

STIMULUS CONTROL OF SCHEDULE-INDUCED ACTIVITY IN PIGEONS DURING MULTIPLE SCHEDULES

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Stimulus control of schedule-induced general activity was demonstrated with pigeons using multiple schedules of response-independent food delivery. In Experiment 1, the introduction of food during a multiple variable-time 30-second variable-time 30-second schedule produced a tenfold increase in activity above the no-food baseline. Each pigeon developed stable differential activity rates during the components (correlated with red and green lights) of a multiple variable-time 30-second extinction schedule. Lengthening the extinction component from 1 to 7 minutes increased the rate differences and produced a reliable pattern of responding during S⁻ (the stimulus correlated with extinction): Activity rate was high immediately following the change from S⁺ (the stimulus correlated with variable-time 30-second) to S⁻, then decreased abruptly and remained low throughout the middle of the interval, and subsequently showed a positively accelerated increase until the stimulus changed to S⁺. In Experiment 2, three pigeons were exposed to a mixed variable-time extinction schedule prior to a multiple variable-time extinction schedule. Auditory rather than visual stimuli were used to determine the generality of Experiment 1 results. The multiple- versus mixed-schedule results indicated that stimulus control of activity occurred for two of the birds, but rate differences between S⁺ and S⁻ were much less than those demonstrated with visual stimuli. A direct comparison of visual and auditory stimulus control in Experiment 3 supported this conclusion. These parallels between the stimulus control of reinforced responding and that of schedule-induced activity suggest that the stimulus control of induced activity may be a factor in operant stimulus control.

Key words: schedule-induced behavior, visual stimulus control, auditory stimulus control, multiple schedules, mixed schedules, general activity, pigeons

During operant discrimination training, reinforcement is dependent upon responding in the presence of S⁺ but not in the presence of S⁻. Several investigators (e.g., Bower & Grusec, 1964; Estes, 1948; Morse & Skinner, 1958) have demonstrated that a stimulus correlated with response-independent food presentation increases the rate of a food-reinforced operant that was acquired in the absence of and following exposure to the stimulus. This procedure of response-independent pairings between stimuli and rein-

forcement (S⁺) and nonreinforcement (S⁻) has been labeled "Pavlovian pretraining" (Staddon, 1972) and is typically part of a "transfer of control" design (Trapold & Overmier, 1972) in which the separately established Pavlovian stimuli are presented during opportunities for operant responding. Estes (1948) and Morse and Skinner (1958) assessed the influence of the Pavlovian conditioned stimulus (CS) in the course of extinguishing the operant response and demonstrated that the CS increased response rate. Bower and Grusec (1964) examined the effect of Pavlovian pretraining upon speed of learning an operant (lever pressing) discrimination involving the same stimuli; they found that the operant discrimination was learned faster by rats for which S⁺ and S⁻ were the same as in Pavlovian discrimination training than for rats for which the S⁺ and S⁻ stimuli were reversed.

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Bower and Grusec concluded:

Since neither S1 nor S2 was associated with lever pressing . . . their later effect on this response must be mediated through some other process, normally concomitant with acquisition of an operant discrimination, which modulates the operant output. This other process may be labelled variously as conditioned incentive motivation, hope or joy (in S^D) [S+] and depression or frustration (in S^A) [S-]. . . . It is further supposed that this modulating process is based upon the classical conditioning of respondents (and attendant emotions) to S^D and S^A. (p. 403)

The results of a recent Pavlovian pretraining experiment provide support for an explanation of this phenomenon based upon the mediation of classically conditioned respondents. Lovibund (1983) reported that a CS that elicited a consummatory response (jaw movement) facilitated operant responding on a variable-interval (VI) schedule and reinstated responding on a variable-ratio (VR) schedule; an inhibitory CS blocked facilitation of responding by the excitatory CS but did not affect operant responding when presented by itself. Lovibund suggested that previous findings of suppression of operant responding by an excitatory CS (e.g., Azrin & Hake, 1969; Soltysik, Konorski, Holownia, & Rentoul, 1976) may have derived from the CS eliciting responses that interfered with the performance of the operant response (see Karpicke, 1978), such as food-magazine approach. In Lovibund's experiments, intra-oral reinforcement was used to minimize interference from peripheral responses.

An important problem in studies of Pavlovian-operant interactions is the response to be measured during Pavlovian training. The preparations necessary for measuring respondents often make the concurrent measurement of operant and respondent behavior difficult. For example, Lovibund (1983) was unable to measure conditioned jaw movement and lever pressing

simultaneously. A series of experiments has provided evidence that activity may be used as an index of classically conditioned excitement (e.g., Amsel & Work, 1961; Sheffield & Campbell, 1954; Zamble, 1967). These experiments demonstrated that the presentation of a stimulus that has been paired with food delivery increases activity level in deprived animals.

Trapold, Carlson, and Myers (1965) reported that response-independent delivery of reinforcers on a fixed-time (FT) schedule was followed by a significantly faster development of "scalloping" on a fixed-interval (FI) schedule. In an analysis of the effects of classical conditioning procedures on operant behavior, Zamble (1969) measured general activity changes in rats during FI and FT schedules. He demonstrated the expected scalloping of activity during Pavlovian training, and the transfer of this pattern to the operant response. He concluded that these results support the general two-process theory that appetitive conditioned stimuli can exert motivational control over instrumental responding (Bindra, 1968; Rescorla & Solomon, 1967). This view proposes that conditioned stimuli incite an incentive-motivational system that energizes operant responding. In the transfer test, Zamble reported significant differences between the patterns of results with bar pressing and with activity measures, and suggested that these differences may reflect an interaction between the hypothesized two factors, in which response-linked stimuli control the conditioned motivational factor. Thus, activity may predict the pattern of operant responding prior to the transfer test, but not correlate well with the operant response when measured concurrently.

Although general activity exhibited in response-independent schedules of stimulus presentation has traditionally been regarded as the manifestation of classically conditioned excitement (e.g., Zamble, 1969), a more recent and extensive line of research (Staddon, 1977) has focused on the nature of the activities that emerge when an animal is exposed to a schedule of periodic food. Such

experiments have typically examined single classes of behavior (e.g., schedule-induced polydipsia, schedule-induced aggression). Staddon and Simmelhag (1971) provided an exception to this in their analysis of the effect of response-independent food delivery upon several species-typical responses of pigeons (e.g., wing flapping, pecking, pacing). They suggested that the presentation of reinforcers directly induces a set of activities ("interim" responses) from which a few responses may later be selected by contingencies of reinforcement.

The present study provides a more molar analysis of the activities induced by response-independent delivery of food than is provided by Staddon and Simmelhag (1971). The behavioral measure of interest was general activity, rather than several separately measured responses, to obtain the most inclusive measure of the activating effects of reinforcement. This approach does not imply that the authors considered the specific responses comprising general activity to be of little interest. Rather, the present strategy was first to determine whether lawful relations would emerge when general activity was used as the behavioral measure; and then, once such functional relations had been established, to analyze specific component responses.

The experiments reported here were conducted to assess changes in schedule-induced activity with procedures similar to those typically used to analyze operant stimulus control. In Experiments 1 and 2, multiple and mixed schedules of variable-time reinforcer delivery and extinction were introduced to assess the effects of Pavlovian discrimination training upon schedule-induced activity. Foree and LoLordo (1973) have shown that a visual stimulus is more likely than an auditory stimulus to acquire control over food-reinforced responding in pigeons. In view of these effects, Experiment 3 provided a direct comparison of the effects of visual and auditory stimuli in the control of general activity.

EXPERIMENT 1

Experiment 1 employed a Pavlovian discrimination training procedure similar to that of Morse and Skinner (1958) to determine whether differential rates of activity would be induced by S+ and S-.

METHOD

Subjects

Three experimentally naive male White Carneaux pigeons were maintained at 80% of their free-feeding weights. A screw eye, affixed under ether anesthesia to the cranium with dental cement, was used to attach the pigeon to the activity-measuring device.

