served as stimuli for the responding of the follower. A similar procedure was used by Azrin and Lindsley (1956) in their study of cooperation in children. However, animal research with this procedure has consisted of a demonstration (Skinner, 1962) or a part of a more complex communication procedure (Epstein, Lanza, & Skinner, 1980), and no data on the acquisition of the discrimination have been presented. The present research simplified the procedure further and provided data on the course of acquisition.

The second objective was to evaluate the effects of a behavioral stimulus when it is restricted to the visual sense modality. In all of the above-mentioned experiments the critical stimulus was described as visual, and the studies by Danson and Creed (1970) and Millard (1979) attempted to eliminate other social stimuli such as auditory cues with fans and 100-db white noise, respectively. Why are visual stimuli typically selected to represent the class of stimuli designated as "social"? The reasons have not been spelled out in the research. One possible reason is simply face validity: Although all social stimuli are physical products of the presence or behavior of the other animal (e.g., reflected light, sound waves, chemicals in the air), reflected light may be more salient as a social stimulus because of its physical proximity to the location of the other animal. A second reason is that reflected light usually co-varies more with behavior than other stimuli that may be in part controlled by the equipment (e.g., the "click" sound from pressing a key). This is important, because discriminative control by behavioral stimuli differs from nonsocial discriminative control primarily in that behavioral stimuli depend on another animal and are therefore more variable than nonsocial stimuli that are tightly controlled by the equipment. Even the behav-

ior of a trained confederate will vary with respect to rate, topography, and accuracy. It is difficult to describe the control by a visual social stimulus, because only Millard (1979) and Danson and Creed (1970) have attempted to isolate this type of control and their results are not conclusive. For example, in Millard's study, visual stimuli were eliminated for only 12 min and, as Millard indicated, the change in the environment per se (i.e., the cover placed over the partition between the animals) could have disrupted behavior temporarily. Danson and Creed's (1970) control procedures were equally brief, and they did not evaluate the effect of sounds produced by the behavior of the other animal. The position taken here is not that behavioral stimuli are unique such that they require separate laws, but that they do differ from nonsocial stimuli in that (1) they are more variable since they are not as easily controlled, (2) they have been controlled and manipulated only rarely, and (3) they may not be easily separated from other behavioral and nonbehavioral stimuli. The present research identified several possible sources of confounding when discriminative control by the behavior of another animal is restricted to the visual dimension, because what appeared to be obvious visual control by the behavior of the other animal was affected by other types of behavioral and nonbehavioral stimuli.

EXPERIMENT 1

METHOD

Subjects

Two female hooded rats, about 120 days old, were maintained at approximately 80% of their free-feeding body weights. Subjects had free access to water in their individual home cages and in the experimental chamber.

Apparatus

The experimental chamber was a Plexiglas box 34 cm wide by 28.5 cm long by 31.5 cm high inside a sound-insulated plywood box. The chamber was divided by a clear Plexiglas partition into two mirror-image compartments, one for the leader and one for the follower (Figure 1). Two translucent response keys on the front panel of each compartment were arranged vertically with the center of the lower
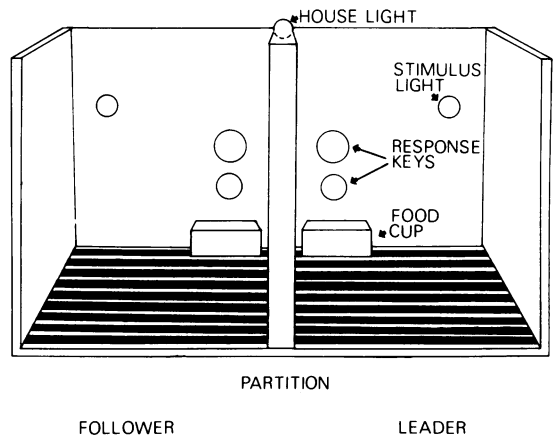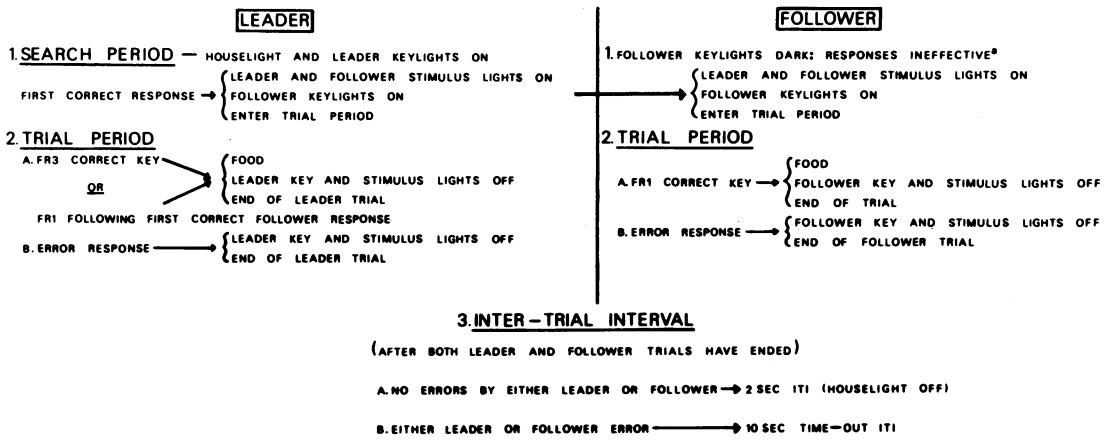

Fig. 1. Diagram (not to scale) of the front panels of the experimental compartments.

key 6.5 cm from the grid floor and the center of the upper key 3.5 cm directly above it. The upper key was 2.5 cm in diameter and the lower key was 1.9 cm in diameter. The center of each key was 2.5 cm from the partition and required a force of approximately .15 N to operate. The food cup in each compartment was on the floor directly beneath the lower key. A white 5-W stimulus light in each compartment was located 15 cm above the floor and 1.5 cm from the outside wall. A clear 5-W houselight at the top of the front panel (between the two compartments) provided general illumination. Water bottles were mounted at the rear of each compartment. An exhaust fan provided fresh air and masking noise that, along with a room fan, raised the noise level inside the chamber to 86 db. Electromechanical programming and recording equipment was in another room.

Basic procedure on each trial. Leader and follower portions of the trial began and ended separately. Figure 2 shows a diagram of the procedure of each trial for the leader and the follower. There were 200 trials per session.

