Sign and goal tracking during delay and trace autoshaping in pigeons

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In two experiments, pigeons were exposed to an autoshaping procedure in which a keylight was followed by food under delay or trace conditions, while measures were taken of keypecking and time spent near the key. In Experiment 1, the birds in the trace group spent less time near the key than did the delay birds. Moreover, the trace birds exhibited a pattern of withdrawal from the key during the trial. In Experiment 2, visual observations of the birds' location and latencies to eat both indicated that the trace birds' withdrawal from the conditioned stimulus was accompanied by goal tracking. The difference in performance between the delay and trace conditions was taken as evidence that a trace stimulus may exert control over behavior as an occasion setter.

The contemporary study of Pavlovian conditioning has been invigorated by the development of associative learning models (e.g., Gibbon & Balsam, 1981; Pearce & Hall, 1980; Rescorla & Wagner, 1972). However, despite their heuristic value, these models are silent regarding a persistent problem in Pavlovian conditioning—the manner in which learned associations are mapped onto behavior. A converging body of evidence indicates that the strength of a learned association may not be readily inferred from the magnitude of a single conditioned response (CR; see, e.g., Davey & Cleland, 1982; Dickinson, 1980; Henton & Iversen, 1978; Holland, 1977). Even the widely studied autoshaped keypeck response does not always yield lawful data (Hemmes, Brown, & Cabeza de Vaca, 1990; Picker & Poling, 1982).

These considerations have prompted the search for more sensitive tests (e.g., higher order conditioning) and more sensitive behavioral indices of associative learning. We pursued the latter approach in a study of trace and delay autoshaping with pigeon subjects. Newlin and LoLordo (1976) reported that while keypeck acquisition speed differed between trace and delay groups, keypeck rate be-

came less sensitive to treatment differences following acquisition. With continued training, keypeck topography tended to drift for half the trace birds toward pecks off or near the key. These observations suggest that although sign tracking (conditioned stimulus, or CS, approach) may persist in trace conditioning, it is only detectable in measures other than keypecking. One such measure was described by Kaplan (1984), who reported systematic variation in a key approach/withdrawal measure as a function of trace gap size in an autoshaping procedure.

In Kaplan's (1984) study, approach/withdrawal was indexed by means of a teeter-totter floor. CSs were presented on one of two side keys of a standard three-key pigeon intelligence panel. Approach/withdrawal was scored as the relative amount of time spent by the subject on the side of the conditioning chamber corresponding to the location of the CS. Kaplan found that approach gave way to withdrawal as the intertrial interval (ITI) decreased among groups while the trace gap was held constant (Experiment 1) and as the trace gap lengthened while the interfood interval was held constant (Experiment 2). However, in both experiments, the approach/withdrawal measure was somewhat insensitive for conditions associated with withdrawal.

A basis for this insensitivity may be that, rather than withdrawing from the CS by moving to the opposite side of the chamber, the birds retreated to the back of the chamber, regardless of the side (see Cohen & Campagnoni, 1989). Alternatively, the pigeons may have paced from side to side in front of the intelligence panel (see Silva, Silva, & Pear, 1992). Finally, CS presentation may have occasioned goal-directed behavior (goal tracking) under

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some conditions (Boakes, 1977; Silva, et al., 1992; van Hest, van Haaren, Kop, & van der Schoot, 1986). Each of these patterns of responding could yield the near-.50 ratios seen across several conditions in Kaplan's (1984) study. Since uncorrelated presentations of the CS and unconditioned stimulus (US) also yield approach/withdrawal ratios of .50 (Hearst & Franklin, 1977; Wasserman, Franklin, & Hearst, 1974), a more precise measure of CS approach may be needed to detect contingency effects.

The present report describes an alternate measure of CS approach—CS proximity—which is sensitive to withdrawal from the CS in three dimensions. The sensitivity of the behavioral measure was further enhanced by recording behavior in 2-sec time bins throughout the CS-US interval. With few exceptions (e.g., Ellison, 1964; Kehoe & Napier, 1991) data on the temporal pattern of responding during trace conditioning trials are unavailable, possibly owing to the historic use of response measures that are silent under these procedures.