Apparatus

The experiment was conducted in a sound-attenuating, ventilated operant conditioning chamber. The bird's compartment measured 37.5 cm (height) by 30 cm by 30 cm. The inside walls and ceiling of the chamber were painted flat white. A 2.5-cm diameter response key was located 23 cm above the floor and central in the interface panel. The key could be operated by a minimum force of 0.15 N and was illuminated with either green light or red light by a stimulus projector located behind the panel. The keylights provided general illumination and also functioned as the multiple-schedule stimuli. The 5-cm by 5-cm opening of the grain hopper was in the center of the front panel and 8 cm above the floor. During hopper presentations, which consisted of 3-s access to mixed grain, chamber illumination came only from the hopper light. Activity was not recorded during the presentation of the food hopper or for the following 2 s. In this way, movement produced by eating and movements toward and away from the food hopper were excluded from the record. The activity-measuring device has been described in detail elsewhere (Hake, Enoch, & Kelly, 1971). The electrical signals from the device, based upon distance of head movement rela-

tive to the center of the ceiling of the cage, operated a pulseformer (Scientific Prototype 4053J) that delivered 30-ms pulses to the counters. Electromechanical scheduling and recording equipment was located in an adjacent room.

In each of the present experiments, activity was measured from the head. This choice was based on the observation that, with the possible exception of wing flapping, body movements of the pigeon are accompanied by head movement; in addition, the bird's head may be quite active (e.g., head bobbing or pecking) when there is little body movement. Therefore, measurement of head movement was taken as providing a more complete indication of activity than measurements from any other part of the body. Throughout each of the experiments it was a common practice of the first author to observe the topography of the pigeon's behavior during the experimental session. Summaries of these unquantified observations were immediately jotted down on the data sheet.

Procedure

Two-component multiple schedules were used in which one component was correlated with a red keylight and the other with a green keylight. For Bird 3 the red light accompanied the constant component and the green light accompanied the variable component. The stimuli were reversed for Birds 1 and 2. The keylight was the sole source of

chamber illumination because available evidence (Wasserman, 1973) suggested that a keylight alone would serve as a nonlocalized stimulus and thereby prevent autoshaped key pecking. Food presentations consisted of 3-s access to mixed grain. Table 1 shows the sequence of conditions and number of sessions in each condition for each bird. These conditions were used to evaluate the effects of three variables: (1) the introduction of grain in the hopper; (2) extinction in one component; and (3) changes in the duration of the extinction component. To assess the operant level of activity during the first condition, the empty food magazine was operated in both components according to a VT 30-s schedule. Before introducing the second condition, the birds were trained to eat from the food magazine. During Conditions 1, 2, 3, 5, 7, and 8, both components lasted 1 min. The duration of the variable component was increased to 7 min in the fourth and sixth conditions to provide an ABAB manipulation of duration of the extinction component.

Extinction probes were conducted in multiple VT 30-s EXT conditions to assess the effects of the different keylights when no food was available during either stimulus. Differential activity rates in the former S+ and S- during these probes would indicate that properties of the S+ itself, rather than simply excitation of behavior by food presentation, was inducing heightened activity in this component. The EXT probe also assessed whether the presentation of food was

Table 1
Schedule conditions and session durations for Experiment 1. The duration of each component is given in parentheses.

Condition	Schedules (s)	Session Duration	Number of Sessions		
			P1	P2	P3
1. (Operant Level)	mult VT 30 (1 min) VT 30 (1 min) ^a	60 min	10	10	9
2. (Baseline)	mult VT 30 (1 min) VT 30 (1 min)	60 min	25	23	18
3. (A)	mult VT 30 (1 min) EXT (1 min)	60 min	16	20	22
4. (B)	mult VT 30 (1 min) EXT (7 min)	120 min	20	21	21
5. (A)	mult VT 30 (1 min) EXT (1 min)	60 min	20	20	20
6. (B)	mult VT 30 (1 min) EXT (7 min)	120 min	18	21	23
7. (A)	mult VT 30 (1 min) EXT (1 min) ^b	60 min	—	—	20
8. (Baseline)	mult VT 30 (1 min) VT 30 (1 min)	60 min	15	15	15

^aThe grain hopper was empty throughout this condition.

^bOnly Bird 3 was exposed to Condition A at this point (see Figure 1).

-serving a discriminative function and thereby controlling differential rates of activity in S+ and S-. (Both of these issues were analyzed more thoroughly in Experiment 2 by comparing data from mixed and multiple schedules.) The extinction probe was conducted when the difference in the two components had stabilized, and was followed by at least three more sessions before conditions were changed. Session durations were 60 min for multiple VT 30-s VT 30-s conditions and for conditions with a 1-min EXT component. In conditions with a 7-min EXT component, session durations were increased to 120 min. This was done to increase the number of stimulus alternations and also to make the amount of food obtained within a session more comparable across conditions

of the experiment. During the first three conditions, the stimuli alternated according to a predetermined random sequence. Thereafter, stimuli were presented in strict alternation.

Stability was assessed by visual inspection of the data because it was unknown at the outset of the experiment to what extent it was possible to induce stable rates of general activity with VT schedules of food delivery. For each condition following Operant Level, there was a minimum of 15 sessions.

RESULTS AND DISCUSSION

Figure 1 presents response rates for Pigeons 1, 2, and 3 during the conditions of Experiment 1. Rates are reported in activity counts per minute, computed by dividing the

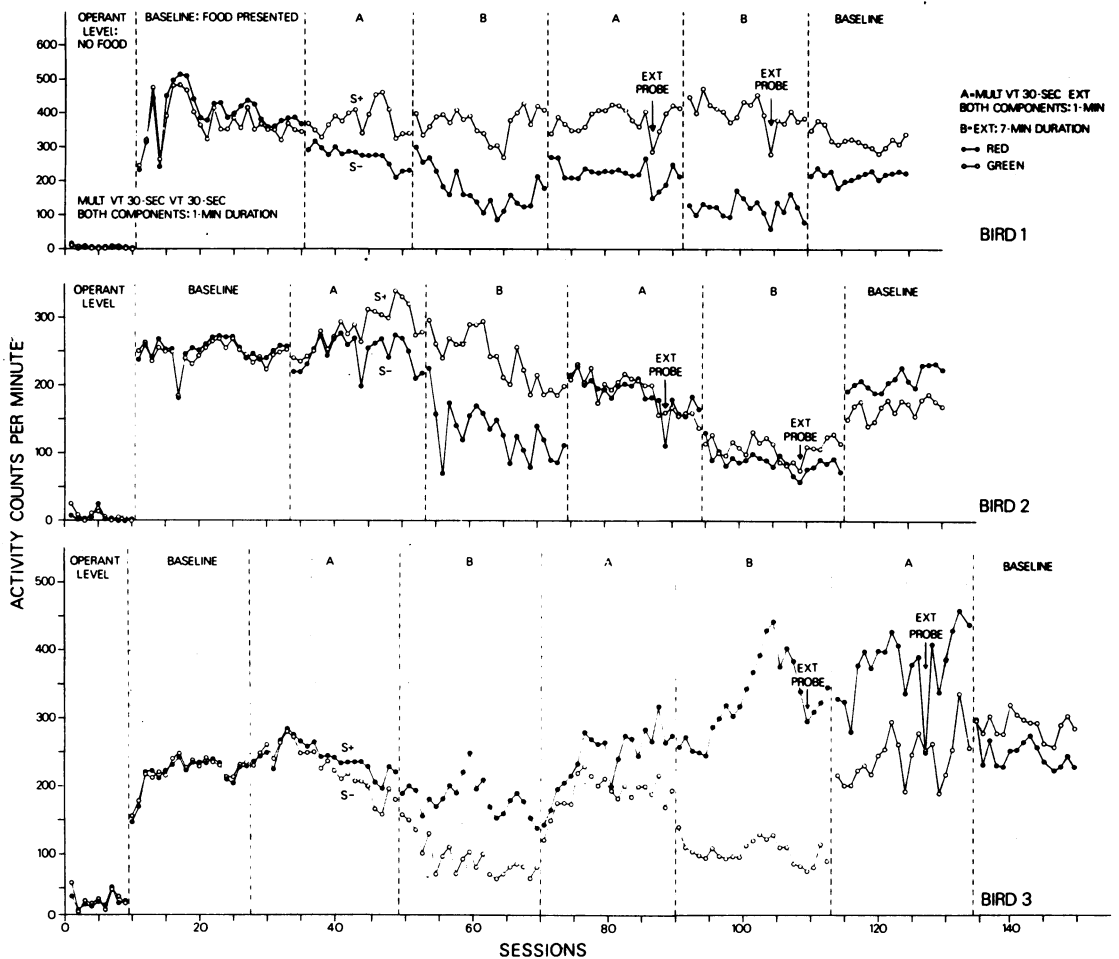


Fig. 1. Session activity rates for Pigeons 1, 2, and 3 during the conditions of Experiment 1.