Leader. Each trial started with illumination of the houselight and both response keys in the leader's compartment. The stimulus lights in both compartments and the keylights in the follower's compartment were illuminated when the leader pressed the key designated correct for that trial. A random-probability generator determined the correct key. Presses on the incorrect key by the leader had no effect until the correct key had been pressed. The period from the onset of the leader's key-

BASIC PROCEDURE FOR ONE TRIAL


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                    LEADER                    |                    FOLLOWER

1.SEARCH PERIOD — HOUSELIGHT AND LEADER KEYLIGHTS ON    | 1.FOLLOWER KEYLIGHTS DARK: RESPONSES INEFFECTIVE*
                    ⎧LEADER AND FOLLOWER STIMULUS LIGHTS ON    |                    ⎧LEADER AND FOLLOWER STIMULUS LIGHTS ON
FIRST CORRECT RESPONSE →⎨FOLLOWER KEYLIGHTS ON              |                    ⎨FOLLOWER KEYLIGHTS ON
                    ⎩ENTER TRIAL PERIOD                      |                    ⎩ENTER TRIAL PERIOD

2.TRIAL PERIOD                                               | 2.TRIAL PERIOD
   A.FR3 CORRECT KEY          ⎧FOOD                          |                          ⎧FOOD
        OR                    ⎨LEADER KEY AND STIMULUS LIGHTS OFF |  A.FR1 CORRECT KEY →⎨FOLLOWER KEY AND STIMULUS LIGHTS OFF
                             ⎩END OF LEADER TRIAL             |                          ⎩END OF TRIAL
   FR1 FOLLOWING FIRST CORRECT FOLLOWER RESPONSE            |
   B.ERROR RESPONSE ———→⎧LEADER KEY AND STIMULUS LIGHTS OFF |  B.ERROR RESPONSE ———→⎧FOLLOWER KEY AND STIMULUS LIGHTS OFF
                        ⎩END OF LEADER TRIAL                |                          ⎩END OF FOLLOWER TRIAL
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3.INTER-TRIAL INTERVAL

(AFTER BOTH LEADER AND FOLLOWER TRIALS HAVE ENDED)

A.NO ERRORS BY EITHER LEADER OR FOLLOWER —→ 2 SEC ITI (HOUSELIGHT OFF)

B.EITHER LEADER OR FOLLOWER ERROR ————→ 10 SEC TIME-OUT ITI

*IN EXPERIMENTS 2,3,4, FOLLOWER RESPONSES
ON DARK KEYS DURING THE SEARCH
PERIOD WERE TREATED AS FOLLOWER ERROR
RESPONSES

Fig. 2. Sequences of possible events for leader and follower during one trial.

lights until the leader pressed the correct key once was designated the "search period," and the following period until food was delivered was designated the "trial period." A 45-mg Noyes food pellet was delivered to the leader's food cup either (1) after three more consecutive correct key presses, or (2) following the first correct key press after the follower pressed the correct key. An error was recorded for the leader when the leader switched to the incorrect key after first pressing the correct key; the leader did not receive food on that trial and the keylights and stimulus light in the leader compartment were darkened, ending the leader portion of the trial. The requirement of four correct responses for the leader, unless the follower responded correctly, was intended to increase the probability that the follower would see the leader responding. (This could be important, for example, when the follower was not at the front of the chamber at the start of a trial.)

The trial ended for the leader when the leader produced a food pellet or made an error. A 2-sec intertrial interval (ITI) began after both rats had successfully completed the trial. If either rat made an error, a timeout period (a longer ITI of 10 sec) was instated after both rats completed the trial.

Follower. The two keylights and the stimulus light in the follower's compartment were not illuminated until the leader pressed the key designated correct for that trial. Key presses by the follower had no effect prior to this time. In this way, the follower's portion of the trial always began with a correct response by the leader. After the follower's keylights were illuminated, the first key press by the follower on the corresponding correct key produced a food pellet for the follower. Pressing the incorrect key darkened the follower's keylights and stimulus light and ended the follower's portion of the trial. An incorrect response by either the follower or the leader had no effect on the contingencies in the other rat's portion of that trial.

There was a correction procedure for follower errors. When the follower pressed the wrong key, the key that had been designated correct on that trial was designated as correct on the next trial. This continued until the follower completed a successful trial. At that point, either key was again selected by the random-probability generator. The correction procedure was designed to ensure that the rats pressed both keys.

Experimental design. Key pressing was shaped in nonsocial sessions. In addition, the leader was given sessions with small FR requirements on the correct key. During social training, when the follower consistently followed at 90% correct, leader and follower

roles were reversed by switching compartments. The initial reversal was followed by two more role reversals.

RESULTS AND DISCUSSION

Figure 3 shows the percentage of trials without errors for both the leader and the follower. The first panel of Figure 3 shows that the leader, Rat 2, learned not to switch to the incorrect key once the correct one had been found. The accuracy of Rat 2 did not drop below 90% after the third session. The follower, Rat 1, responded at below 50% accuracy in the first session, partly because of the correction procedure that repeated a trial until the correct response was made. With correction trials, accuracy can be less than 50% if an animal perseverates on one key. Accuracy improved gradually: It reached 60% by Session 4, 75% by Session 10, 85% by Session 13, and 90% by Session 20.

When leader-follower roles were reversed (second panel of Figure 3), the new leader, Rat 1, reached about 90% correct by the fourth session. Rat 2 gradually learned to follow: The first two sessions were near chance, followed by gradual improvement until accuracy reached 90% correct in Session 14. The last two reversals (Panels 3 and 4) show that the rats followed at 90% correct within one (Rat 2, last panel) or two (Rat 1, third panel) sessions.

EXPERIMENT 2

In Experiment 1, illumination of the keylights in the follower compartment was dependent upon a correct key press by the leader, but this did not prevent the follower from emitting responses on the dark keys as soon as the leader's keys lit. When this happened, who was leading whom was difficult to determine, because the leader was sometimes observed to press a key after the follower had pressed its corresponding key. Also, if the leader had been pressing the incorrect key, the follower was sometimes observed to shift to and press the other (dark) key before the leader. In these cases, key pressing of one of the rats was under the control of key pressing of the other, but which one was under the control of which was difficult to determine. To prevent the follower rat from leading, its dark-key responses were treated as errors in Experiment 2 and aborted
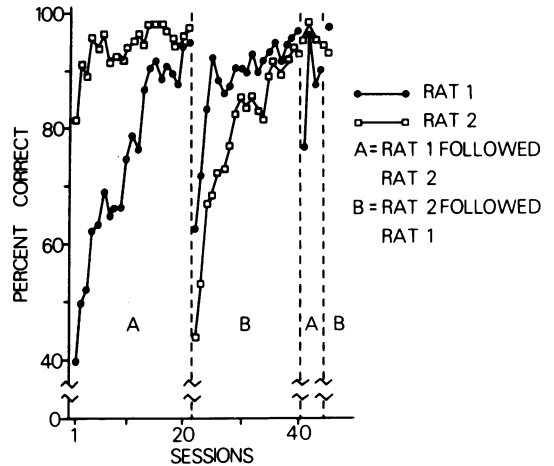

Fig. 3. Percent correct for leader and follower during acquisition and during reversals of leader and follower roles in Experiment 1.

the follower's portion of the trial. This temporal-following requirement ensured that control of responding was in a specific direction, viz., from leader to follower.

Dark-key responses aborted the follower's trial, thereby reducing the number of follower trials per session. Part of Experiment 2 was devoted to decreasing these dark-key responses by the follower.