EXPERIMENT 1

The properties of these expanded measures of conditioning were explored in Experiment 1. One group of pigeons was exposed to a trace conditioning procedure, the parameters of which were chosen to yield little, if any, evidence for learning when the conventional keypeck measure was studied (Balsam, 1984). Extended training was provided against the possibility that learning, even though it is retarded under an associatively weak trace conditioning procedure, would eventually occur. For purposes of comparison, a second group of birds was exposed to a delay conditioning procedure.

Method

Subjects. Six experimentally naive male White Carneau pigeons served as subjects. A 7th bird was discarded for failure to eat reliably during magazine training. The birds were maintained at 75% of their ad-lib feeding weight on mixed grain delivered in their home cages, where water and grit were continuously available.

Apparatus. The sessions were conducted in a standard-sized chamber (36 cm tall $\times$ 30.5 cm wide $\times$ 35 cm deep), the side walls, rear walls, and ceiling of which were lined with .8-mm stainless steel sheets. A 6.4-mm flat black plywood panel was constructed as a liner for the front wall. The side keys of a three-key aluminum front panel (BRS/LVE Model PIP 010) were covered; a 2.5-cm clear lucite center key (.2 N force) and a 5-cm-square hopper aperture were located in line, 26.2 and 13.5 cm, respectively, from the mesh floor. The center key could be transilluminated with red light by means of a rear-mounted projector. An infrared emitter/detector device (Skan-A-Matic) was flush mounted in a 20-mm-wide $\times$ 9-mm-high aperture, the top edge of which was located 2 cm below the lower rim of the center key. Output from a light-emitting diode reflective scanner (Squint-Skan, S12 series, Skan-A-Matic) was amplified and fed to circuitry that delivered an output when reflected light reached a threshold level. The device was calibrated daily with a 35-mm-wide surface for an effective distance of approximately 45 mm; lateral deviations of more than approximately 5 cm from the center were not detected. Owing to the height, depth, and width of the detection zone, the proximity of the bird's head was recorded only when the bird faced the key. Proximity dura-

tion was defined as the amount of time spent by the bird in the detection zone.

A photobeam directed across the hopper cavity permitted the detection of the bird's head in the hopper. Sound masking was provided by white noise in the chamber, which was located in a room separate from that with the programming equipment. The programming, implemented with an IMSAI microcomputer, provided data acquisition with .01-sec timing precision.

Procedure. The birds were trained to eat reliably from the lighted hopper in successive steps, during which access to grain was reduced from 20 sec to 1 sec and variable interfood intervals were increased from a mean of 15 sec to a mean of 60 sec. During magazine training, the black plywood liner was placed against the front wall. The liner was subsequently removed for the remainder of the study.

Training consisted of 48 autoshaping sessions conducted under delay or trace conditions to which birds were randomly assigned ($n = 3$). A session contained 50 presentations of a red keylight, the CS, for a duration of 6 sec, followed by food presentation, the US. In the delay condition, US presentation was contiguous with CS offset, whereas in the trace condition, a 6-sec gap intervened between CS offset and US delivery. In all other respects, sessions were identical under the two conditions. A session began with illumination of the houselight, which initiated the first cycle. The houselight remained on until 30 sec following the last US presentation. Cycle duration, timed from US offset to US delivery, was held constant at 60 sec. The US duration was 1 sec, timed from the interruption of the photobeam in the hopper cavity. Proximity duration and keypeck frequency were recorded in successive 2-sec time bins throughout each cycle.

Sessions were run 5 days per week, and the birds were assigned randomly to fixed daily running positions.

Results and Discussion

The delay group acquired keypecking more rapidly than did the trace group. All 3 delay birds met the acquisition criterion of five consecutive trials with at least one peck early in the first session—in 2, 5, and 12 trials. In contrast, only 2 of the trace subjects met the acquisition criterion (in 160 and 1,960 trials).

Figure 1 depicts the temporal pattern of performance of both groups in the last 24 sessions of training, during which performance appeared stable. The keypeck rate and proximity duration measures during the CS-US interval are shown in the upper and lower panels, respectively.

The keypeck rate during the CS period appeared to be higher for the delay than for the trace group, but a group $\times$ time-bin analysis of variance (ANOVA) yielded no reliable effects. When the change in rate from the last ITI bin to the first CS bin was evaluated between groups in an ANOVA, no significant effects were obtained. However, all 6 birds showed an increase in rate between those bins, a significant effect with a sign test ($p < .05$).