number of activity counts during a component by the total component time. For all subjects, rate of activity was low during the Operant Level condition. However, the pigeons appeared to be awake and exhibited sporadic activity such as preening and ambulatory movement. With the introduction of food (multiple VT 30-s VT 30-s), the activity of each subject increased over successive sessions until stable rates developed. Each pigeon developed differential rates of activity in the presence of S+ and S- during the multiple VT 30-s EXT condition (Figure 1, first Panel A). Although differential rates of activity occurred in S+ and S- during the first exposure to this condition, the rate during S- was high considering that no food deliveries occurred during the interval. When the extinction component was lengthened from 1 to 7 min (Figure 1, first Panel B), the difference in rates in the components widened. For Birds 2 and 3, lengthening the S- component resulted in negative induction (i.e., decreased responding in the unchanged component of a multiple schedule with decreases in responding in the other component). For Bird 3 autoshaped pecking on S+ developed in this condition (e.g., during the final session, key pecking occurred at rates of 25 pecks/min during S+ vs. 2.1 pecks/min during S-). When the duration of the extinction component was changed back to 1 min (Figure 1, second Panel A), activity rates in S- increased for all three birds. For Bird 2, S+ and S- rates merged in this condition and differential rates did not develop. This seemed to be due to incipient autoshaping to S+ (Brown & Jenkins, 1968). Brown and Jenkins described the following progression of directed movements that resulted in the first peck: excited activity → orientation towards the key → approach → key contact. Unquantified observations indicated that a discrimination did exist for Bird 2 in the topography of the activities exhibited in S+ and S-. When the stimulus changed to S+, the bird oriented toward the key and remained looking at the key throughout S+, with some head bobbing. When S+ changed to S-, the animal always turned away from

the stimulus and began moving about the chamber. Inasmuch as Bird 2 eventually autoshaped to the keylight during S+, its behavior in this condition suggested that it was in the second stage of the progression described by Brown and Jenkins (1968).

With the reintroduction of the 7-min EXT component (Figure 1, second Panel B), S- rates again decreased for both Birds 1 and 3. For Bird 3, S+ activity rate increased as a result of an increase in rate of pecking at the S+ stimulus. As before, rate of key pecking was correlated with rate of activity, with the majority of pecks occurring during S+ (e.g., 173 pecks/min during S+ vs. 13 pecks/min during S- were recorded during the last session of this condition). Bird 2 exhibited negative induction with a marginal, but consistent, separation in S+ and S- activity rates. This marginal separation in rates appeared to reflect the same autoshaping behavior as in the previous condition (i.e., orienting to the stimulus throughout the S+ component with little head movement). In later sessions of this condition, Bird 2 was observed to make pecking movements toward the key ("air pecking"). Bird 1 also began air pecking toward S+ during this condition, with occasional pecks striking the key. In previous conditions, Bird 1 had exhibited head bobbing along the front panel throughout the S+ component, but this movement gradually became more and more directed toward the key.

Bird 3 was exposed to the 1-min EXT condition (Figure 1, third Panel A) before returning to multiple VT 30-s VT 30-s. As before, S- activity rate increased but the degree of stimulus control was maintained. During the final condition of the experiment (multiple VT 30-s VT 30-s), rate differences in the two components narrowed for Bird 1. For Bird 2, the rate of activity in both components increased and activity rate in the previous S- was higher than in the previous S+. Observations of Bird 2 revealed that the two stimuli induced different topographies of behavior: The previous S+ induced air pecking at the stimulus, but the previous S- induced pacing back and forth along the front

panel. The figure shows a reversal in activity rate induced by the former S+ and S- for Bird 3, as well as for Bird 2. During this condition, rate of key pecking for Bird 3 was not correlated with rate of activity. The following topography was observed for Bird 3: A burst of key pecking occurred each time the stimulus changed and also following each food presentation. Between food presentations, the subjects exhibited head movement back and forth in front of the stimulus with an occasional circle turn.

For all subjects (with the exception of the second extinction probe for Bird 3), activity rates in S+ and S- remained apart (if they had been apart) when the animals were exposed to extinction probes. Activity rates in S+ and S- merged for Bird 3 in the second extinction probe. However, there was stimulus control of key pecking (i.e., 80 pecks/min in S+ compared to 18 pecks/min in S-) during this extinction probe. Visual inspection of the data revealed that in all previous sessions of the condition, activity and key-peck rates for Bird 3 were positively correlated.

Figure 2 shows activity rates in each component plotted as a function of the time since component alternation for the first exposure to the 7-min EXT duration. Activity was recorded for successive 15-s subintervals during both S+ and S- for Birds 1 and 2. For Bird 3, activity was recorded for successive quarters of both stimuli (i.e., successive 15-s subintervals during S+ and successive 105-s subintervals in S-). Subinterval activity for Bird 3 was recorded differently because it was the first subject exposed to this condition. The development of a pattern in S- by this subject prompted a more precise analysis of the S- pattern for Birds 1 and 2. Each data point in Figure 2 represents the average of subinterval rates for the last 5 sessions of this condition. Each subject developed a different pattern of activity within the S+ component. During the 7-min EXT period, similar patterns of activity within the component developed for all three pigeons. Activity rate was high immediately following the change from S+ to S-, but was lower than

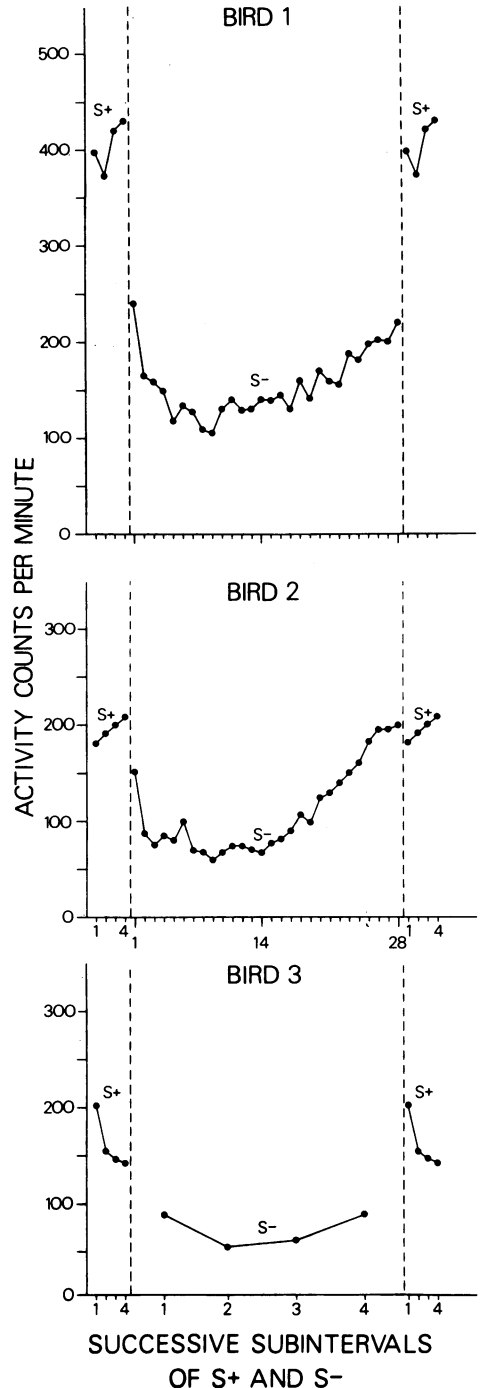


Fig. 2. Activity rates in successive subintervals of the components of the multiple VT 30-s EXT schedule of Experiment 1 (first exposure to 7-min EXT). Each data point represents the average of subinterval rates for the last 5 sessions of this condition. S+ subinterval rates are repeated to demonstrate more clearly the change in activity rate from the last subinterval of S- to the first subinterval of S+.

the rate in S+. It then decreased abruptly and remained low throughout the middle of the interval, and finally showed a positively accelerated increase until the stimulus changed to S+. Casual observations indicated that the following classes of behavior were typical of all subjects during S- when the extinction component was 7-min: turning away from S- at its onset, occasional preening and roosting during the middle of the interval, and orienting toward the stimulus late in the interval. As previously noted, for Bird 3 autoshaped pecking on the key-light developed during this condition, with the majority of pecks occurring in S+ (e.g., 25 pecks/min during S+ vs. 2 pecks/min during S- were recorded on the last day of this condition). The pattern of key pecking during S- was identical to the pattern of activity in S- shown by all three birds. Although Bird 2 developed only a marginal difference between S+ and S- rates during the second exposure to the 7-min extinction component (Figure 1, second Panel B), it exhibited the same pattern of activity in S- as in the first exposure, as did Birds 1 and 3.

