CONTROL OF RESPONDING DURING STIMULI THAT PRECEDE TRANSITIONS IN REINFORCEMENT FREQUENCY

MARIA G. ORTEGA AND HENRY MARCUCELLA

BOSTON UNIVERSITY

Pigeons' responses were reinforced on a variant of a mixed variable-interval extinction schedule of reinforcement in which the transition to the higher reinforcement rate was signaled by a trace stimulus projected on the response key prior to the onset of the component correlated with food delivery. In the first of two experiments, the duration of the trace stimulus preceding the component correlated with food delivery was varied from 1.5 to 50.0 s and in the second experiment, the reinforcement frequency in the same component was varied from 10 to 60 reinforcers per hour. Pigeons pecked at the trace stimulus preceding the onset of the component correlated with food delivery even though responding was not reinforced in its presence and only one of the changes in reinforcement rate (i.e., from extinction to reinforcement) was signaled. The rate of pecking during the trace stimulus was a function of its duration but not of the reinforcement frequency in the following component. Higher rates generally occurred at the shorter trace-stimulus durations. Component responding following the offset of the trace stimulus was under discriminative control of the trace stimulus whether or not responding occurred in the presence of the trace stimulus.

Key words: elicited and operant responding, stimulus control, mixed schedules, trace stimuli, key peck, pigeons

A number of experiments have reported that key pecking can come under control of stimulus-reinforcer as well as response-reinforcer relations (Brown & Jenkins, 1968; Gamzu & Williams, 1971, 1973); that is, pigeons tend to peck a key when it is illuminated with stimuli that reliably precede (signal) reinforcement. Stimulus-reinforcer and response-reinforcer relations are simultaneously present in many discrimination procedures. Because pecking can be controlled by either relation, attempts have been made to separate the pecks controlled by each relation either spatially (Keller, 1974) or temporally (Brown, Hemmes, Coleman, Hassin, & Goldhammer, 1982; Hassin-Herman, 1984; Marcucella, 1981).

In the spatial separation procedure, the discriminative stimuli of a multiple schedule are

presented on a second, stimulus, key. Reinforcers are produced by pecking at the main response key, which is always white. The color of the second key is the discriminative stimulus for responding on the white key. Keller (1974) demonstrated that while pecking at the white key remained constant, pigeons pecked at the stimulus color that accompanied the higher reinforcement rate. When stimulus-key colors were not correlated differentially with reinforcement, signal-key pecking decreased to near-zero levels.

In the temporal separation procedure, brief trace stimuli (stimuli separated in time from the events they reliably precede) are presented on the response key. The trace stimuli are differentially correlated with the reinforcement or nonreinforcement of responding during the subsequent interval, which is accompanied by other stimuli. Marcucella (1981), Brown et al. (1982) and Hassin-Herman (1984) reported that pigeons pecked at stimuli that preceded intervals in which responding was reinforced on a variable-interval (VI) 1-min schedule of reinforcement but not at stimuli that preceded intervals of extinction (EXT).

Although all three temporal separation studies reported pecks at the trace stimuli, response rates during the trace stimuli varied

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considerably among the studies. These rate differences reported by Brown et al. (1982), Marcucella (1981), and Hassin-Herman (1984) may have resulted from differing trace-stimulus durations. Marcucella, using the shortest duration (1.5 s), reported the highest rates; Brown et al. reported intermediate rates with intermediate durations (4 to 8 s); and Hassin-Herman reported near-zero rates with the longest durations (12 to 30 s). If so, these data suggest that the temporal separation procedure controls such responding most effectively when its signaling-stimulus durations are shorter than those of the standard autoshaping procedure. For example, Gibbon, Baldock, Locurto, Gold, and Terrace (1977), in a standard autoshaping procedure in which the intertrial interval (ITI) was 96 s, reported maximum trial response rates at trial durations of 4 s. At both longer and shorter trial durations, pecking rates during the trial decreased. At the 1-s-trial duration, pecking during the trial did not develop.

The temporal separation procedure resembles the standard autoshaping procedure in that brief stimuli (trace stimuli in the temporal separation procedure vs. trial stimuli in the standard autoshaping procedure), which are occasionally followed by reinforcement, are presented on the response key. The procedures differ in that reinforcers (1) are response dependent in the temporal separation procedure and (2) are often delivered some time after the offset of the trace stimulus. When used in the standard response-independent procedure, such separation usually weakens responding (Gamzu & Williams, 1973).