METHOD

Subjects

Four female hooded rats were maintained at approximately 80% of their free-feeding body weights. The two leaders (R1 and R2) had been in the previous experiment and were about 300 days old at the start of Experiment 2. Two naive rats (R3 and R4), about 120 days old, served as followers. Rat 1 was always the leader for R3, and R2 for R4. Subjects had free access to water at all times.

Apparatus

The experimental compartments and stimuli were the same as in Experiment 1, except for the addition of a 90-db buzzer located behind the front panel. The 90-db buzzer was presented for about 1 sec following a dark-key response by the follower or following an error on a lit key by either rat. After acquisition of following, a higher-frequency pulsing tone from a Sonalert was presented during the

search period in an attempt to make the search period more discriminable.

Procedure

The basic procedure was identical to Experiment 1, except for the addition of the temporal-following requirements. Responses by the follower during the search period (before the leader pressed the correct key and lit the follower's keys) were treated as errors and resulted in timeout for the follower. Timeout for the follower began with the sounding of the 90-db buzzer. The follower's keys remained dark and inoperative while the leader completed the trial. A 10-sec ITI, instead of the usual 2-sec ITI that occurred after successful trials, followed trials with an error.

Several procedures were tried to reduce dark-key responses by the follower: The duration of the ITI was varied; the 90-db buzzer sounded for various durations following a dark-key response; the Sonalert tone was presented during the search period. Then, the presence and absence of the follower's dark-key timeout contingency was manipulated in an AB (R-4) or ABA (R-3) design.

RESULTS AND DISCUSSION

Figure 4 shows three types of data: (1) overall percent correct for the leaders, (2) overall percent correct for the followers, and (3) the adjusted percent correct, omitting trials when the follower pressed a dark key during the leader's search period. The adjusted curve
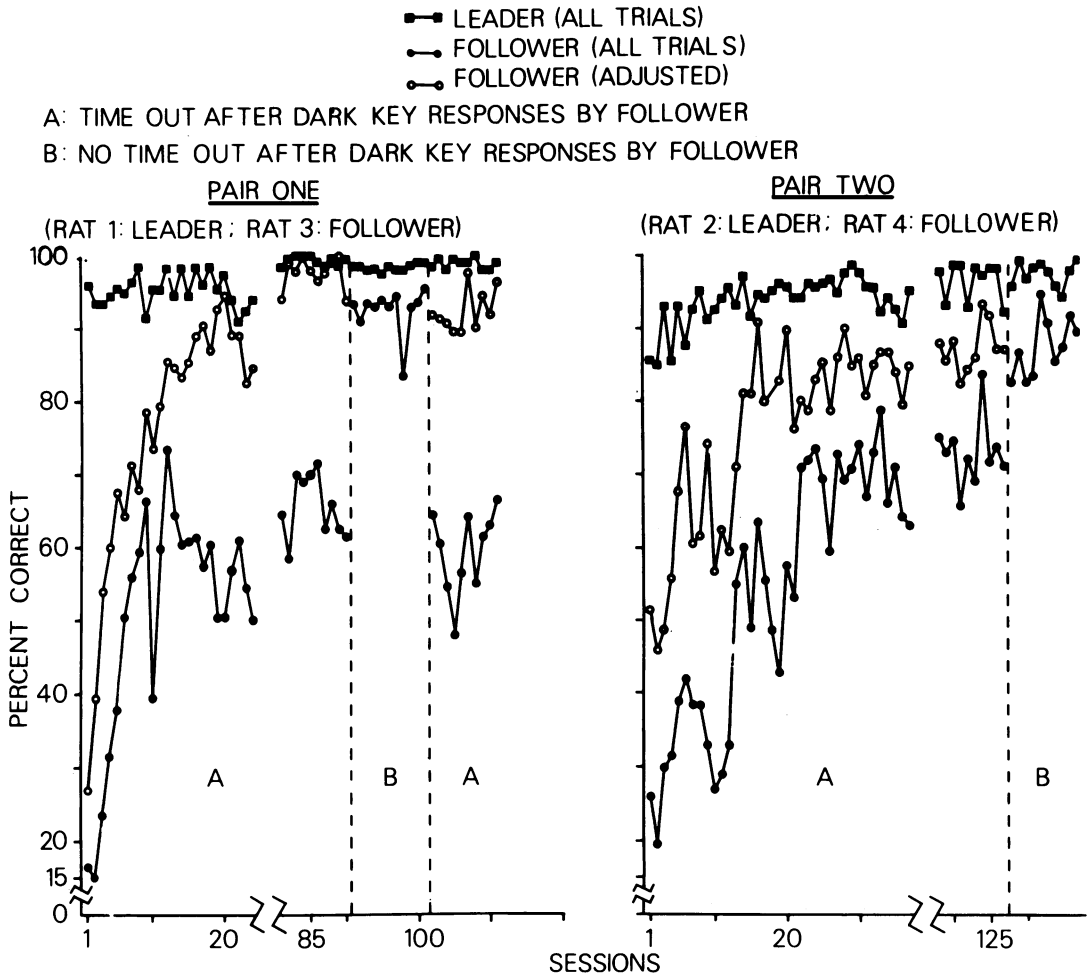

Fig. 4. Percent correct for leader and follower in Experiment 2 during acquisition and then during manipulation of the presence and absence of the timeout contingency for dark-key presses. Trials that were terminated by dark-key presses have been omitted in the adjusted percent correct.

represents completed follower trials, when the follower waited until the leader pressed the correct key; it thereby measures accuracy of following given a correct model to follow.

Both leaders ordinarily responded in the range of 90% to 98% correct. The overall percent correct for the followers, which now counted premature dark-key responses as errors, increased more gradually than in Experiment 1, requiring 6 sessions for Rat 3 and 13 sessions for Rat 4 just to reach 50% correct. Overall accuracy eventually reached 60% to 70% for Rat 3 and about 70% to 80% for Rat 4. The adjusted curve reveals that both followers eventually averaged over 85% correct when they waited for the leader to press the correct key. That is, given the signal to follow a correct key press (i.e., lighting of the follower's keys), Rats 3 and 4 responded correctly on 85% to 95% of the trials. As in Experiment 1, the 85% level was reached in 12 to 14 sessions.

None of the procedures to reduce dark-key responses by the follower was effective, and the sessions when these manipulations occurred have been omitted from Figure 4, as indicated by the break in the X-axis. The data in Panel B show that it was merely the number of timeouts for dark-key responses that kept the overall percent correct below the adjusted measure. When the timeout contingency was removed, overall accuracy approximated the adjusted levels of about 95% for Rat 3 and 85% to 90% for Rat 4. Premature presses on the dark key averaged 34% and 15% of the total trials for Rats 3 and 4, respectively, over the last 20 sessions.

The dark-key responses could have occurred because control of follower responding by the leader also extended to the search period. Observation of three sessions for each follower revealed that 96% of Rat 3's and 91% of Rat 4's dark-key responses were on the same key that the leader was either currently pressing or oriented toward (head or paw within .5 inch of a key). These percentages are near the adjusted percent correct for these same sessions, i.e., the "A" condition after the break in the X-axis for Rat 3 or slightly before the break in the X-axis for Rat 4. The three investigators each observed one session for each rat and these three observations for each rat never differed by more than 9%. Thus, coordinated responding extended to dark-key

presses and it was likely a factor in reducing the control that the onset of the follower's keylights exerted over follower responses.