When both components lasted 1 min (Figure 1, second Panel A), Pigeons 1 and 3 showed patterns of decreasing activity across the subintervals of S-, but Bird 2 exhibited monotonically increasing activity rates across the four subintervals. As in conditions with a 7-min EXT component, each pigeon developed a different pattern of activity within the S+ component.

These results indicate the following: First, the pigeons were relatively inactive until the introduction of food. Therefore, deprivation alone was not sufficient to induce activity in the experimental context. The large increase in activity when food was presented is consistent with Staddon and Simmelhag's (1971) observation that reinforcer presentation directly induces a set of general activities. Second, it is possible to establish a stable baseline rate of induced activity (across and within sessions) with VT schedules of food delivery. Third, the stimuli of a multiple VT 30-s EXT schedule with short component durations developed marginal control over

activity rates (Figure 1, first Panel A) during S+ and S-. That is, although differential rates of activity occurred in S+ and S-, activity rate during S- was high considering that it was never accompanied by food deliveries. Finally, when the extinction component was lengthened, the difference in rates in the two components widened (Figure 1, first Panel B) and reliable patterns of responding emerged during S- (Figure 2). The effects of lengthening the S- component seem to be due to the fact that when both components are short (1-min duration), "spill-over" activity in S- from S+ comprises a larger percentage of S-. This explanation was based on the finding that when the extinction component was lengthened (to 7 min), activity rate in the first part of S- was high relative to the rest of the S- interval. The increase in activity as the time for S+ neared developed gradually, thereby suggesting a temporal discrimination.

Experiment 1 demonstrated that Pavlovian discrimination training in the context of multiple schedules of response-independent food delivery results in the stimulus control of activity. Experiment 2 used auditory instead of visual stimuli in order to determine the generality of this phenomenon and to assess whether the results of Experiment 1 were attributable to autoshaping.

EXPERIMENT 2

Although differential activity rates accompanied S+ and S- in Experiment 1, changes in the stimuli were confounded with changes in the rate of food presentation. Therefore, the differential rates of activity during the two stimuli might have been due mainly to direct activating or reinforcing effects of food delivery, irrespective of S+ and S- stimuli. Experiment 2 assessed the contribution of the stimuli to the development of differential rates by exposing pigeons to a mixed VT EXT schedule prior to exposure to a multiple VT EXT schedule.

Hearst and Jenkins (1974) have defined sign tracking as "behavior that is directed toward or away from a stimulus as a result of

the relation between that stimulus and the reinforcer or between that stimulus and the absence of the reinforcer" (p. 4). The present experiment used auditory instead of visual stimuli to reduce the possibility of sign tracking and its resulting specific topography. According to Hearst and Jenkins, if sign tracking (e.g., autoshaping) is to occur, the stimulus must be localized so that behavior can be directed toward or away from it. In Experiment 1, S+ and S- were different keylight colors (i.e., red and green) and the keylight provided the sole source of chamber illumination. There was reason to believe that a keylight alone would function as a nonlocalized stimulus and therefore would not lead to autoshaped key pecking (Wasserman, 1973). However, with extended exposure to the procedure, all three birds in Experiment 1 eventually began pecking at S+ (the keylight) and turning away from S-. Therefore, to prevent sign tracking in the proposed study, nonlocalized auditory stimuli were used.

METHOD

Subjects

Three experimentally naive male White Carneaux pigeons were maintained at 80% of their free-feeding weights. As in Experiment 1, a screw eye was used to attach the pigeon to the activity device.

Apparatus

The apparatus was the same as in Experi-

ment 1 but the response key was covered. General illumination throughout each session was provided by two houselights centered at the top of the intelligence panel. Auditory stimuli were generated by a Mallory Sonalert that was centered on the ceiling of the chamber. The Sonalert produced an intermittent tone with equal on-off phases cycling at 2 pulses per second.

Procedure

In the absence of the tone, the pigeons were exposed to a series of four mixed schedules; the two components of each mixed schedule were presented in strict alternation. The sequence of conditions is shown in Table 2. During the first condition (Operant Level), the grain hopper was presented in both components according to a VT 30-s schedule, but it contained no grain. Prior to the second condition (mixed VT 1-min VT 1-min), the food magazine was filled and the birds were trained to eat from it. In all conditions following Operant Level, feeder presentations consisted of 4-s access to mixed grain. For each condition subsequent to Operant Level, one component of the mixed schedule remained unchanged; this constant component lasted 1 min and consisted of a VT 1-min schedule. The variable component was a VT 1-min schedule in Conditions 2 and 4; the food hopper was not presented (extinction) during Condition 3. The variable component lasted 5 min in all conditions. This duration was chosen for the

Table 2

Schedule conditions and session durations for Experiment 2. Throughout the experiment, the duration of the fixed component was 1 min and the variable-component duration was 5 min:

Condition	Schedules		Session Duration	Number of Sessions		
	Fixed Component	Variable Component		P4	P5	P6
1. (Operant Level)	mix	VT 30-s	48 min	6	14	6
2. (A)	mix	VT 1-min	48 min	14	11	10
3. (B)	mix	VT 1-min	90 min	19	20	14
4. (A)	mix	VT 1-min	48 min	10	12	10
5. (C)	mult	VT 1-min	48 min	13	14	13
6. (D)	mult	VT 1-min	90 min	22	23	20
7. (C)	mult	VT 1-min	48 min	7	7	10

^aThe grain hopper was empty throughout this condition.

variable component in order to minimize the effects of spill-over activity from the constant component (VT 1-min) when the variable component was EXT.

Conditions 5 through 7 were identical to Conditions 2 through 4 except that they were a series of multiple schedules instead of mixed schedules. One component of each multiple schedule was correlated with an intermittent tone (S1), and the other component was correlated with the absence of the intermittent tone (S2). S1 and S2 alternated. For Birds 4 and 5, one session of both Conditions 5 (multiple VT 1-min VT 1-min) and 6 (multiple VT 1-min EXT) was an extinction probe in which the stimuli alternated but the food hopper was not presented in either component. The extinction probe was introduced when the bird's activity had stabilized. The extinction probes were not used with Bird 6 because it did not exhibit differential rates in the two components of the multiple VT 1-min EXT condition.

Session durations were 48 min, except for conditions with an extinction component, in which session durations were increased to 90 min.

Conditions were changed only when there was no monotonic and/or sizable change for the last three sessions, for either S1 or S2 rates. A rate change between two consecutive sessions was judged "sizable" if the difference was greater than 20% of the 3-day mean. For all conditions except Operant Level, there were at least 10 sessions.

RESULTS AND DISCUSSION

Figure 3 presents response rates for Pigeons 4, 5, and 6 during the mixed and multiple schedules. Rates are reported in activity counts per min, computed by dividing the number of activity counts during a component by the total component time. During the Operant Level condition, rate of activity stabilized at less than 50 counts/min for all subjects. The mixed VT 1-min VT 1-min food schedule induced activity, which then increased from session to session until stable rates developed. During mixed VT 1-min EXT, no subject responded differentially

during the two components. However, the activity of Birds 4 and 5 did decrease during this condition. The reintroduction of reinforcement in the variable component (mixed VT 1-min VT 1-min) increased the birds' activity to previous levels.