Using a within-subjects design, the first experiment reported here examined response rates during the trace stimulus as a function of trace-stimulus duration over the range of durations used in the experiments described above. To assess the rate-reducing effect of the reduction in overall reinforcement frequency caused by the increase in the trace-stimulus duration, a second experiment examined changes in trace-stimulus response rate as a function of the reinforcement frequency in the VI component.

EXPERIMENT 1

The purpose of Experiment 1 was to examine (1) whether pecking during the trace

stimulus would develop if only a trace stimulus preceding the transition to the VI component occurred, and (2) how pecking rates during the trace stimulus and during the subsequent VI and EXT component varied as a function of the duration of the trace stimulus.

METHOD

Subjects

Four adult male, experimentally naive, White Carneaux pigeons, obtained from the Palmetto Pigeon Plant, were maintained at 85% of their free-feeding weights. Water and grit were available continuously in the home cage.

Apparatus

Two identical standard pigeon test chambers (Behavior Systems International, Model 417) were used. Each contained three clear response keys, but only the center key was used. Pecks of a force of at least 0.15 N were recorded and operated a feedback relay mounted behind the front panel. The reinforcer was 4-s access to mixed grain delivered by a food hopper located directly below the center key. Light from a Behavior Systems International inline projector transilluminated the key. The houselight remained on except during reinforcement cycles, when both the houselight and keylight were turned off and the food hopper was illuminated. Masking noise was provided by a white-noise generator and by an exhaust fan in the chamber. Electromechanical control and recording equipment was located in an adjacent room.

Procedure

Each pigeon initially was magazine trained and then trained to peck a white key by the method of successive approximations. Key pecking then was reinforced on a mixed VI 1-min VI 1-min schedule of reinforcement in the presence of a white key. The values of the 20 intervals that made up the constant-probability VI schedules were derived from Catania and Reynolds (1968). Components, correlated with these independent VI schedules, alternated every 60 s. A 1.5-s interval during which responses were not reinforced was accompanied by a white key and preceded one of the components. Sessions occurred 5 days a week and consisted of 30 presentations of each of the three components. Responses during

these intervals were counted separately to provide a baseline against which to assess the effect of adding the trace stimulus. During this unsignaled condition, extraneous stimuli exerting differential control over component responding (e.g., keylight flicker) were identified and removed.

The key color during the 1.5-s component preceding the first 60-s white component (VI) then was changed from white to blue, and the reinforcement schedule in the second 60-s white component was changed to extinction (EXT). Responses during the blue stimulus had no scheduled consequences. Thus, a 1.5-s blue trace stimulus preceded a 60-s component (VI) during which responding on a white key was reinforced according to a VI 1-min schedule. A second 60-s component (EXT) immediately followed during which responding on the same white key was not reinforced. No stimulus preceded the change from the VI to the EXT component.

During the next several conditions, the duration of the blue stimulus was varied for each bird. The sequence of trace-stimulus durations for each bird and the number of sessions at each duration are presented in Table 1. The duration of the VI and EXT components was held constant at 60 s throughout the experiment.

Conditions were changed after stable responding was obtained. Stability was established by visual inspection of plots of daily response rates.

RESULTS

Figure 1 shows the mean response rate during the trace stimulus (left half) as a function of the trace-stimulus duration. Mean component response rates during the VI (filled circles) and EXT (open circles) components are presented in the right half of Figure 1. Unconnected data points to the right of the vertical dashed line in each panel represent redetermined values. Mean response rates during white before the introduction of the blue trace stimulus are presented to the left of the vertical dashed line. Prior to the introduction of the blue stimulus, response rates in the three components were approximately equal. For 3 of the 4 birds (all except Bird M3), changing the trace-stimulus key color from white to blue at the 1.5-s duration increased the trace-stimulus response rate above that during the white trace stimulus of the prior

condition. The trace-stimulus response rate of Bird M3 was equal to that during the 1.5-s white interval prior to its introduction, but above the response rate during both the VI and EXT components (right half of figure) following the first introduction of the 1.5-s blue trace stimulus. The VI and EXT response rates were essentially equal at the 1.5-s blue trace-stimulus duration, but both either increased (Bird M2), remained constant (Bird M1, Bird M4), or decreased (Bird M3) from that observed prior to the introduction of the trace stimulus. However, all birds pecked at a higher rate during the first exposure to the 1.5-s blue trace stimulus than they pecked during either the VI or EXT component.

