A COMPARISON OF PECKING GENERATED BY SERIAL, DELAY, AND TRACE AUTOSHAPING PROCEDURES[1]

Robert J. Newlin and Vincent M. LoLordo

UNIVERSITY OF NORTH CAROLINA, CHAPEL HILL AND DALHOUSIE UNIVERSITY

Pigeons were exposed to serial, delay, and trace autoshaping procedures. In Experiment I, all conditioned stimuli (CSs) were changes in illumination of the response key. The number of trials to acquisition of the keypeck increased from serial, to 4-sec delay, 8-sec delay, and 8-sec trace procedures, in that order. In Experiment II, which used a longer intertrial interval, trials to criterion increased from 8-sec delay, to 28-sec delay, 8-sec trace, and 28-sec trace procedures, in that order. In Experiment III, two groups received serial procedures in which the first CS was either a tone or a houselight, and the second was a keylight. The tone group acquired the key peck more rapidly than the houselight group. Early in conditioning in these experiments, and when the conditioned stimulus was a change in the keylight, there was a short latency to the onset of pecking and pecking was directed at the CS. After extensive conditioning, or when the CS was relatively diffuse, pecking still occurred, but had a longer latency and was not reliably directed toward the conditioned stimulus.

Key words: autoshaping, respondent conditioning, delay conditioning, trace conditioning, serial conditioning, peck, keypeck, pigeon

Brown and Jenkins (1968, Experiment IV) demonstrated that the key pecking of pigeons could be conditioned by means of a Pavlovian procedure. Birds received repeated trials consisting of illumination of a keylight for 8 sec (the conditioned stimulus or CS) followed immediately by 4-sec access to grain (the unconditioned stimulus or UCS). This sequence of events was response-independent. Nonetheless, nine of 12 pigeons made a substantial number of pecks on the key, and nearly all pecking occurred during the CS. Brown and Jenkins (1969) called this phenomenon autoshaping.

The identity of autoshaping and Pavlovian conditioning procedures, as well as the general similarity of the phenomena of autoshaping and phenomena considered examples of Pavlovian conditioning, suggest that a wider variety of Pavlovian paradigms could be extended to the autoshaping situation (see re-

views by Hearst and Jenkins, 1974; Moore, 1971; Schwartz and Gamzu, in press). The present experiments investigated the effects of short- and long-delay, short- and long-trace, and serial conditioning procedures on autoshaping of the pigeon's key peck. The research focused on two dependent variables, the temporal distribution of pecks within trials, and the spatial distribution of pecks.

EXPERIMENT I

The first experiment investigated the effects of serial, delay, and trace autoshaping procedures. Experimental sessions consisted of two periods: trials and intertrials. Each trial was divided into three equal parts designated CS1, CS2, and UCS (food) in that temporal order. If CS1, CS2, and the intertrial stimulus were three different stimuli, the procedure was called serial conditioning. Procedures in which CS1 and CS2 were the same, and the intertrial stimulus was different, or the intertrial stimulus and CS1 were the same and CS2 was different, were delay conditioning procedures with different CS-UCS intervals. If CS2 was identical to the intertrial stimulus but CS1 was different, the procedure was called trace conditioning. These four procedures are diagrammed in Figure 1, which includes the tem-

poral values used in the experiment. All stimuli were changes in the illumination of the response key. Representative key colors are indicated in Figure 1.

The experimental literature on Pavlovian conditioning suggests some predictions about the relative rates at which key pecking should be acquired in serial-, delay-, and trace-autoshaping procedures. Frey, Englander, and Roman (1971) found that rabbits' eyeblink responses were acquired more rapidly when a brief CS-UCS interval was filled by two stimuli in sequence, rather than by a single CS. On the other hand, when the interval between onset of the second CS of the series and the UCS was equated with the CS-UCS interval for a group receiving a single CS, there were no differences in the rate of acquisition. In an autoshaping experiment that used CS-UCS intervals of 30 or 120 sec for pairs of groups, Ricci (1973), who held trial duration constant, found that pigeons that received a four-component serial CS on the key tended to begin pecking the key after fewer trials than did pigeons that received a single CS, though the differences were not statistically significant.