Introduction of the multiple schedule stimuli (multiple VT 1-min VT 1-min) had little effect; activity stabilized at rates similar to those of the preceding mixed schedule. Both Birds 4 and 5 developed differential rates of activity in the presence of S+ and S- during the multiple VT 1-min EXT condition. As in the mixed VT 1-min EXT condition, negative induction occurred during the multiple VT 1-min EXT condition. Bird 6 did not develop differential rates in S+ and S- but there was some negative induction. For Birds 4 and 5, the final multiple VT 1-min VT 1-min condition was prematurely terminated following Session 7 due to mechanical problems with the activity-measuring device. However, activity rates of all animals in the previous S- stimulus were about equal to rates in the constant S+ stimulus.

Figure 4 shows activity rates in each component of the multiple VT 1-min EXT condition, plotted as a function of time since component alternation. Activity was recorded for successive 15-s subintervals during both S1 and S2. Each data point represents the average of subinterval rates for the last 5 sessions of the multiple VT 1-min EXT condition. Data for Bird 6 are not presented because neither differential rates nor a consistent pattern developed for this bird during S+ and S-. Bird 4 developed a pattern similar to that shown by Pigeons 1, 2, and 3 in Experiment 1, in which the multiple schedule stimuli were visual rather than auditory. Bird 5 developed a different pattern (Figure 4): Activity during the first subinterval of S- increased above the rate of the last subinterval of S+; during the next several subintervals of S-, activity rate decreased and then remained low until the onset of S+ at which time activity increased.

Extinction probes were conducted to assess the effects of S+ and S- per se, when no

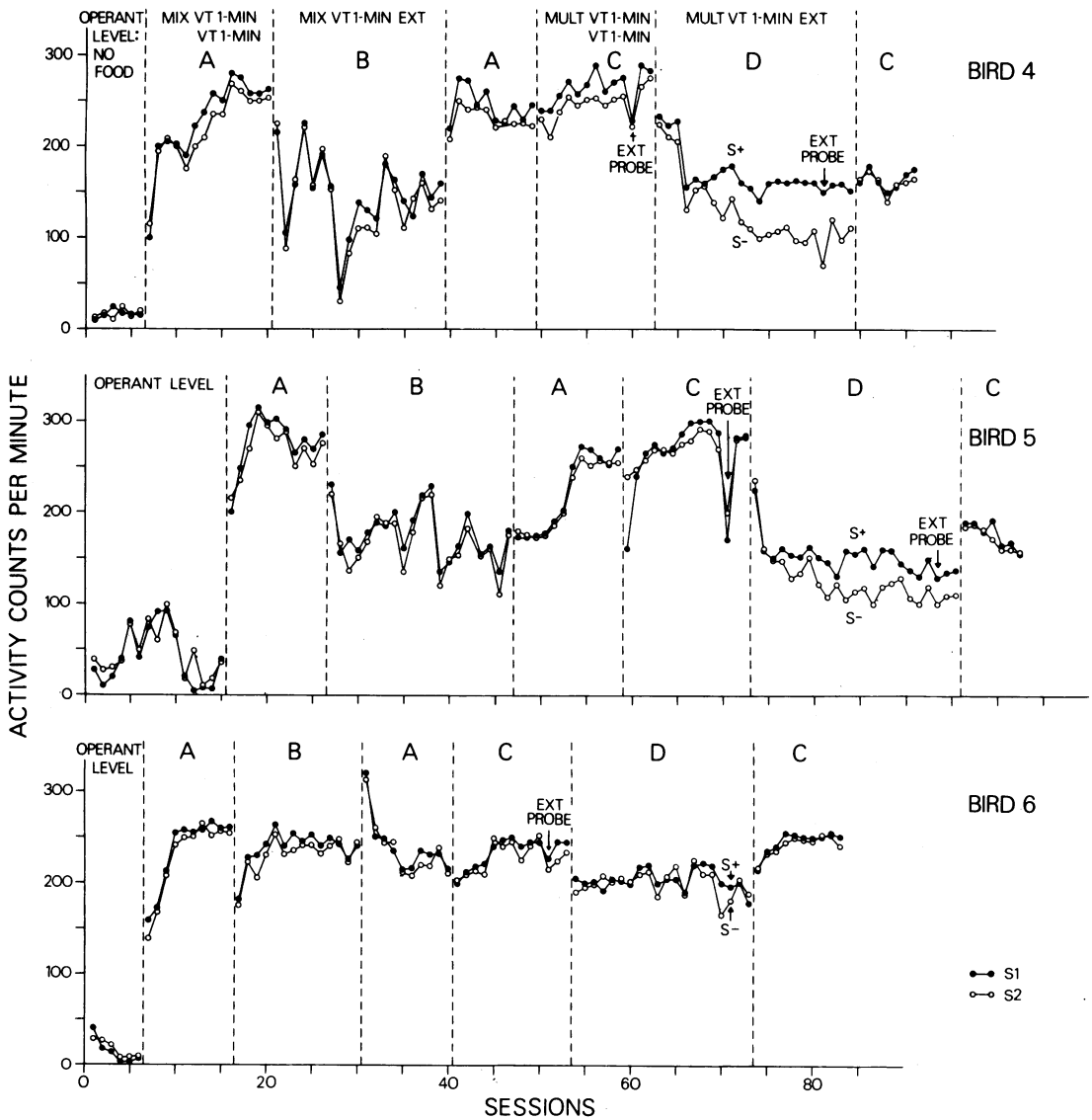


Fig. 3. Session activity rates for Pigeons 4, 5, and 6 during the conditions of Experiment 2.

food was available during either stimulus. For Birds 4 and 5, activity rates in both components decreased during the extinction probe conducted in the first multiple VT 1-min VT 1-min condition (Figure 3). Activity rates during S+ and S- remained apart when these birds were exposed to extinction probes in the multiple VT 1-min EXT condition; also, no significant decrease in S+ rate was shown for either bird.

As in Experiment 1, all three birds in Experiment 2 developed stereotyped responses during the VT 1-min schedule of food deliv-

ery. This induced stereotypy was similar for the three pigeons and remained the same throughout all conditions of Experiment 2: All three birds exhibited head movement and pacing back and forth along the front panel of the chamber. The only condition of Experiment 2 in which this stereotypic behavior did not persist throughout the session was multiple VT 1-min EXT. Bird 6 did not develop differential S+ and S- activity rates during this condition. However, a discrimination did develop for Bird 6: During S+, the previously described stereotypy

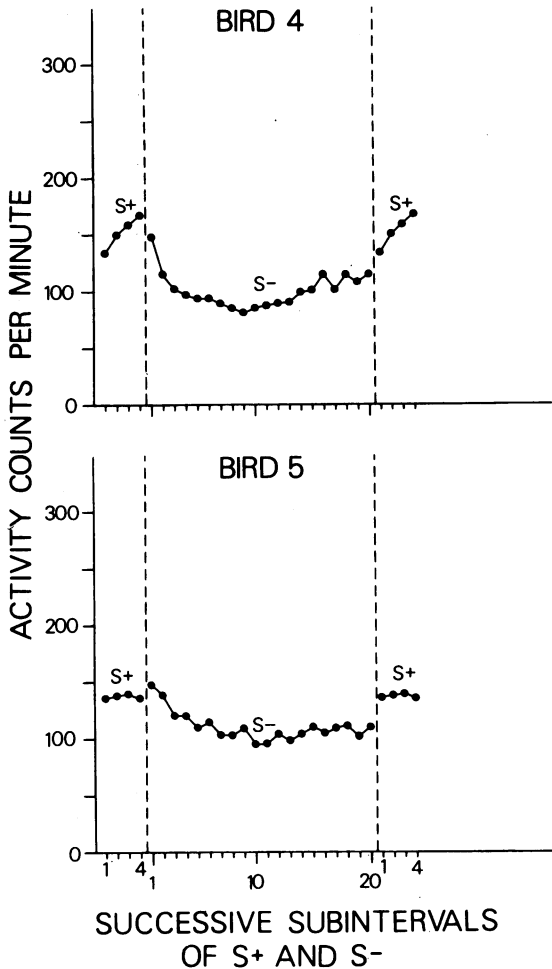


Fig. 4. Activity rates in successive subintervals of the components of the multiple VT 1-min EXT condition of Experiment 2. Each data point represents the average of subinterval rates for the last 5 sessions of this condition. S+ subinterval rates are repeated to demonstrate more clearly the change in activity rate from the last subinterval of S- to the first subinterval of S+.

predominated, but nonstereotypic behavior was interspersed with this behavior during the S- component (mostly during the middle of the interval). Birds 4 and 5 also exhibited a variety of activities during S- (e.g., preening, circle turning, roosting).