Group differences were apparent on the proximity duration measure, for which an ANOVA indicated a significant groups $\times$ bin interaction [$F(2,8) = 10.44$, $p < .01$]. The delay group exceeded the trace group in proximity duration in the last bin of the CS period, but not in the first bin [$t(4) = 4.40$, $p < .05$, and $t = 1.03$, n.s., respectively]. Additional tests on the proximity measure indicated no reliable trend across bins during the CS period for the delay group [$F(2,4) = 4.69$, $p > .05$], but the trace group exhibited a reliable decrease in proximity duration [$F(2,4) = 8.35$, $p < .05$].

Figure 1. Experiment 1: Group mean rate of keypecking (upper panel) and proximity duration (lower panel) as a function of 2-sec time bins during the conditioned stimulus-unconditioned stimulus (CS-US) interval, in the last 24 sessions. The first point on each panel represents the intertrial interval (ITI) bin immediately prior to CS onset. For the delay and the trace groups, filled symbols represent the CS period, and open symbols, the ITI and/or the gap period. The arrows point to the time bin preceding US delivery.

A comparison of the change in proximity duration from the last ITI bin to the first CS bin indicated a difference between groups [$F(1,4) = 15.07, p < .05$, for the interaction]. A reliable increase was found for the delay group [$F(1,2) = 31.60, p < .05$], but not for the trace birds [$F(1,2) = 10.60, p > .05$]. For the trace birds, then, the behavior occasioned by the CS was withdrawal from the region of the key.

Of greatest interest is the emergence of stimulus control by the CS for the trace group, as revealed by the systematic within-trial change in proximity. These results, which were not evident for the keypeck measure, demonstrate the usefulness of approach/withdrawal as a behavioral index in autoshaping (Hearst & Franklin, 1977). The pattern of withdrawal is reminiscent of the time course of the well-established conditioned response as observed in autonomic measures (see, e.g., Ellison, 1964), heretofore unobserved for the autoshaping preparation.

Consistent with prior accounts of trace conditioning (e.g., Hinson & Siegel, 1980; Kaplan, 1984), the pattern of CS withdrawal may be interpreted as reflecting inhibitory control by the CS. Arguing against this interpretation is that, on the basis of scalar expectancy theory (Bal-

sam, 1984), the trace conditioning parameters used in this study would be expected to yield a slightly excitatory CS (expectancy ratio = 3.0). Alternatively, the proximity data may reflect control by the CS of a competing response tendency, such as goal tracking. Goal tracking has been reported in autoshaping procedures with rats (e.g., Boakes, 1977; Davey & Cleland, 1982; Farwell & Ayres, 1979; Henton, 1978; Holland, 1977), and with pigeons (Newlin & LoLordo, 1976; Silva et al., 1992; van Hest et al., 1986; Wasserman, 1973).

Of course, these accounts may not be mutually exclusive. In the next experiment, we sought additional evidence for the competing response analysis by directly observing where birds were headed as they left the region of the CS. Movements toward the hopper would be consistent with goal tracking, whereas movements laterally or toward the rear of the chamber might imply inhibitory control by the CS (see, e.g., Bottjer, 1982; Hearst & Franklin, 1977; Kaplan, 1984).

EXPERIMENT 2

As in Experiment 1, birds were assigned to trace or delay conditions. However, for both groups, the CS-US interval and ITI were held constant. This was achieved by extending the CS duration to 12 sec for the delay group. In addition to measures of keypeck rate and proximity duration, visual observations of the birds' position in the conditioning chamber were conducted systematically throughout the experiment.

Method

Subjects. Eight naive male White Carneau pigeons were maintained under conditions identical to those in Experiment 1.

Apparatus. Except for the following modifications, the apparatus was the same as that in Experiment 1. The access door to the animal chamber was replaced with a 1/8-in. sheet of transparent lucite that enclosed only the subject's compartment. It was marked with a 1-mm-wide vertical line placed 45 mm from and parallel to the front panel of the chamber, as depicted in Figure 2. Two additional horizontal lines created three rectangular areas adjacent to the panel. The top area enclosed the region of the key extending approximately 7 mm below its lower rim, and the bottom area enclosed

Figure 2. Experiment 2: Observation view of the chamber.

the region of the hopper from its upper edge to the chamber floor. A video camera transmitted this image to a remote TV monitor.

Procedure. The experiment was conducted in successive replications with two squads of 4 birds. Within squads, 2 birds were randomly assigned to the delay and trace conditions, and the 4 birds were run 5 days per week in a fixed within-day block-random order.