Although all birds pecked at the trace stimulus when its duration was 1.5 s, the highest response rates during the trace stimulus occurred at different durations for different birds. For Birds M1 and M3, the maximum response rate occurred at 1.5 s; for Bird M4, maximum rates occurred at 3.0 s; and for Bird M2, response rates were roughly equal and maximum at 1.5 and 3.0 s. Trace-stimulus response rates of all birds eventually decreased as trace-stimulus duration was increased. However, the duration at which the decrease occurred differed across birds. For Bird M3, trace-stimulus response rates approached zero at the 5.0 s duration, whereas for Bird M2, considerable responding was still occurring at trace-stimulus durations as long as 50.0 s. In five of the six instances, when trace-stimulus durations were then decreased, response rates increased to, or to slightly below, the values previously obtained. Trace-stimulus response rates increased even though they were near zero in the prior condition.

Table 1 presents the mean number of trace-stimulus responses during the first and last five sessions of each condition, the mean number of responses in each white component during the last five sessions of each condition, and the standard deviations (in parentheses). It can be seen that at trace-stimulus durations of 3 s or longer, the trace-stimulus response frequency during the first five sessions of a condition was, in 14 of 16 cases, greater than that during the last five sessions. That is, the initial effect of introducing several of the longer trace-stimulus durations was to increase the frequency of trace-stimulus pecks. The frequency then fell during the condition to a level below that of the first five sessions.

Table 1

Sequence of trace-stimulus durations (seconds), number of sessions at each duration, number of responses on the trace stimulus during the first and last five sessions of a condition, and number of responses/session during the VI and the extinction components during the last five sessions of each condition. Standard deviations are included in parentheses.

Trace-stimulus duration	Sessions	Blue resp. First 5 sess.	Blue resp. Last 5 sess.	VI responses	EXT responses
Bird M1					
White trace stimulus					
1.5	60	14 (6)	31 (4)	1,173 (34)	1,157 (56)
Blue trace stimulus					
1.5	58	7 (3)	54 (8)	1,317 (23)	1,301 (31)
3.0	83	94 (33)	58 (14)	1,232 (52)	911 (103)
10.0	19	135 (25)	68 (10)	1,281 (86)	717 (152)
20.0	31	141 (38)	90 (36)	1,691 (112)	675 (141)
30.0	9	53 (33)	69 (25)	1,689 (89)	505 (62)
1.5	5	54 (7)	54 (7)	1,329 (144)	992 (108)
Bird M2					
White trace stimulus					
1.5	92	21 (14)	32 (8)	1,478 (138)	1,446 (255)
Blue trace stimulus					
1.5	35	24 (3)	82 (16)	2,577 (221)	2,616 (184)
3.0	68	198 (48)	172 (7)	2,403 (152)	2,115 (226)
10.0	19	478 (90)	437 (14)	2,620 (132)	2,356 (56)
20.0	32	716 (56)	373 (85)	1,808 (142)	1,034 (196)
30.0	15	630 (86)	614 (90)	1,976 (291)	1,143 (291)
50.0	20	881 (95)	651 (85)	2,165 (186)	1,281 (271)
1.5	10	61 (16)	70 (6)	2,069 (175)	1,911 (196)
Bird M3					
White trace stimulus					
1.5	83	17 (10)	56 (7)	2,098 (121)	2,054 (121)
Blue trace stimulus					
1.5	25	12 (6)	59 (4)	1,206 (249)	927 (188)
3.0	67	136 (40)	36 (8)	2,034 (210)	1,196 (139)
5.0	19	42 (6)	19 (11)	2,539 (322)	1,357 (390)
1.5	23	12 (5)	40 (13)	2,770 (176)	1,448 (355)
3.0	8	39 (16)	20 (7)	2,695 (167)	1,543 (307)
Bird M4					
White trace stimulus					
1.5	60	8 (4)	28 (5)	969 (79)	959 (77)
Blue trace stimulus					
1.5	74	8 (3)	59 (13)	1,229 (299)	912 (162)
3.0	69	199 (75)	185 (22)	2,242 (396)	695 (207)
5.0	19	312 (33)	291 (27)	2,214 (307)	581 (294)
30.0	8	701 (578)	137 (116)	2,652 (287)	671 (162)
1.5	15	52 (19)	34 (12)	2,678 (143)	924 (136)
3.0	9	134 (20)	179 (12)	2,691 (343)	844 (230)