The main purpose of Experiment 2 was to determine whether auditory stimulus control of schedule-induced general activity could be demonstrated in multiple schedules of response-independent reinforcement. Both the extinction probes and the multiple- versus

mixed-schedule results indicate that stimulus control of activity occurred for Birds 4 and 5.

As in Experiment 1, the pigeons were relatively inactive until the introduction of food (multiple VT 1-min VT 1-min), which induced a steady rate of activity. All subjects exhibited overall negative induction of activity during both the mixed and multiple schedules when one component was changed to extinction. This reliable negative induction suggests that the overall frequency of food presentation also affected the rate of activity during S+.

The degree of stimulus control with the auditory stimuli appeared to be less than that demonstrated with visual stimuli in Experiment 1. This finding is not surprising considering "the well-known difficulty of establishing control over food-reinforced key-pecking in pigeons by an auditory stimulus" (Mackintosh, 1977, p. 485). For example, Foree and LoLordo (1973) found that a visual stimulus is more likely than an auditory stimulus to acquire control over food-reinforced treadle pressing in pigeons. However, the fact that the schedule parameters were not identical in Experiments 1 and 2 could also be a factor. For example, food presentation during S+ was more frequent in Experiment 1 (VT 30-s) than in the second experiment (VT 1-min). Also, the pigeons in Experiment 1 were exposed to from 16 to 22 sessions of discrimination training prior to the lengthened duration of the S- component. Thus, the larger differences in S+ and S- rates in Experiment 1 could have been simply the result of prolonged training. To resolve these questions, Experiment 3 provided a direct comparison of visual and auditory stimulus control.

EXPERIMENT 3

Several empirical issues were raised by the results of Experiment 2. In Experiment 3, Birds 4, 5, and 6 were exposed to discrimination training with nonlocalized visual stimuli but with the same schedule parameters as those of Experiment 2—an attempt

to answer the following questions: First, would Bird 6 (no discrimination with auditory stimuli) exhibit differential rates during S+ and S-? Second, would Birds 4 and 5 show greater differences in S+ and S- rates than those acquired previously with auditory stimuli? Finally, would the auditory stimuli acquire stronger stimulus control over activity than was demonstrated in Experiment 2 if the pigeons were exposed to auditory discrimination training following visual discrimination training?

METHOD

Subjects

Birds 4, 5, and 6 continued as experimental subjects.

Apparatus

The apparatus was the same as in Experiments 1 and 2. The response key remained covered. To make the visual stimuli less localized than in Experiment 1, houselights rather than keylights were used. During the multiple schedule conditions with visual stimuli, the two houselights were alternately illuminated red or green, in synchrony with component alternations. In all other conditions the two (white) houselights were continuously illuminated except during grain presentations.

Procedure

The sequence of conditions for all subjects is shown in Table 3. The mixed VT 1-min EXT and multiple VT 1-min EXT (auditory stimuli) conditions were identical to those of Experiment 2. One component of the multiple VT 1-min EXT (auditory stimuli) condition was correlated with an intermittent tone (S1 of Experiment 2), and the other component was correlated with the absence of the intermittent tone (S2). During the first two conditions (multiple VT 1-min VT 1-min and multiple VT 1-min EXT), visual stimuli instead of auditory stimuli were correlated with the multiple-schedule components. S1 (1-min component) was red chamber illumination and S2 (5-min component) was green

chamber illumination. Extinction probes were conducted during the multiple VT 1-min EXT conditions. Stability criteria were the same as in Experiment 2.

RESULTS AND DISCUSSION

Figure 5 shows response rates for Pigeons 4, 5, and 6 during the conditions of Experiment 3. In the multiple VT 1-min VT 1-min condition (visual stimuli), activity rates during both stimuli stabilized at about 250 to 300 counts/min. When S2 was changed to extinction (multiple VT 1-min EXT), all subjects developed differential rates of activity in the presence of S+ and S-. When exposed to mixed VT 1-min EXT, no subject responded differentially during the two components. During the multiple VT 1-min EXT condition with auditory stimuli, Bird 4 developed differential S+ and S- rates; however, session-to-session activity rates during S- were much more variable than those controlled by the visual S- in the previous multiple VT 1-min EXT condition. Stimulus control did not develop for Bird 5 when it was exposed to the auditory S+ and S-. Bird 6 did develop differential S+ and S- rates that maintained for 15 sessions. However, excitatory stimulus control by the auditory S+ was transitory for this animal; S+ rates eventually dropped below S- rates and this difference maintained for the remainder of the condition. When the visual stimuli were reintroduced, the difference in the two rates widened for Bird 4, and the session-to-session variability in S- decreased. As before, stimulus control of activity by visual stimuli developed for Bird 5. For Bird 6, differential rates developed and were maintained for 30 sessions; however, rate differences were much smaller than in the previous exposure to multiple VT EXT with visual stimuli. For all subjects, S+ and S- activity rates remained apart when the animals were exposed to extinction probes. In order to provide a comparison of the degrees of discrimination in conditions with visual and auditory stimuli, a discrimination ratio for each multiple VT EXT condition is presented in Table 3. The ratio is response

Table 3

Schedule conditions for Experiment 3. For each multiple schedule, the stimulus modality is given in parentheses. A discrimination ratio for each multiple VT EXT condition is presented. The ratio is response rate in VT/response rate in VT + response rate in EXT. Each discrimination ratio represents the mean of the last five sessions of the condition prior to the EXT probe.

Condition	Schedules		Discrimination Ratio			Number of Sessions		
	Fixed	Variable						
	Component	Component	P4	P5	P6	P4	P5	P6
1.	mult VT 1-min	VT 1-min (visual)	—	—	—	14	11	13
2.	mult VT 1-min	EXT (visual)	.66	.64	.61	16	17	42
3.	mix VT 1-min	EXT — —	—	—	—	17	11	15
4.	mult VT 1-min	EXT (auditory)	.60	.50	.44	47	21	37
5.	mult VT 1-min	EXT (visual)	.65	.63	.54	20	17	80