In fact, coordinated responding appeared to extend even to drinking from the water bottle at the back of the chamber. Although data were not taken, when one rat went to the back of the chamber and drank, she was usually followed by the other rat. Skinner (1962) also observed coordinated drinking in his pigeons. Coordinated drinking may have developed in part because the follower learned that the next trial did not start until the leader returned to the front of the chamber.

EXPERIMENT 3

This experiment analyzed the nature of the discriminative stimuli for accurate following. Although it seemed probable that the sight of the leader pressing one key or the other controlled the follower's responding, it was possible that auditory, tactile, or other complex stimuli controlled or contributed to the control of the follower's behavior. The major manipulation in this experiment consisted of using an opaque partition to separate the animals instead of the clear one, so that the rats could not see one another. If visual discriminative stimuli had controlled the follower's behavior, correct responding by the follower would be expected to decrease.

METHOD

Subjects

The rat pairs (1 and 3, 2 and 4) from Experiment 2 were maintained at 80% of their free-feeding weights.

Apparatus

The chamber was the same as in Experiment 2. An opaque partition was used in place of the clear Plexiglas partition during several phases to eliminate the visual stimuli.

Procedure

There was no interruption between the end of Experiment 2 and the start of Experiment 3. The basic procedure for each pair was the same as at the end of Experiment 2. Only follower Rat 3 had the timeout for dark-key presses. The clear and opaque partitions were alternated in a series of four ABA sequences. Following the first ABA manipulation, the
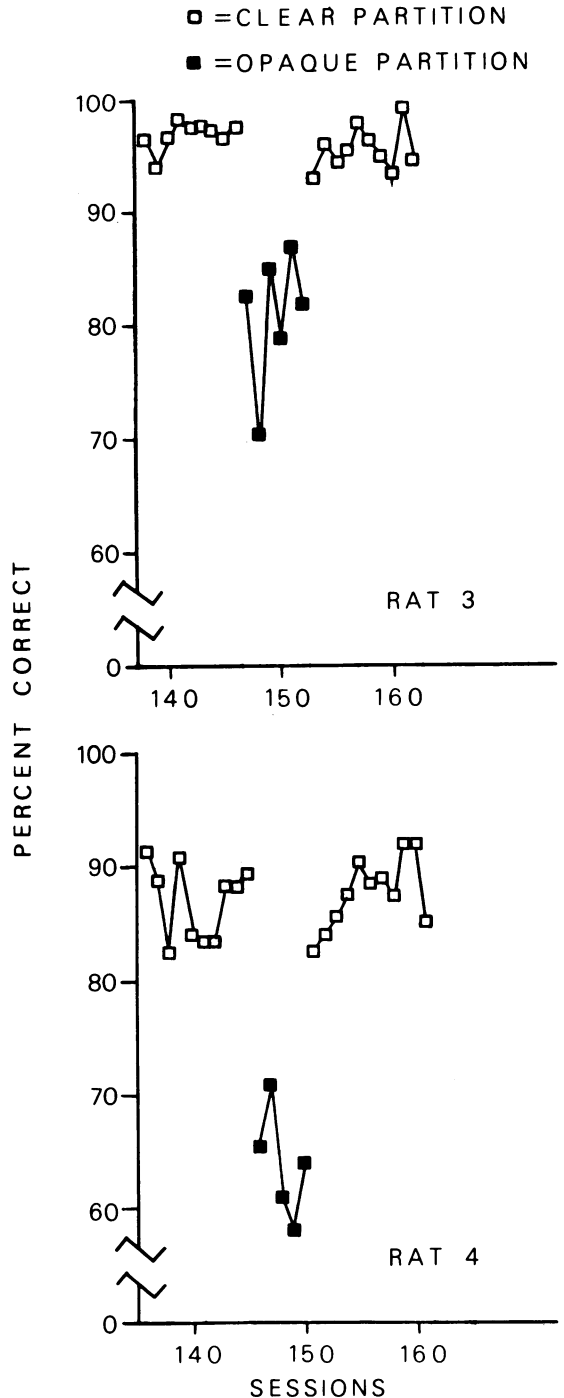
correction procedure and the Sonalert tone during the search period were removed. After a second manipulation of the partitions, white noise was presented throughout sessions to eliminate auditory stimuli. The intensity of the noise was 90 db for the third ABA manipulation, and it was increased to 106 db for the last ABA manipulation. The timeout procedure for dark-key responses was in effect for both followers at 106 db, and the correction procedure was reinstated for Rat 4 at 106 db, because of a decrement in upper-key responding that had developed in the previous ABA manipulation.

Opaque conditions were in effect for only a few sessions at a time after an initial long opaque condition. There were two reasons. First, it seemed likely that many sessions with the opaque partition might enhance stimulus control by previously ineffective nonvisual stimuli and thereby potentially affect performance in subsequent clear-partition phases. Second, at 106-db levels, it appeared that upper-key responding might extinguish altogether in the opaque condition, affecting performance in subsequent clear conditions.

RESULTS AND DISCUSSION

All percentages reported in the following graphs have been adjusted by omitting trials that were terminated because of dark-key responses. Figure 5 shows the follower's percentage correct with clear and opaque partitions for the first ABA manipulation without white noise. With the opaque partition blocking visual social stimuli, follower's accuracy decreased from about 95% to 80% (Rat 3) and from about 85% to 65% (Rat 4).

With the opaque partition, leader Rat 2's accuracy dropped from about 95% to 81%, but averaged 95% for leader Rat 1 despite an initial session at 82%. It should be realized, however, that the leader response that turned on the follower's keylights was correct, and accuracy was measured from that point on. Leader errors occurred in the remainder of the leader's response requirement, which was frequently larger (FR 4) with the opaque partition because of more frequent follower errors. It will be recalled that only two leader responses were required if the follower immediately responded correctly (one before and one after the follower's response), but all four

Fig. 5. Adjusted percent correct for followers in Experiment 3 when clear and opaque partitions were first alternated. Trials that were terminated by dark-key presses have been omitted in the percentages. The timeout procedure was not in effect for Rat 4.

responses were required if the follower did not respond right away or made an error.

Although the removal of the visual behavioral stimuli decreased follower accuracy, it did not decrease to chance (50%). This above-chance accuracy indicated control by stimuli other than visual behavioral stimuli. The most likely were auditory stimuli generated by the leader's behavior. Although there was masking noise of 86 db from the chamber and room ventilation fans, it may not have been sufficient to mask sounds produced by the leader's responding. For example, the position of the leader with respect to the keys may have been revealed by high vs. low sources of key-pressing noise. Another factor may have added to this control. Both leaders were observed consistently to respond first on the lower key. As will be shown in Figure 6, followers also responded more often on the lower key. Given auditory stimuli produced by the leader's responding, plus the lower-key preference, a timing stimulus may have also been available to the follower. A short delay between onset of sounds of the leader responding and onset of the follower's keylights may have served as a discriminative stimulus for a lower-key response, whereas a longer delay (while the leader first responded on the preferred but incorrect lower key) may have served as a discriminative stimulus for an upper-key response by the follower. To mask auditory stimuli between subject compartments, white noise was introduced. The opaque condition in the initial ABA manipulation with 90-db white noise (not shown) produced a larger decrease in accuracy than obtained without white noise, but overall accuracy was still not reduced to chance level and some recovery was evident from the first to the second condition with the opaque partition. For these reasons the white noise was increased to 106 db.