All 4 birds eventually responded differentially in VI and EXT even though the transition from VI to EXT was unsignaled. The differential performance, which required at least 90 sessions of differential reinforcement

to develop (Table 1), consisted primarily in the following pattern of behavior. At the onset of VI, pigeons would respond at a relatively high rate for 30 s or so. If a reinforcer was encountered, this high rate would continue re-

Fig. 1. Mean responses per minute during the trace stimulus (left half) and mean response rates during the VI (filled circles) and EXT (open circles) components (right half) during the last five sessions of each condition as a function (log scale) of the trace-stimulus duration. Mean response rates prior to the introduction of the trace stimulus are presented to the left of the vertical dashed line in each panel. The unconnected points at the 1.0- and 3.0-s durations are redeterminations.

ardless of whether VI or EXT was in effect. If not, pigeons pecked at a more moderate rate until the next reinforcer or trace stimulus was presented. At this point pecking again would be emitted at the higher rate. Differential responding during VI and EXT increased for all pigeons as the duration of the trace stimulus was increased. However, during the re-determination of the 1.5- and 3.0-s trace-stimulus durations, differential responding decreased substantially from that during the immediately prior condition for Birds M1 and M2 but not for Birds M3 and M4.

Figure 2 shows the number of responses per minute during the trace stimulus (open circles), the VI (filled circles, solid lines), and EXT (filled circles, dashed lines) components, as a function of successive sessions following the first introduction of the 1.5-s blue trace stimulus. Data to the left of the vertical line in each panel are for the last five sessions of unsignaled mixed VI 1-min VI 1-min. For these sessions, the open circles represent the response rate during the 1.5-s white component. Data are shown for each session until the response rate during the blue trace stimulus exceeded the response rates in VI and EXT. Changing the 1.5-s component stimulus from white to blue decreased the response rate during that component. Subsequently, the response rate during blue gradually increased until it exceeded the response rates in VI and EXT. This increase was not systematically related to differential responding in the VI versus EXT components.

DISCUSSION

The results support earlier reports (Brown et al., 1982; Marcucella, 1981) that pigeons will peck at a stimulus that signals impending reinforcement availability even though responding is not reinforced in the presence of the trace stimulus. The change in trace-stimulus response rates as a function of trace-stimulus duration is most likely responsible for the differences between rates observed by Brown et al., Hassin-Herman (1984), and Marcucella. The present results demonstrated that trace-stimulus response rates were higher than component response rates only at the shorter trace-stimulus durations. Trace-stimulus response rates of all birds in the present study decreased to levels below the VI and EXT component rates at trace-stimulus durations

of 20 s or longer. This decrease in trace-stimulus response rate as trace-stimulus duration increased was not due simply to dividing a constant number of pecks occurring per trace-stimulus presentation by a larger time base. Table 1 shows that for 3 of the 4 pigeons, when the trace-stimulus duration was increased, response frequency during the trace stimulus first increased, and then decreased.

Both Marcucella (1981) and Brown et al. (1982) interpreted trace-stimulus responding as respondent pecking elicited by the trace stimulus. Because of the unequal distribution of reinforcers across components, the trace stimulus was correlated differentially with reinforcement and, thus, elicited pecking (Gamzu & Schwartz, 1973). An alternative explanation of the development of trace-stimulus pecking is that pecking during the trace stimulus was adventitiously reinforced by reinforcement of the first peck in the VI component. If, for example, reinforcers became available during the VI component but were not collected, they would remain available until the next VI component, and the probability of reinforcement would be higher for the first response following the offset of the signal. The finding of Brown et al. that shorter delays to reinforcement led to higher trace-stimulus response rates supports this view. The adventitious reinforcement interpretation is unlikely, however, because Marcucella demonstrated that trace-stimulus response rates decreased to zero when responses were reinforced on equivalent VI schedules in both white components. If adventitious reinforcement were responsible for trace-stimulus pecking, then pecking should have increased during both trace stimuli in that experiment, because the conditions for adventitious reinforcement were present during both components.