Magazine training was conducted as in Experiment 1, but without the plywood liner. Trace and delay conditioning were then conducted for a total of 50 sessions. The training procedure was identical to that in Experiment 1, except for the extension of the CS duration to 12 sec for the delay group. Thus, the CS-US interval was 12 sec for both groups. Following this phase, an additional 15 sessions were run with the CS (keylight) omitted. This CS-omission phase was added to assess control by the CS as opposed to control associated with presentations of the US alone.

Keypeck frequency and proximity duration were recorded in 2-sec time bins throughout the interreinforcer interval. The latency to eating was recorded on each trial from US presentation to the interruption of the hopper photobeam.

Visual observations were scored by dividing the pigeon chamber into four regions, as is shown in Figure 2. Regions 1, 2, and 3 referred to the top, middle, and bottom areas within 45 mm of the front chamber panel. Regions 1 and 3 contained the key and hopper, respectively. Region 4 (away) referred to the area beyond 45 mm from the front panel. Observations were conducted by means of a momentary time sampling procedure. The location of the tip of the bird's beak in Regions 1-4 was observed and recorded at 2-sec intervals, commencing immediately prior to CS onset, and signaled by the sound of a solenoid-operated relay. The first observation was taken as the location of the bird during the ITI immediately prior to a trial. Visual observations were made on a minimum of 30 trials per session, following the first 3 trials. Two squads of 4 birds were observed at a minimum of every other session by a pool of six observers. Interobserver measures taken on 25% of all observed sessions yielded a median agreement score (agreements/agreements + disagreements) of 91% among all pairs of observers.

Results

Keypecking. As in Experiment 1, the delay birds achieved acquisition more rapidly (in 30, 37, 49, and 73 trials) than did the trace birds, of which 2 reached acquisition (in 736 and 1,323 trials) and 2 did not. Figure 3 depicts group mean keypeck rate (upper panel) plotted as a function of elapsed time in the CS-US interval for each of the five 10-session blocks over the course of training, and for the first 10-session block during CS omission. (Data from the CS-omission phase are discussed below.) A group $\times$ session block $\times$ time bin ANOVA yielded two reliable effects, a block $\times$ bin interaction [$F(20,120) = 2.14, p < .01$] and a group $\times$ block $\times$ bin interaction [$F(20,120) = 1.95, p < .05$]. Both interactions represent a change in temporal pattern of responding for the delay group, and both disappeared when the analysis was restricted to the last three blocks [$F(10,60) = 1.05$ for both]. The group effect was not reliable, owing to highly variable rates in the delay group. However, there was no overlap in the birds' mean rates of responding between groups, and when the data were subjected to a log (rate + 1) transformation, a reliable group effect emerged [$F(1,6) = 12.73, p < .05$].

Proximity. The proximity duration measure closely resembled the pattern of results in Experiment 1, as can be seen in the lower panel of Figure 3. While delay birds

spent most of the trial in the vicinity of the key, the trace birds tended to spend less time near the key as the CS-US interval elapsed. In a group $\times$ blocks $\times$ time bin ANOVA of proximity duration, all main effects and interactions were reliable, except the second-order interaction ($F < 1$). Of particular interest was the group $\times$ bin interaction [$F(5,30) = 11.19, p < .01$] that refers to the difference between groups in the temporal pattern of proximity duration within the trial. Separate analyses of trace group data confirmed that the within-trial pattern of proximity changed during the course of training [$F(20,60) = 3.30, p < .01$, for the blocks $\times$ bin interaction] and had stabilized in Blocks 3-5 ($F < 1$ for the interaction), during which a reliable downward trend was exhibited in the CS-US interval [$F(5,15) = 7.89, p < .01$]. Moreover, the decrease in proximity duration was evident within the CS period of the trial [$F(2,6) = 5.41, p < .05$].

The increase across blocks in proximity duration reflects a concomitant increase in proximity during the ITI. Across the five blocks, the values during the pre-CS second of the ITI were .23, .37, .69, .86, and .75 sec for the delay group, and .20, .18, .32, .42, and .50 sec for the trace group. In a group $\times$ blocks ANOVA of the pre-CS second, the change in proximity duration across blocks was reliable [$F(4,24) = 6.41, p < .01$], but group effects were not ($F_s \leq 1$). For the trace group, there was no reliable difference in proximity values between the pre-CS bin and the first CS bin [$F(1,3) = 2.05$, n.s.]. Thus, as in Experiment 1, control acquired by the trace CS governed withdrawal from the region of the key.