Figure 6 shows a session-by-session plot of the last 23 sessions with 106-db noise including sessions with the opaque partition interspersed after each of two series of 8 to 10 sessions with the clear partition. Accuracy of the follower on each key (rows) has been subdivided into three categories (columns) based on the follower's behavior on the previous trial: (1) accuracy following a correct response, (2) accuracy when switching to the other key, and (3) accuracy following an error (either an incorrect response or a dark-key response). Analysis of the accuracy in these categories revealed that the opaque partition had a selective effect in reducing the accuracy in those categories where responding was most dependent on visual-behavioral stimuli. First, consider Rat 3 which did not have the correction procedure. Rat 3's strong preference for the lower key is indicated by the finding that Rat 3 pressed on that key when it was correct (averaged over 95%) during opaque as well as clear-partition conditions (second row of graphs). Hence, responses on the upper key should be the most sensitive measure of visual cues by the behavior of the leader if auditory cues have been eliminated by the 106-db noise. Accuracy on the upper key decreased from the 50 to 60% range with the clear partition to the 0 to 10% range (top row of graphs) when visual behavioral cues were eliminated by the opaque partition, as Rat 3 responded nearly exclusively on the lower key. Rat 4 also preferred the lower key, but she did respond more accurately on the upper key during the two 106-db opaque conditions than Rat 3, who responded exclusively on the lower key. It seemed likely that the correction procedure used with Rat 4 may have exerted some control over responding on both keys. First, the opaque partition did not have as large an effect on responses in the category "following errors on the upper key" (top row, third column for Rat 4), which suggests that Rat 4 learned a "lose-shift" response pattern. Thus, Rat 4 could respond predominantly on the lower key until an error was made and then switch to the upper key on the next trial. This did not occur for Rat 3. Second, the correction procedure may have prevented perseveration on the lower key when the opaque partition was in place, as indicated by about 20% correct on the upper key "following correct responses on the same key" (top row, first column) and a slight decrease in accuracy for lower-key categories (second row). The category that shows accuracy on the upper key after "switching from other key following a correct" response on the other (lower) key (top row, second column) is the measure that should be most sensitive to visual behavioral control if auditory cues are eliminated: It is not dependent on other nonsocial factors such as key preference and the correction procedure, and it requires switching from
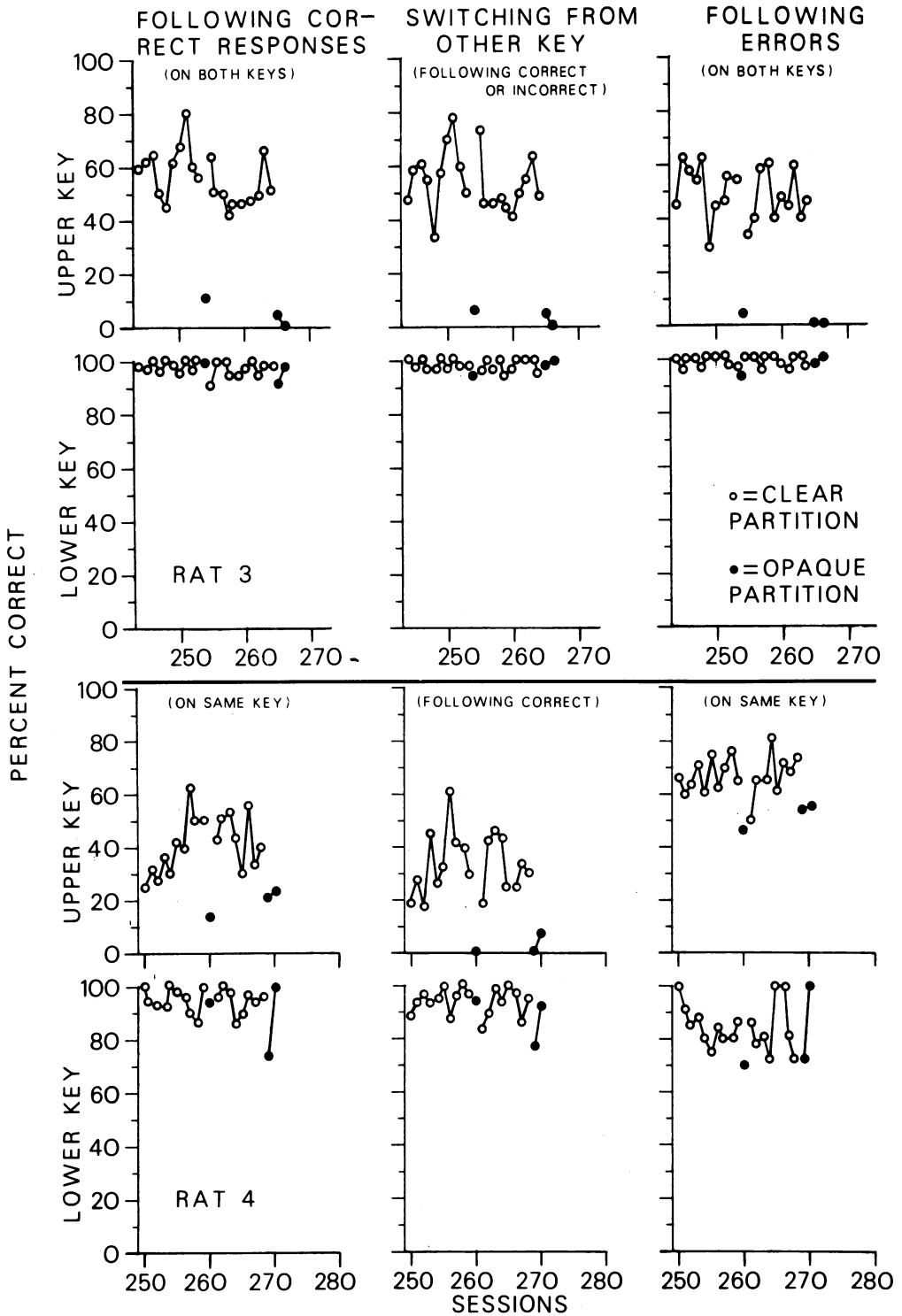
Fig. 6. Adjusted percent correct in six categories for both rats in Experiment 3. The analysis includes consecutive sessions with 106-db white noise when clear and opaque partitions were alternated. Categories were determined by the follower's behavior on the previous trial and whether the upper (top graph) or lower (bottom graph) key was correct on that trial. The differences in the categories between the two rats (indicated in parentheses) were necessary because Rat 3 did not have the correction procedure and Rat 4 did.

the preferred to the nonpreferred key. Rat 4 was correct on less than 5% of these trials with the opaque partition but averaged 34% with the clear partition. This category can also be considered in terms of a signal-detection analysis. For example, without the partition both Rats 3 and 4 rarely pressed the upper key when the leader pressed the lower key, $P(R_u/S_l)$. This can be seen in the small deviations from 100% correct for the lower key without the partition (second row, second column for each rat). Hence, the sight of the leader pressing the upper key as opposed to the lower key increased the average conditional probability of an upper-key response, $P(R_u/S_u)$, to .54 (R-3) and .34 (R-4) from the average conditional probability of an upper-key response given the sight of the leader pressing the lower key, $P(R_u/S_l)$, of .01(R-3) and .06(R-4).