The present results suggest that the decrease in trace-stimulus rate was directly due to the increase in trace-stimulus duration. Alternatively, the trace-stimulus response-rate decreases could have resulted from the decrease in the overall session reinforcement rate produced by the increase in trace-stimulus duration. The purpose of Experiment 2 was to examine the effect of altering the rate of reinforcement for component key pecking on the trace-stimulus pecking rate.

In order to determine the effect of an ad-

Fig. 2. The numbers of responses per minute as a function of sessions, during the trace stimulus and during both the VI and EXT components, during the last five sessions of mixed VI 1-min VI 1-min and for each session following the introduction of blue until the response rate in blue exceeded the component response rates.

Table 2

Sequence of conditions, number of sessions at each condition, trace-stimulus color, and mean number of responses during the trace stimulus, the reinforced (VI) and nonreinforced (EXT) components for the last five sessions of each condition. Standard deviations are presented in parentheses.

Schedule		Number of sessions	Trace-stimulus color	Mean number of responses			
VI	EXT			VI	EXT	Red	Green
Bird 481							
VI 1-min	VI 1-min	29	white	3,845 (234)	3,790 (279)	92 (8)	95 (5)
VI 1-min	VI 1-min	33	red & green	3,107 (144)	2,943 (111)	9 (3)	8 (4)
VI 1-min	EXT	21	red & green	3,097 (375)	2,634 (226)	103 (8)	8 (3)
VI 3-min	EXT	34	red & green	2,881 (298)	1,929 (503)	110 (22)	2 (2)
VI 6-min	EXT	20	red & green	3,057 (242)	2,182 (276)	115 (12)	7 (3)
VI 1-min	EXT	10	red & green	3,198 (230)	2,805 (191)	104 (10)	2 (2)
Bird 722							
VI 1-min	VI 1-min	15	white	1,910 (275)	1,855 (246)	46 (8)	47 (10)
VI 1-min	EXT	27	white	1,901 (173)	1,816 (287)	49 (5)	53 (7)
VI 1-min	EXT	16	red & green	2,471 (192)	2,382 (275)	96 (16)	7 (4)
VI 3-min	EXT	27	red & green	1,719 (72)	1,374 (136)	97 (4)	2 (1)
VI 6-min	EXT	11	red & green	1,763 (161)	1,205 (274)	81 (9)	7 (4)
VI 1-min	EXT	10	red & green	2,368 (163)	2,083 (57)	95 (12)	4 (1)

ditional brief stimulus preceding the EXT component on the relation between trace-stimulus pecking and reinforcement rate, two additional birds were trained on a two-signal procedure: a red 1.5-s trace stimulus preceded the VI component and a green 1.5-s trace stimulus preceded the EXT component. Red and green trace stimuli were used to facilitate comparison with the results of Marcucella (1981).

EXPERIMENT 2

METHOD

Subjects and Apparatus

Birds M1 and M4 of Experiment 1 and two additional experimentally naive adult male White Carneaux pigeons, also obtained from the Palmetto Pigeon Plant, were used as subjects. Each was maintained at 85% of its free-feeding weight. Water and grit were available continuously in the home cage. The apparatus was the same as that used in Experiment 1.

Procedure

The responses of Birds M1 and M4 continued to be reinforced on the variant of the mixed VI 1-min EXT schedule of reinforcement used in Experiment 1. Either a 1.5- (Bird M1) or a 3.0-s (Bird M4) blue signal pre-

ceded two successive minutes during which the key was white. As in Experiment 1, the reinforcement schedule during the first minute was VI 1-min and the schedule during the second minute was EXT. Following the 10th session, the reinforcement schedule in the first minute was changed to VI 2-min.

Birds 481 and 722 were trained on a procedure that entailed two trace stimuli: a red 1.5-s trace stimulus preceded the VI component and a green 1.5-s trace stimulus preceded the EXT component. Reinforcers that became available during a component but were not collected were canceled at the end of the component. The sequence of conditions and the number of sessions at each condition are presented in Table 2 for each bird. Except for Condition 2, both birds were exposed to the same sequence of conditions. For Bird 481, the red and green trace stimuli were added prior to the schedule change in the EXT component from VI 1-min to EXT. For Bird 722, that schedule change preceded the introduction of the trace stimuli. Subsequently, these 2 birds were exposed to VI schedules with mean values of 3 min and 6 min, with a return to VI 1-min.