Location. The main goal of the present experiment was to determine the destination of the birds in the trace group during their withdrawal from the CS. Figure 4 depicts the results of visual observations for the delay (upper panels) and trace (lower panels) groups. Results for the first 10 and last 30 sessions of training are presented in the left and middle columns, respectively. In each panel, group mean proportion of trials in each region is plotted against observation time during the trial, with the first point representing the ITI observation prior to the trial. Since the regions were exhaustive (1 = key, 2 = middle, 3 = hopper, 4 = away from front panel), the values at each point on the abscissa sum to 1. Prior to the separate examination of each group, an ANOVA of proportion data confirmed an interaction for groups $\times$ blocks of 10 sessions $\times$ location $\times$ time [$F(60,360) = 1.68, p < .01$].

The delay birds spent a greater proportion of time during a trial in Region 1, at the key, than at any other location, a difference that was evident early in training. Separate location $\times$ time ANOVAs of proportion for early and late phases of training indicated reliable location effects in both phases [$F(3,9) = 225.93$ and $18.83, p < .01$].

Results for the trace group differed markedly from those for the delay group. The lower left panel of Figure 4 suggests no evidence of control of location by the CS during early sessions for trace birds. A location $\times$ time ANOVA of proportion yielded no reliable effects during this phase. During the late phase, however, a clearly discernible pat-

Figure 3. Experiment 2: Group mean rate of keypecking (upper panel) and proximity duration (lower panel) as a function of 2-sec time bins during the conditioned stimulus-unconditioned stimulus (CS-US) interval. For each measure, functions are shown for the delay and the trace groups in successive 10-session blocks; the last block presents performance during the first 10 sessions of the CS-omission phase. For the trace group, closed and open symbols represent the CS and gap, respectively.

tern of movement emerged. As the CS-US interval elapsed, birds were observed increasingly more often in the hopper area, Region 3, and perforce less often in the remaining three regions. The difference in temporal pattern of location was reflected in a reliable location $\times$ time interaction [$F(15,45) = 2.92, p < .01$]. The interaction was also present when the location factor was restricted to Regions 1 and 3. The increase in proportion in the hopper region as a function of trial time was reliable [$F(5,15) = 5.71, p < .01$], but the decrease for Region 1 was not [$F(5,15) = 2.02$].

Analyses of location in the ITI, immediately prior to CS onset, indicated that group differences were confined

to the CS-US interval. A group $\times$ location $\times$ phase ANOVA yielded a significant location $\times$ phase interaction [$F(3,18) = 13.12, p < .01$], but no group effects. The interaction reflected movement toward the front panel across phases. As is shown in Figure 4, the predominant position during the ITI in early sessions was in Region 4. During late sessions, birds were positioned in either Region 1 or Region 4 prior to CS onset. Separate LSD tests ($p < .05$) for each group indicated a difference between proportion of time in Region 4 and in all other regions early in training. Late in training, proportion in Region 1 increased so that it differed from proportion in Regions 2 and 3, but not from proportion in Region 4.

Figure 4. Experiment 2: Group mean proportion of trials in which birds were observed in Regions 1–4 plotted against observation times. The first point in each panel represents the intertrial interval observation immediately prior to conditioned stimulus (CS) onset. The delay and trace group data are shown in the upper and lower panels, respectively. The left and center panels depict performance during the first 10 and last 30 training sessions, respectively; the right panels show performance during the first 10 sessions of the CS-omission phase.

These results are compatible with the increase during training in proximity duration observed immediately prior to CS onset.

Eat latency. Figure 5 depicts group mean latency to eat over 10-session blocks. On the first session block, this latency was longer for the trace group, but the difference reversed by the third block. An ANOVA for training data indicated a significant interaction between groups $\times$ blocks [$F(4,24) = 16.24, p < .01$], and separate t tests ($p < .05$) revealed significant group differences on both first and last blocks. This finding is consistent with the visual observation data that showed that trace birds were more likely to be detected in the hopper region than at any other location prior to US presentation, whereas delay birds were located in the key region, farther from the hopper.