The combined or overall accuracy for both keys with the clear partition and 106-db noise averaged 80% for Rat 3 and 70% for Rat 4. Both followers averaged about 55% with the opaque partition and 106-db noise. The leader's accuracy averaged about the same across opaque and clear conditions with 106-db white noise. For leader Rat 1, accuracy was about 93% with both partitions and about 90% for leader Rat 2.

It is doubtful that the effects of the opaque partition with 106-db noise could be accounted for by a general disruptive effect of the noise per se. First, accuracy was higher with the clear partition than with the opaque partition with the same level of noise. Second, there was no indication that the noise per se had any disruptive effect on other visual discriminations. The major effect of raising noise level with rats has been the increase in response rate observed with a pulsed tone of 100 db (e.g., Pierrel, Sherman, Blue, & Hegge, 1970; Raslear, 1981). The 106-db noise in the present experiment, however, was continuous and there was no change in time to complete the trial. In fact, the percentage of trials terminated by premature dark-key responses with the clear partition in place (i.e., a nonsocial visual discrimination of keylights on and off) either decreased from 34% (Rat 3) without white noise (last 20 sessions of Experiment 2) to 9% by the last 20 sessions of Experiment 3 with 106-db white noise or remained the same at 14% (Rat 4). Also, leader accuracy (i.e., a visual position discrimination to respond on same key or other

key) remained constant across no noise and noise conditions in the range of 90 to 98%.

EXPERIMENT 4

Both followers in Experiment 3 had acquired accurate responding before the white noise eliminated auditory cues. Hence, some question remained concerning the importance of the auditory stimuli to learning accurate following. Had both visual and auditory stimuli served as discriminative stimuli during acquisition? Or had visual stimuli controlled acquisition, with auditory stimuli becoming discriminative only after the initial condition with the opaque partition that had eliminated visual but not auditory cues? Experiment 4 studied acquisition without auditory cues.

Experiment 4 also provided a longer evaluation of the effects of the opaque partition.

METHOD

Subjects

Two naive rats (R-7 and R-8) served as followers with leader Rats 2 and 1, respectively. Rat 6 served as Rat 7's leader for the first 10 sessions but was replaced by Rat 2, because Rat 6 did not respond for long periods. All rats were maintained at about 80% of their free-feeding weights.

Apparatus

The apparatus was the same as in Experiment 3.

Procedure

After magazine and key-press training, each naive follower was paired with its leader and run in the basic procedure with the correction procedure and the timeout for dark-key responses. The 106-db white noise was presented continuously throughout all sessions. After both followers acquired a stable level of accuracy with the clear partition, the clear and opaque partitions were alternated in an ABAB manner with the first opaque-partition phase lasting 3 to 4 sessions and the second lasting 10 to 13 sessions.

RESULTS AND DISCUSSION

Both followers required at least three times as many sessions to reach asymptotic accuracy levels as did the four rats previously trained without white noise. Figure 7 shows that Rat 8

reached about 85% correct within 45 sessions, whereas Rat 7 averaged about 75% correct by Session 50. Rats trained with white noise never quite reached the maximum no-noise accuracy levels of previous rats (90% to 95%), but only reached the accuracy levels of Rats 3 and 4 with 106-db noise in Experiment 3. These data suggest that the auditory stimuli available to previous followers affected speed of acquisition and maximal level of accuracy.

The two manipulations of the opaque partition shown in Figure 7 indicate that visual behavioral stimuli were effective, but the above-chance accuracy of 55% (Rat 7) to 65% (Rat 8) with the opaque partition also indicates the effects of other factors.

Figure 8 categorizes the follower's accuracy on each key (rows) in terms of the follower's behavior on the previous trial (columns). First, the figure shows that the correction procedure reduced perseveration on the lower key when
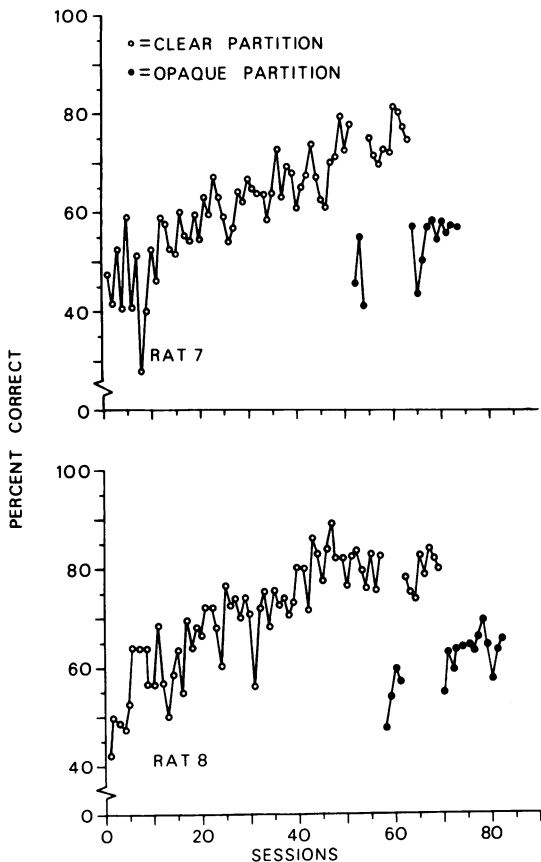

Fig. 7. Adjusted percent correct for the followers in Experiment 4 when 106-db white noise was in effect throughout the experiment.

the opaque partition was present; preference for the lower key with the opaque partition in place was not as pronounced as in Experiment 3. This can be seen by the higher percent correct on the upper key (top row of graphs for each animal) and the lower percent correct on the lower key (bottom row) than obtained in Experiment 3 with the opaque partition. However, the preference was still evident. Lower-key accuracy was higher than upper-key accuracy in nearly every category. Second, Figure 8 shows that the above-chance accuracy with the opaque partition may be accounted for in part by responses on trials following an error (third column). Rat 8 learned the "lose-shift" response pattern forced by the correction procedure. In the second series of sessions with the opaque partition, Rat 8 averaged 70% correct following an error on the upper key (top row, third column for Rat 8). Figure 8 also suggests that Rat 7 may have learned that if a key was correct once, it might be correct again. The random-probability generator often allowed several trials with one key correct. The category for a response on the same key following a correct response on that key indicates that Rat 7 attained better-than-chance accuracy on the upper key (top row, first column) with the dark partition by staying with the upper key if it had been correct on the previous trial.