RESULTS

Figure 3 shows the response rates during the trace-stimulus presentations and during

Fig. 3. Response rates as a function of sessions for Birds M1 (top) and M4 (bottom) during the trace stimulus, the VI, and the EXT components for mixed VI 1-min EXT (left panel) and mixed VI 2-min EXT (right panel).

the component stimuli for Bird M1 (top panel) and Bird M4 (bottom panel). These data represent the last 10 sessions of mixed VI 1-min EXT and all sessions of mixed VI 2-min EXT. Decreasing the overall session reinforcement rate from 0.5 to approximately 0.25 had little effect upon the trace-stimulus response rates.

Figure 4 shows comparable data in somewhat different format, for Bird 481 (top) and

Bird 722 (bottom). Response rates during both the components and trace stimuli are plotted as a function of the number of reinforcers per minute in the VI component following the red trace stimulus. The unconnected points at the 1.0 reinforcement rate represent redeterminations at that reinforcement value. Both pigeons pecked during the red trace stimulus at substantially higher rates than they did during either the VI or EXT component, and the

Fig. 4. Mean responses per minute during the red trace stimulus, the green trace stimulus, the VI, and the EXT components for Birds 481 (top) and 722 (bottom) as a function of the reinforcers per minute in the VI component. Data points are based on the last five sessions of each condition. The unconnected points at the 1.0/min reinforcement rate represent redeterminations at that reinforcement value.

rate during the red trace stimulus remained relatively constant as the reinforcement rate decreased. The component response rates of Bird 722 decreased somewhat as the reinforcement rate decreased. For both pigeons, response rates during the green trace stimulus preceding the EXT component remained near zero throughout the experiment.

DISCUSSION

The results of Experiment 2 indicate that, in Experiment 1, the response rate decreases during the trace stimulus obtained with increases in trace-stimulus duration were not a function of decreases in the overall reinforcement rate. In Experiment 1, the largest decrease in reinforcement rate, obtained at the

50.0-s duration, was from 0.5 to 0.35 reinforcers per minute. In Experiment 2, a decrease in rate from 0.5 to 0.08 reinforcers per minute had little effect upon trace-stimulus response rates.

Experiment 2 also supported the elicitation explanation of trace-stimulus pecking by demonstrating that pecking will occur during a stimulus that precedes a transition to a higher reinforcement rate even though pecks during the trace stimulus were not reinforced and component pecks immediately following the offset of the trace stimulus did not have a higher probability of reinforcement than pecks occurring later in the VI component.

GENERAL DISCUSSION

The present experiments demonstrated that trace-stimulus pecking rates were a function of the trace-stimulus duration. As the trace stimulus is analogous to the conditioned stimulus or trial stimulus in the standard auto-shaping procedure, the relation between response rate and stimulus duration is similar to that obtained with response-independent auto-shaping procedures (Gibbon et al., 1977; Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, & Ricci, 1975). However, with the temporal separation procedure, maximum response rates were obtained at shorter stimulus durations.

The higher pecking rates at shorter trace-stimulus durations observed in the present experiments than in standard auto-shaping procedures suggest the joint contribution of the response-reinforcer dependency and the stimulus-reinforcer correlation. Operant key pecking produced the reinforcers that maintained the respondent behavior. However, because many of the reinforcers were not immediately preceded by the trace stimulus (i.e., reinforcers were most often obtained after variable delays that often were as long as a minute from the offset of the trace stimulus), high rates of pecking were maintained during both of the white components. Consequently, the pigeons probably were very close to the key at the trace-stimulus onsets.

However, at the same time the variable-duration delay between the trace stimulus and many of the reinforcer deliveries functioned to keep the pigeon near the key, it simultaneously functioned to reduce the frequency of

elicited key pecking. Reinforcing pecking in the absence of the trace stimulus reduced the stimulus-reinforcer correlation (Gamzu & Schwartz, 1973).

The ability of the temporal separation procedure to control responding at short trace-stimulus durations when all reinforcers immediately follow the offset of the trace stimuli, as is the case in the standard autoshaping procedure, is likely to be a function of the above two factors. If all reinforcers immediately follow the offset of the trace stimuli, the white components will be correlated with EXT and little responding will occur during those components. Consequently, the pigeon will be more likely to move away from the key and not return quickly enough to peck whenever a brief trace stimulus is presented. The fact that the original trace-stimulus response rates in Figure 2 were not recovered for all pigeons during the redeterminations supports such an analysis. During the EXT component, the pigeons were observed to emit stereotyped behavior away from the response key. If the 1.5-s stimulus occurred while the pigeons were at the opposite side of the chamber, they often were unable to return to the key before the offset of the trace stimulus. At the same time, however, this trace-stimulus rate decrease may be offset by an increase in the rate of trace-stimulus pecking produced by the increase in the stimulus-reinforcer correlation that would result when reinforcers were no longer delivered in the absence of the trace stimulus.