CS-omission phase. Analyses of all dependent measures were conducted for Sessions 51–60, during which the keylight CS was omitted. The rightmost panels in Figures 3, 4, and 5 present data from this phase. In order to evaluate stimulus control by the CS as opposed to control by elapsed time during the 60-sec inter-US period, performance on each measure was compared during the last 10 sessions of the training phase and during the first 10 sessions of the CS-omission phase.

Virtually no keypecking was observed during the CS-omission phase (Figure 3, top panel). A group $\times$ phase ANOVA of $\log(\text{rate}+1)$ yielded a reliable interaction [$F(1,6) = 12.73, p < .05$], owing to a decrease in rate for the delay group [$F(1,3) = 16.11, p < .05$], but no change for the trace group [$F(1,3) = 3.07, \text{n.s.}$].

The difference in proximity pattern between groups was lost when the CS was omitted (Figure 3, bottom panel). A group $\times$ phase $\times$ bin ANOVA of proximity duration yielded a reliable second-order interaction [$F(5,30) = 8.24, p < .01$], owing to the collapse of temporal patterns in both groups in the CS-omission phase. The phase $\times$ bin interaction was significant for each group [$F(5,15) = 5.28$ and $4.41, p < .01$ and $p < .05$, respectively, for trace and delay]. That is, for each group a reliable bin effect was observed during training ($ps < .05$), but not during CS omission.

Figure 5. Experiment 2: Group mean latency to eat as a function of 10-session blocks during training and conditioned-stimulus-omission phases, for the delay and trace groups.

Examination of observation data during the CS-omission sessions (Figure 4, right panels) indicated a loss of temporal pattern effects in proportion scores during the trial period. An ANOVA of proportion scores for Region 3, the hopper area, yielded a reliable group $\times$ phase $\times$ time interaction [$F(5,30) = 3.46, p < .05$], indicating a change in temporal pattern between phases for the trace group [$F(5,15) = 3.49, p < .05$, for the phase $\times$ time interaction], but not for the delay group ($F < 1$). That is, for the trace group, a reliable time effect was present in training [$F(5,15) = 3.61, p < .05$], but not during CS omission ($F < 1$).

Finally, latencies to eating (Figure 5) did not differ reliably between groups during CS omission [$F(1,6) = 2.36$]. Although the difference was significant in training, the group $\times$ phase interaction was not reliable ($F < 1$), nor was the main effect of groups [$F(1,6) = 5.52, \text{n.s.}$]. Latencies during CS omission were longer than those in training [$F(1,6) = 7.88, p < .05$], and more variable.

The loss of group differences and temporal patterning during CS-omission sessions indicates that those effects during training were attributable to stimulus control by the CS.

Discussion

Consistent with the results of Experiment 1, birds in the trace group showed a temporal pattern of withdrawal from the site of the CS during the CS-US interval. However, rather than indicating retreat from the CS to the back of the chamber, as has been reported for some autoshaping procedures (e.g., Cohen & Campagnoni, 1989; Matthews & Lerer, 1987), CS withdrawal was associated with movement toward the hopper and short latencies to eating. These findings indicate acquisition of a positive CS-US association under a trace procedure that does not support key-pecking. They are consistent with an account of Pavlovian conditioning in which a CS acquires control over two competing response tendencies—CS and US orienting (e.g., Boakes, 1977; Buzsaki, 1982; Holland, 1977).

The delay group did not exhibit goal tracking. The absence of goal tracking during the delay CS in both Experiments 1 and 2 rules out CS duration and the CS-US interval, respectively, as explanations of that behavior and confines goal tracking to the trace arrangement of CS and US events. Interestingly, goal tracking is not found following delay conditioning when keypecking is eliminated by random presentations of the US in the presence and absence of the CS (Lindblom & Jenkins, 1981). We confirmed this result in extensive observations of the delay birds following Experiment 2. Thus, weakening of sign-tracking tendencies does not uncover possibly coexistent, but hidden goal-tracking tendencies. These results are consistent with observations that CR topography is largely determined by physical stimulus properties of the CS (e.g., Holland, 1977, 1980a, 1980b).