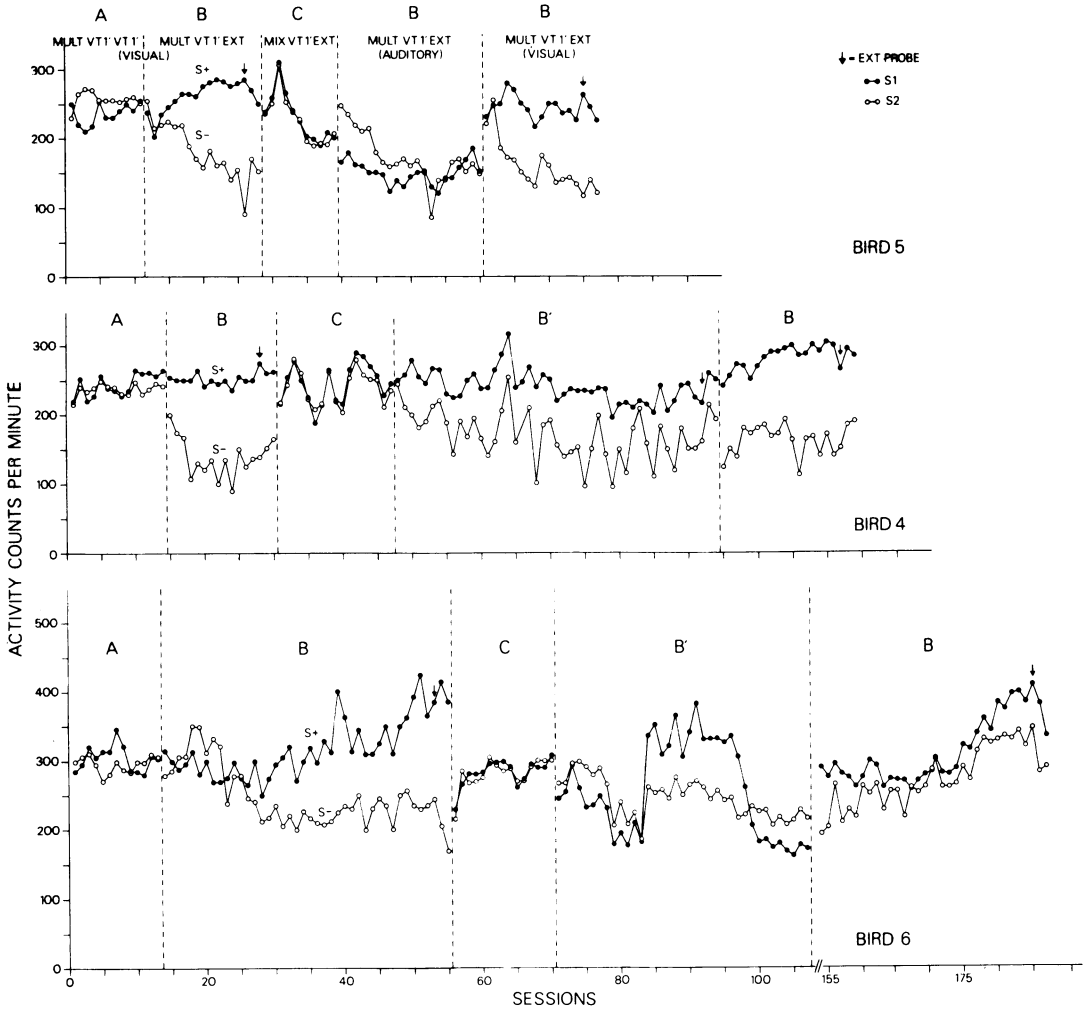


Fig. 5. Session activity rates for Pigeons 4, 5, and 6 during the conditions of Experiment 3.

rate in VT/response rate in VT + response rate in EXT. Each ratio represents the mean of the last five sessions of the condition prior to the EXT probe.

Figures 6 (visual stimuli) and 7 (auditory stimuli) show the temporal patterns of activity during S+ and S- for each pigeon during the multiple VT 1-min EXT conditions of Experiment 3 (data are plotted only for conditions in which differential rates developed). Activity was recorded for successive 15-s subintervals during both S+ and S-. Each data point represents the average of

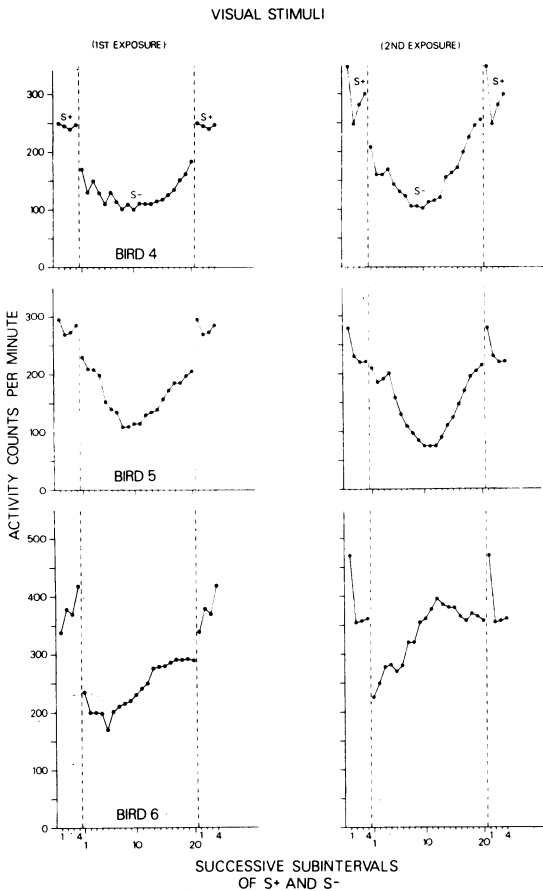


Fig. 6. Activity rates in successive subintervals of the components of the multiple VT 1-min EXT conditions (visual stimuli) of Experiment 3. Each data point represents the average of subinterval rates for the last five sessions of the condition. S+ subinterval rates are repeated to demonstrate more clearly the change in activity rate from the last subinterval of S- to the first subinterval of S+.

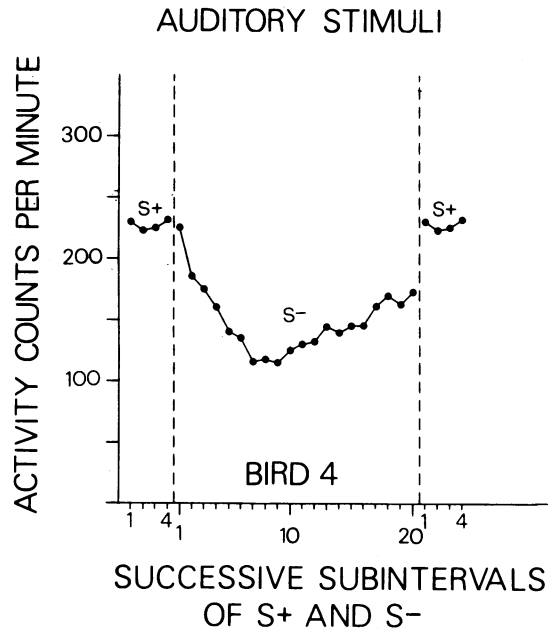


Fig. 7. Activity rates in successive subintervals of the multiple VT 1-min EXT (auditory stimuli) condition of Experiment 3. Data are plotted only for Bird 4 because Bird 5 did not develop differential rates and excitatory stimulus control of activity in S+ was not maintained for Bird 6.

subinterval rates for the last five sessions of the condition prior to the extinction probe. As in Experiments 1 and 2, each subject developed a different pattern of activity within the S+ component. With the exception of the second exposure of Bird 6 to multiple VT EXT with visual stimuli, the pattern that developed in S- (both auditory and visual) was the same as that shown by all subjects in Experiment 1 and by Bird 4 in Experiment 2. For Bird 6, the pattern during its second exposure to discrimination training with visual stimuli differed from the typical S- pattern in that the lowest rate occurred in the first subinterval of S- rather than during the middle of the interval, and activity thereafter increased almost linearly until reaching an asymptotic level at about midpoint of the interval.

Subinterval data for S+ and S- reveal one salient difference between the stimulus control of activity by auditory versus visual stimuli: With one exception (Bird 5, second exposure to visual S+ and S- in Experiment 3), all subjects showed a decrease in activity

rate of at least 50 counts/min in the first subinterval of S⁻ when the stimuli were visual; however, when the stimuli were auditory, activity rate in the first subinterval of S⁻ was always within 10 counts/min of the rate in the last subinterval of S⁺.

The topography of behavior induced by the schedules was similar to that of previous conditions. During both multiple VT 1-min VT 1-min and mixed VT 1-min VT 1-min, all subjects were observed to pace back and forth along the front panel throughout both stimuli. For each animal that exhibited differential rates during the multiple VT 1-min EXT conditions, the following behavioral pattern was reliably observed: Throughout S⁺, head bobbing and/or pacing along the front panel predominated and this behavior continued for a short period when the stimulus changed to S⁻. During the middle of the S⁻ interval, behavior was less stereotyped, but roosting with occasional preening was exhibited by all subjects. Finally, toward the end of the interval, each subject began to pace back and forth along the front panel and this continued until the onset of S⁺.