The category showing the biggest difference between clear and opaque conditions was switching to a new key following a correct response on the other key (second column). This is also the category that should be most dependent upon visual behavioral stimuli when auditory stimuli are eliminated, because it is not dependent on other factors such as the correction procedure or the likelihood that the same key would be correct, and it goes counter to key preference in the case of switching to the upper key (top row, second column for each animal). This effect was also clear when this latter category was considered in terms of a signal-detection analysis. Without the partition, neither Rat 7 nor 8 pressed the upper key often when the leader pressed the lower key, $P(R_u/S_l)$. This can be seen in Figure 8 in the relatively small deviations from 100% correct for the lower key without the partition (second row, second column for each rat). Hence, in Experiment 4, the sight of the leader pressing the upper key as opposed to the lower key increased the average conditional probabil-

FOLLOWING CORRECT
ON SAME KEY

FOLLOWING CORRECT
AND SWITCHING FROM
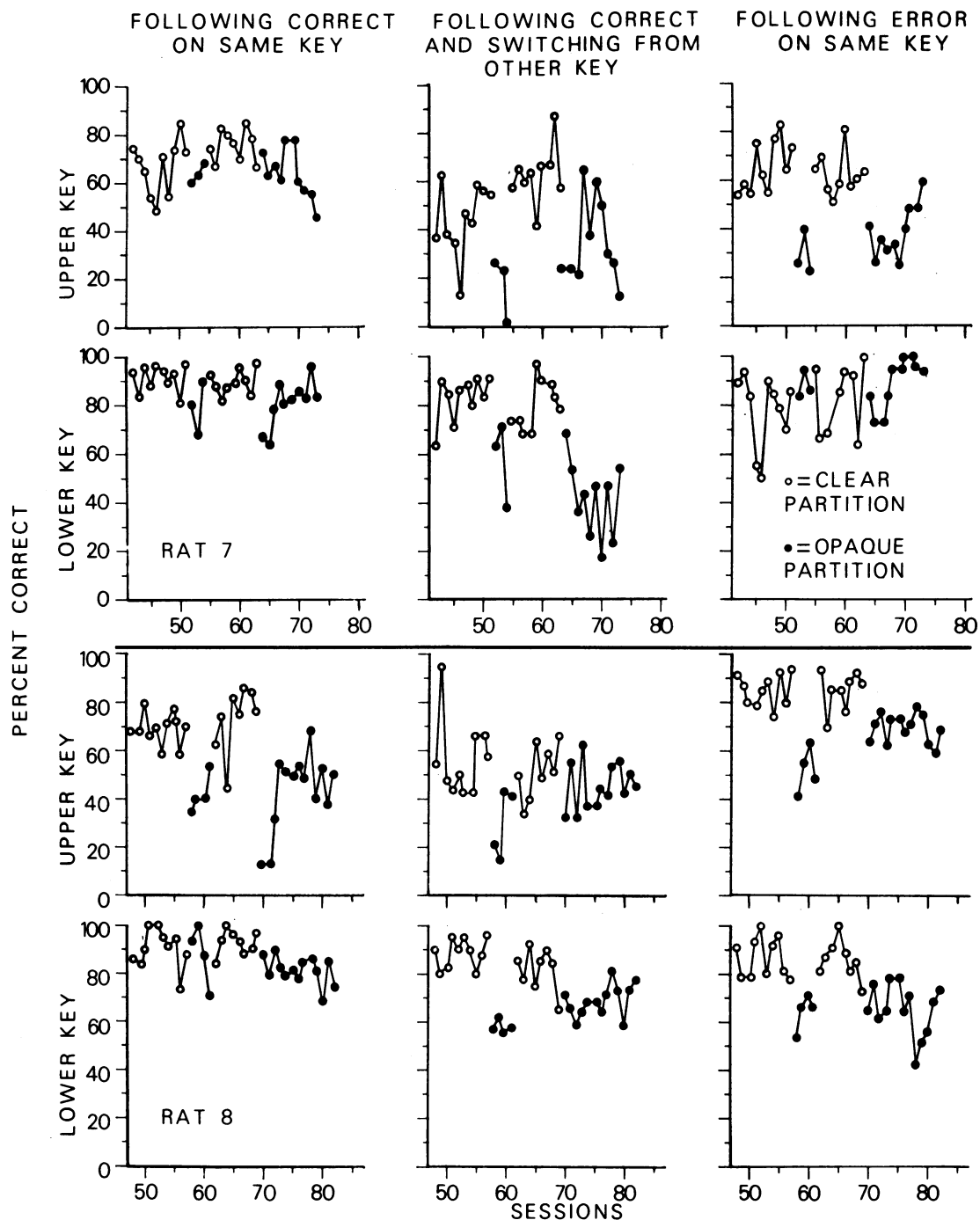OTHER KEY

FOLLOWING ERROR
ON SAME KEY

Fig. 8. Adjusted percent correct in six categories for both rats in Experiment 4. The analysis includes consecutive sessions at the end of Experiment 4 when clear and opaque partitions were alternated. Categories were determined by the rat's behavior on the previous trial and whether the upper (top graph) or lower (bottom graph) key was correct on that trial.

ity of an upper-key response, $P(R_u/S_u)$, to averages of about .54 (R-7 and R-8) from the average conditional probability of an upper-key response given the sight of the leader pressing the lower key, $P(R_u/S_l)$, of .18(R-7) and .14(R-8).

In summary, stimuli other than the sight of the leader pressing one key or the other did contribute to response accuracy. The previous figure (Figure 7) showed that these additional stimuli maintained the combined accuracy for both keys at about 7% (Rat 7) and 14% (Rat 8) above the 50% chance level to be expected had the rats had no discriminative stimuli. The visual behavioral stimuli increased response accuracy about another 17% (Rat 7) and 15% (Rat 8), as shown by Figure 7. Both rats did, then, learn to match to a visual behavioral sample ("follow") without the auditory stimuli but, as indicated in Figure 8, they also learned cues provided by the procedure, such as the correction procedure and the likelihood that the probability generator would designate one key as correct for several successive trials.

Leader accuracy in Experiment 4 was similar to that obtained in the previous experiments. Rat 1 (Rat 8's leader) averaged about 96% correct with clear and opaque partitions, and Rat 2 (Rat 7's leader) averaged 92% with the clear partition and 84% with the opaque one. Rat 6, which led for the first 10 sessions, averaged 87% correct. For the sessions in Figure 8, trials prevented by dark-key responses of the follower averaged about 9% and 17% with the clear partition for Rats 7 and 8, respectively, and about 15% and 7% with the opaque partition.