An implication of the present data is that an approach/withdrawal measure that indexes behavior in only one dimension may lead to an incomplete, or even misleading, account of learning. For example, Kaplan (1984) has ar-

gued that CS withdrawal provides evidence for inhibitory control, insofar as it is a response antagonistic to the response tendency controlled by a conditioned excitator (in the present study, the delay CS). Withdrawal thus implies acquisition of a negative association between the CS and US. However, the present findings demonstrate that withdrawal is not, in itself, indicative of inhibition, because goal tracking by birds in the trace group implies acquisition of a positive CS-US association. Rescorla (1969) addressed this issue, and cautioned that an excitatory CS could pass a summation test for inhibition if it controlled a competing response. (The corequisite retardation test was added to preclude that possibility.) Although the criteria for inhibition are arguable (see Williams, Overmier, & LoLordo, 1992, for a review), clearly the same caution applies to an approach/withdrawal test, to which other tests should be added prior to the inference of inhibition.

Two alternate accounts for the performance of birds in the trace group can be considered. First, owing to our use of a fixed cycle duration, goal tracking may be attributable to temporal control by the US-US interval. However, this account is excluded by data from the CS-omission phase. When the CS was omitted, temporal control over goal tracking was lost. Goal tracking may also be influenced by an embedded operant contingency under which positions of a bird that are relatively close to the US site would enjoy differential reinforcement (shorter delays to eating). Although some reports of goaltending in pigeons are subject to this interpretation (e.g., Silva et al., 1992), it is implausible as an account for the present data, since the distance between the key and hopper was short, and, more importantly, access time to grain was held constant regardless of the latency to eat.

Finally, the temporal properties of goal-directed behavior are noteworthy. As in other reports of goal tracking in rats and pigeons (e.g., Davey, Oakley, & Cleland, 1981; Holland, 1977; Silva et al., 1992), goal tracking in the present study tended to occur later in the trial. Since that pattern developed within the CS segment of the trial, its growth is not attributable simply to CS offset. Rather, it could reflect the sort of temporal control familiar in other Pavlovian preparations, though generally not in autoshaped keypecking (see Hemmes et al., 1990). In that case, a function of a trace CS may be to start the internal clock-based timing of the CS-US interval (Church, 1984).

GENERAL DISCUSSION

The main finding of the present study is that the trace procedure produced evidence of conditioned responding in goal-directed but not sign-directed behavior. That finding joins others in the Pavlovian literature indicating that behavioral evidence of conditioning is not reflected in a single response system, but requires the sampling of a range of behavioral sequelae. Although response mapping rules remain to be determined, it is apparent that response topography is a function of US properties (stimulus substitution), CS properties, and CS-US interactions. In rats,

when the US is held constant, CR topography is largely determined by physical stimulus properties of the CS, including spatial and temporal characteristics (Holland, 1977, 1980a, 1980b). Similar rules appear to apply to pigeons (Silva et al., 1992). At a descriptive level, the present data suggest that sign and goal tracking may reflect the temporal properties of a visual CS.

The performance of the trace group has interesting implications concerning the function of a Pavlovian CS. It is generally held that a decline in response strength as the trace gap lengthens manifests a decline in CS "value" or "expectancy," whether or not such a decline enters an inhibitory region. Differences in sign-tracking tendencies (keypeck and proximity duration) between delay and trace groups are consistent with that characterization. However, goal tracking in the trace group indicates that a CS acquiring little or no excitatory strength (as indexed by sign tracking) may nevertheless exert substantial control over behavior.

Such control may be understood as an example of occasion setting, whereby the trace CS signals a conditional relation between the stimulus conditions present during the gap and subsequent food presentation. As originally described by Ross and Holland (1981), *occasion setting* refers to a serial feature-positive discrimination paradigm under which the first of two serial stimuli (the occasion-setting stimulus) differentially signals the occurrence of food following the second stimulus. The occasion-setting stimulus does not participate in a direct stimulus-reinforcer association; it does not acquire excitatory (or inhibitory) strength. Rather, it modulates behavior in the presence of the second stimulus (see Holland, 1983; Rescorla, 1985). Under a trace conditioning procedure, the CS differentially signals the occasion under which background or context cues (i.e., the stimulus conditions prevailing in the absence of the CS) will be followed by food. In this role, the trace CS sets the occasion for US-related behavior (goal tracking) during the gap.

A similar argument has been made by Thomas, Robertson, Cunliffe, and Lieberman (1989) to account for the performance-enhancing effect of presenting a unique stimulus during the trace gap (the filled-gap procedure). In light of the present findings, analysis of potentiated sign tracking during a trace CS requires dissociation of associative and occasion-setting properties. Additional evidence on the associative status of trace CSs from both filled- and unfilled-gap procedures might be obtained from experiments employing transfer test methodology.

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