GENERAL DISCUSSION

The present studies demonstrated Pavlovian stimulus control of schedule-induced activity in pigeons with both visual and auditory stimuli. Studies concerned with free-operant discrimination learning in pigeons have demonstrated that visual stimuli are more effective than auditory stimuli in controlling food-reinforced responding (e.g., Foree & LoLordo, 1973). Experiment 3 demonstrated an analogous relationship for the stimulus control of induced activity.

The fact that an elevated level of activity was maintained throughout S⁻ after extensive discrimination training is one salient difference between the stimulus control of operants in multiple schedules and that of induced activity. As discussed previously, the pigeons exhibited a greater variety of activities during S⁻ than during S⁺, even though the quantified S⁻ activity rate was lower. Staddon (1977) has designated interim

activities as those "induced behaviors which occur at times when a reinforcer is unlikely to be delivered" (p. 126). The present study provided discrete stimuli correlated with periods of reinforcement (S⁺) and periods of nonreinforcement (S⁻). Because schedule-induced interim activities typically occur during periods in which reinforcement is unlikely, it is not surprising that an elevated level of induced activity was maintained during S⁻. Staddon and Simmelhag (1971) proposed that such interim activities have the adaptive function of removing the animal from the food site at times when food presentation is unlikely. In the context of the discrimination training of operants, these induced responses are presumably present during S⁻ but are directed away from the key.

These experiments also suggest a more general parallel between operant responding and induced activity than that of stimulus control. In an exhaustive study of single VI schedules, Catania and Reynolds (1968) found that, for individual pigeons, the functions relating overall rate of responding to overall rate of reinforcement in VI schedules were generally monotonically increasing and negatively accelerated. The results of Experiments 1 and 2 suggest that the relation between the overall rate of reinforcement and the overall rate of induced activity maintained by VT schedules might be monotonically increasing and negatively accelerated. If such a function holds for activity induced by VT schedules of reinforcement, the analogous changes in response rate on *single* VI schedules could be interpreted simply as manifestation of induced activity that the response contingency had functioned to direct toward the key (cf. Killeen, 1975; Staddon & Simmelhag, 1971). The fact that head movement was used as the measure of activity in these studies adds to the plausibility of this interpretation.

The present experiments demonstrated the stimulus control of general skeletal activity by Pavlovian stimulus-reinforcer contingencies similar to procedures that induce autoshaped pecking when localized stimuli are used (e.g., Gamzu & Schwartz, 1973).

Therefore, these results have implications for the origin of autoshaping. They suggest that the basic process underlying autoshaping is the induction of skeletal activity during the CS. Localization of the stimulus (if it is visual) results in autoshaping (cf. Hearst & Jenkins, 1974). In Experiment 1, S+ and S- were different keylight colors that provided the sole source of chamber illumination. Wasserman (1973) had provided evidence that a keylight alone will function as a nonlocalized stimulus and therefore will not lead to autoshaped key pecking. The results of using such a stimulus in Experiment 1 were as follows: When exposed to Pavlovian discrimination training, all pigeons exhibited increased activity in S+ relative to S- and this activity was not initially directed toward the key; however, after extended training, all pigeons developed autoshaped pecking during the S+ stimulus. These results suggest that the stimulus control of induced activity is a contributing process underlying autoshaping. If the stimulus is localized, this induced activity will eventually be directed toward it in the form of pecking (autoshaping). The Wasserman (1973) study and Experiment 1 results suggest that the less localized the stimulus, the longer it will take for sign tracking to develop if it occurs at all. In their original paper reporting autoshaping, Brown and Jenkins (1968) noted:

Direct observation and a study of motion pictures made of pigeons that were not part of the present group showed the following gross stages in the emergence of the key-peck: first, a general increase of activity, particularly during a trial-on period; second, a progressive centering of movements around the area of the key when lighted; and, finally, pecking movements in the direction of the key. (p. 3)

The peck appears to grow out of and depend upon the development of other motor responses in the vicinity of the key that do not themselves resemble a peck at grain. (p. 7)

These observations are consistent with those made during Experiment 1 and support the contention that induction of general skeletal activity by the CS underlies autoshaping.

In an experiment that preceded the discovery of autoshaping, Slivka and Bitterman (1966) used a discrete-trial Pavlovian conditioning procedure similar to that employed by Brown and Jenkins (1968); however, the stimulus was diffuse (hopper light in a darkened chamber) and the behavioral measure was the pigeon's general activity. In this study, the presentation of the CS increased activity above basal level. A possible mechanism by which general activity induced by the CS becomes directed toward the stimulus was suggested by Brown and Jenkins (1968):

The emergence of the key-peck [from CS-induced general activity] may be characterized as a process of auto-shaping on which a direction is imposed by the species-specific tendency of the pigeon to peck at the things it looks at. The bird notices the onset of the light and perhaps makes some minimal motor adjustment to it. The temporal conjunction of reinforcement with noticing leads to orienting and looking toward the key. The species-specific look-peck coupling eventually yields a peck to the trial stimulus. (p. 7)

Although relatively unsystematic observations were made of the topography of the pigeons' behavior during the present experiments, these observations suggest consistency in topography both within and across pigeons. Some of these observed consistencies are of potential theoretical significance and therefore warrant systematic investigation. In his classification of schedule-induced behavior, Staddon (1977) defined *terminal responses* as "induced behavior that emerges in the presence of, or is directed toward, stimuli that are highly predictive of food or some other positive reinforcer" (p. 126). *Interim activities* are induced responses that occur at times when a reinforcer is unlikely to be delivered. Most

research in this area has focused on the temporal control of behavior induced by periodic (fixed-time or fixed-interval) food schedules. However, the use of discrete exteroceptive stimuli correlated with periods of reinforcement (S+) and nonreinforcement (S-) provides the opportunity to evaluate the occurrence of terminal and interim behavior more directly than by inferring temporal control. Such periods of reinforcement and nonreinforcement are explicit during discrimination training. Observations of behavior in the present experiments suggest that the type of Pavlovian discrimination training described in this paper has potential for extending the analysis of interim and terminal behavior. The following pattern of behavior was consistent for all animals that exhibited differential rates during the multiple VT EXT conditions: During S+, some stereotypic (terminal) behavior predominated (e.g., head bobbing and/or pacing along the front panel). At the onset of S-, the terminal behavior continued for a short period. During the middle of the S- interval, a variety of (interim) activities occurred, such as preening, roosting, standing in place and looking around the chamber. As the onset of S+ neared, the animal became more active; for some animals, behavior at this time was similar to their S+ (terminal) behavior.

Staddon and Simmelhag (1971) found that when pigeons were exposed to response-independent schedules of food presentation, all subjects eventually exhibited pecking as the terminal response. The observations made during the present experiments fail to support their suggestion that pecking tends to predominate as the terminal response for pigeons exposed to response-independent food delivery. None of the pigeons exposed to a nonlocalized visual or auditory S+ stimulus exhibited pecking as the predominant terminal response, even though exposure to response-independent food delivery was extensive for all birds. However, during the last sessions of the final condition of Experiment 3 (multiple VT EXT, visual stimuli), head movement along the front panel was interspersed with occasional floor

pecking for both Birds 4 and 6. Perhaps if discrimination training had been prolonged, pecking would have predominated during S+ for these two subjects.

The interpretation of the data offered here assumes that the effects observed were the consequence of stimulus-reinforcer rather than adventitious response-reinforcer relations. Elaborate arguments against the adventitious-reinforcement hypothesis have been presented elsewhere (e.g., Gamzu & Schwartz, 1973; Rachlin & Baum, 1972; Staddon, 1972, 1975; Staddon & Simmelhag, 1971). Staddon (1977) has provided a summary of these arguments, and his concluding comments seem especially relevant to the present discussion:

The adventitious reinforcement hypothesis arose from a tacit assumption that the effects of response-dependent reinforcement are somehow more fundamental than those of response-independent reinforcement. Skinner explained the response-independent case by means of an account derived from experiments on response-dependent reinforcement. Even if he is right in believing that the two cases share common mechanisms, the proper translation may be in the opposite direction. Perhaps mechanisms derived from a study of response-independent procedures can be applied to explain the effects of response-dependent reinforcement. (p. 128)

It is hoped that the experiments reported here will contribute to the body of research that is oriented toward elucidating such "common mechanisms."

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