Other Pavlovian conditioning phenomena may be studied advantageously with an autoshaping procedure containing a response-reinforcer dependency. For example, in trace conditioning studies using the standard response-independent autoshaping procedure, decreases in trial response rate that occur when reinforcers are delivered during the intertrial interval may reflect response incompatibility produced by the response-independent delivery of reinforcers during the ITI, rather than a response to the reduction in the stimulus-reinforcer correlation (Engberg, Hansen, Walker, & Thomas, 1972; Tomie, 1976, 1981). In the response-dependent procedure, ITI reinforcers are less likely to adventitiously reinforce behavior that is incompatible with key pecking. Consequently, higher rates of elicited pecking are likely to be obtained at lower stimulus-reinforcer correlations and at

longer stimulus-reinforcer delays than would be obtained with the response-independent procedure.

The response-dependent autoshaping procedure may also be a more sensitive measure of the ability of diffuse auditory stimuli to elicit key pecking. For example, contrary to the reported difficulty of producing key pecking with auditory CSs with a response-independent procedure (Bilbrey & Winokur, 1973), Lewis and Stoyak (1979) reported high rates of responding to auditory CSs with a response-dependent procedure.

The present results are also relevant to studies demonstrating that warning stimuli that precede transitions in reinforcement rate will control different rates of pecking even when responding during the warning stimulus is reinforced. For example, Pliskoff (1961, 1963) reported that response rates were higher during a stimulus that preceded a transition to a lower reinforcement frequency than during a stimulus that preceded a transition to a higher reinforcement frequency, even though the reinforcement rate during the warning stimuli was identical (Pliskoff, 1963). The findings of Experiment 2 of the present series of experiments, of Brown et al. (1982), and of Marcucella (1981) are consistent with the findings of Pliskoff; that is, trace stimuli controlled different rates of pecking. However, the direction of the rate changes was opposite. Pigeons pecked at trace stimuli signaling the transition to the higher reinforcement frequency.

Procedurally, Pliskoff's (1963) study differed in several respects. The warning stimuli were of at least 1 min in duration, the warning stimuli were not located on the response key, and responses during the warning stimuli were reinforced. Marcucella (1981) suggested that warning-signal pecking was elicited behavior maintained by stimulus-reinforcer rather than response-reinforcer relations. In Pliskoff's study, both of these relations always accompanied the warning stimulus preceding the transition to the higher reinforcement rate. However, they were working in opposition to each other because the warning stimuli were houselights that were not located on the response key. If the pigeons pecked at the warning stimulus, they could not peck at the response key. As Keller (1974) demonstrated, pigeons will peck only at the signal correlated

with the higher reinforcement rate. Consequently, the rate of key pecking during the warning stimulus preceding the transition to the higher reinforcement frequency will be lower than during the transition to the lower reinforcement frequency. In contrast, in the present study the stimulus-reinforcer relation did not control incompatible responses because the warning (trace) stimulus was located on the response key. The absence of a response-reinforcer relation may have lowered the rate during both warning stimuli to the same extent, but the stimulus-reinforcer relation increased the rate of pecking only during the warning signal preceding the transition to the higher reinforcement frequency.

Alternatively, it may be that pecking maintained by stimulus-reinforcer relations was influenced by transitions in reinforcement frequency differently than pecking maintained by a response-reinforcer relation. In Pliskoff's (1963) procedure, reinforcers were response dependent and were delivered during the warning stimuli. Hassin-Herman (1984) presented data in support of this interpretation. When a response-reinforcer relation and a differential stimulus-reinforcer relation were both present during the trace stimulus, the response rate preceding the transition to EXT was higher than that during the trace stimulus that preceded the transition to the reinforced component. However, this result was obtained only when the trace-stimulus duration was 18 s or longer. At the shortest duration tested (6 s), the response rate during the trace stimulus was higher preceding the transition to the reinforced component. Whether stimulus location or the presence of the response dependency was responsible for the difference in the direction of the rate change remains to be determined.

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