GENERAL DISCUSSION

Our initial goal was to study acquisition of visual discriminative control by the behavior of another rat using a simple automated procedure. We modified the basic procedure described by Skinner (1953, 1962) so that (1) a leader or a follower role could be assigned consistently to an animal, (2) the social stimulus was only where the leader responded instead of when and where, and (3) the social stimulus was restricted to the visual sense modality. We soon discovered that what appeared to be obvious visual control by the behavior of the other animal was affected by other types of behavioral and nonbehavioral stimuli.

The initial problem was to clarify who was leading whom, because on some trials in Experiment 1 the follower responded before the leader pressed the correct key. To ensure that the leader's responding on the correct key was the visual stimulus, in Experiment 2 premature responses by the follower terminated its portion of the trial and trials with premature responses were excluded from the calculation of accuracy of authorized following (adjusted accuracy). As in Experiment 1, the followers reached an 85% level of accurate following within 14 sessions, and visual observation revealed that even the premature responses were on the same key as the one on which the leader was either currently pressing or oriented toward.

The next issue was whether or not the behavior of the follower was in fact under the control of a visual behavioral stimulus. The obvious test was to prevent the sight of the leader responding by placing an opaque partition between the animals. The opaque partition reduced accuracy but the higher-than-chance levels of accuracy indicated there were other controlling stimuli. Additional analyses revealed that these other sources of control were of two types. First, there were nonsocial aspects of the procedure itself that could result in above-chance accuracy. The lower key was preferred, possibly because it was closer to the food tray and the grid floor. Because there were more responses on the lower key, a higher percentage of correct lower-key trials was detected by the follower. The correction procedure also affected accuracy. Analysis of percent correct following errors revealed that some followers learned to shift to the other key following an error cue; they were particularly likely to shift to the upper key following an error on the preferred lower key. There was also some indication that the rats learned to perseverate on a key when a press on that key had been reinforced on the previous trial (see Morgan, 1974, and Terman, 1981, for analyses of related data in nonsocial procedures). Hence, a pattern under nonsocial control was to stay with the preferred lower key until an error and then shift to the upper key for several trials before returning to the lower key. None of this required social cues.

Second, auditory cues were a source of nonvisual cues. It was assumed that the 86-db masking noise from the two fans was sufficient to mask any experimental sounds. However, even if the follower could not hear exactly which key the leader pressed, the temporal pat-

tern of auditory stimuli could have provided cues, because the leader ordinarily pressed the lower key first. The sound of the leader's responding without illumination of the follower's keys could signal that the upper key was correct, whereas illumination of the follower's key soon after the sound of the leader's responding could indicate that the lower key was correct.

The strongest indicator of visual control by the behavior of the leader was the category of switching to a new key after a correct response on the other key, particularly when the other key was the preferred lower key. The cues for this response had to be either visual or auditory cues from the other animal, because it could not be dependent on other factors such as the correction procedure, and it was counter to key preference in the case of switching to the upper key. White noise plus the opaque partition reduced accuracy for this category far below chance. The higher accuracies with the 106-db noise and the clear partition reflect visual control by the behavior of the leader, because that was the only possible stimulus for this category when auditory cues were eliminated by the 106-db white noise.

Experiment 4, with 106-db noise from the outset, revealed that rats could learn to follow on the basis of only visual cues of the leader's behavior, but that acquisition was markedly slower and lower asymptotic levels of accuracy were reached than when auditory cues were also available. These results were in agreement with Experiment 3, which had previously revealed lower accuracy after auditory cues had been eliminated.

The auditory stimuli were probably social also. The focus of the present experiments, however, was on control by behavioral stimuli, and the main difference between behavioral and nonbehavioral stimuli is the greater variability of stimuli that are dependent on the behavior of another animal as opposed to nonsocial stimuli that are tightly controlled by the equipment. Visual stimuli were selected as more representative of behavioral stimuli because of their greater co-variation with behavior than auditory stimuli such as sounds of key pressing, which could be in part determined by the equipment.

As indicated earlier, the literature on social behavior contains examples of apparent con-

trol by appropriate social behavior that may be questioned. There have been two major sources of possible artifactual control—discriminative control by nonsocial stimuli and discriminative control by behavior of the other animal that is not appropriate to the social procedure under investigation (see reviews by Hake & Olvera, 1978; Hake & Vukelich, 1972). As an example of the problem of nonsocial control, consider the human cooperation studies of Lindsley (1966). Coordinated responding, defined as one subject's responding within .5 sec of the other subject, could have been under the discriminative control of the behavior of the other subject or under the control of a contingency on high rate. High and steady response rates by both subjects would have produced a moderate number of reinforcers without regard to the behavior of the partner. Several studies (Brotsky & Thomas, 1967; Schmitt & Marwell, 1968; Vogler, 1968) suggest this was the case for some high-rate subjects.

The second potential source of artifactual control, discriminative control by behavior of the other animal that is not appropriate to the procedure under investigation, may have been a factor in Daniel's (1942) early study of cooperation in rats. One rat ate from a food cup while a second rat made the seemingly cooperative response of remaining on a platform and thereby preventing shock to the grid floor where the food cup was located. The rats learned to exchange positions. In a replication of the Daniel study (1942), Marcucella and Owens (1975) observed that the rat on the platform frequently stretched to and touched the rat at the food cup. Occasionally, the rat left the platform and both rats were shocked. This raised the possibility that the rat at the food cup learned to return to the platform to avoid shock when touched by the rat on the platform. When Marcucella and Owens enlarged the chamber so that the rat on the platform could not touch the eating rat, mutual role shifts dropped to near zero. These studies suggest that the behavior that served as the discriminative stimulus in the original Daniel study was a nudge from the rat on the platform but that this stimulus signaled an individual avoidance contingency rather than cooperative production of food reinforcers (Marcucella & Owens, 1975).

Neither the social-emergent position that behavioral stimuli are unique such that they require separate laws, nor the reductionistic position that they are the same as nonsocial stimuli and therefore do not require any separate treatment, seems warranted (see discussions of these views by Lindsley, 1966; Weingarten & Mechner, 1966). The fact that behavioral stimuli have not been controlled or manipulated as have other nonsocial stimuli in the experimental analysis of behavior (see Danson & Creed, 1970) indicates that the latter view is common. The present results and those of Danson and Creed (1970) and Millard (1979) suggest that behavioral stimuli do differ from nonbehavioral stimuli to the extent that (1) behavioral stimuli are more variable than nonsocial stimuli, since they are not as easily controlled with respect to onset, offset, and consistency from one presentation to the next (e.g., Danson & Creed, 1970), and (2) behavioral stimuli are usually operative in complex discrimination procedures involving nonbehavioral as well as behavioral stimuli and the two must be disentangled before the role of behavioral stimuli can be assessed. In fact, these studies would suggest that future research on social interactions such as cooperation and competition should provide training and/or testing on control by the appropriate behavior of the other subject rather than assuming that such control exists, as has frequently been the case. Further studies of social behavioral stimuli are needed to determine how specific behavioral stimuli can be disentangled from other behavioral and nonbehavioral stimuli and to determine how and which behavioral stimuli can guide different types of social interactions (e.g., competition, cooperation, trust).

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