A variety of relations between the length of the CS-UCS interval in classical delay conditioning and the speed of acquisition of the CR have been found. For example, both Ellison (1964), who studied salivary conditioning in dogs, and Kamin (1965), who explored the conditioned emotional response (CER) procedure with rats, obtained faster conditioning with shorter CS-UCS intervals. On the other hand, Church and Black (1963) found no effect of 5- *versus* 20-sec intervals between a CS and electric shock in heart-rate conditioning of dogs, and Longo, Klempay, and Bitterman (1964) obtained faster acquisition of general activity in pigeons when an auditory-visual CS preceded the delivery of grain by 10 sec, rather than 1 sec. In an autoshaping experiment, Brown and Jenkins (1968) found no difference in the number of trials to the first key peck between groups of pigeons that received 3-sec and 8-sec CS-UCS intervals. On the other hand, Baldock (1974), Groves (1974), and Ricci (1973) found that the number of trials to acquisition of key pecking was directly related to the length of the CS-UCS interval in delay conditioning.

Pavlovian conditioning studies suggest that the trace autoshaping procedure should produce slower acquisition than a delay procedure with the same CS-UCS interval, so long as this interval is sufficiently long. Ellison (1964) and Kamin (1965), using factorial designs, obtained an interaction between CS-UCS interval and the trace *versus* delay-conditioning variable, such that delay conditioning produced faster acquisition than trace conditioning only at longer intervals.

Turning to the temporal distribution of responses within trials, previous research on Pavlovian conditioning suggests that more responses should occur during CS2 than during CS1 in the serial conditioning procedure (Williams, 1965). Using four CSs of equal duration, which summed to either 30 sec or 120 sec for different groups of pigeons, Ricci (1973) found more key pecks in each successive component approaching food.

Delay autoshaping procedures have had divergent effects on the temporal distribution of pecks. Ricci (1973) exposed groups of pigeons to CS-UCS intervals of 30 sec or 120 sec, clearly within the range where a low initial level of responding followed by a progressive increase within the trial would be expected on the basis of data obtained from salivary conditioning studies [Kharchenko (1960) in Razran, 1971; Pavlov, 1927; Williams, 1965], though various response systems behave differently in this respect (*cf.* Schneiderman, 1972). The temporal distribution of key pecks within trials revealed no clear trend. Moore (1971), using a 6-sec CS-UCS interval in a delay procedure, reported a decline in key pecking across the trial after many conditioning trials. He at-
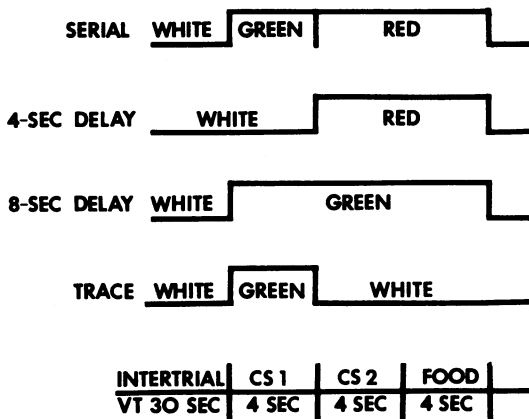

Fig. 1. Representation of the colors of the response key during the intertrial and trial periods for the serial, 4-sec delay, 8-sec delay, and trace autoshaping groups of Experiment I.

tributed this effect to birds leaving the key and pecking down along the wall toward the food hopper as the trial progressed. Wasserman (1973) also observed a decline in the rate of key pecking within the trial. Gardner (1969), using quail, obtained generally increasing rates of key pecking within a 20-sec trial late in conditioning, although the mean rate of key pecking even during the first fifth of the trial was about one per second, and a few of the quail attained their highest rates during this period.

We were particularly interested in the temporal distribution of pecks within trace-autoshaping trials because there is no localized CS, different from the intertrial stimulus, present during the trace period. If autoshaped key pecking requires a CS located on the key, perhaps key pecking should be confined to CS1 in the trace procedure, because the pecks either drift away from the key during the trace (CS2) period, or cease (see reviews by Hearst and Jenkins, 1974; Newlin, 1974, Experiment IV; Schwartz and Gamzu, *in press*). On the other hand, Pavlov (1927) maintained that salivation was confined to the trace period in long-trace conditioning. Kamin (1965) observed the same outcome in a CER procedure with a very intense CS. With less intense CSs, suppression was equal in the trace and CS periods.

METHOD

Subjects

Forty-eight experimentally naive, male White Carneaux pigeons (retired breeders) were maintained at approximately 75% of their free-feeding weights by feedings immediately following daily experimental sessions. Water and grit were continuously available in the home cages, which were located in a constantly illuminated colony room.

Apparatus

Four identical single key, 23 cm by 40 cm long by 26 cm high conditioning chambers were used. The rear and two side walls of each chamber were painted white, and the front wall was covered with black Bakelite. The front wall contained one feeder aperture centered 10 cm from the wire-mesh floor and one pigeon response-key centered 20 cm from the floor. The key was 1.7 cm in diameter and recessed 0.5 cm in a hole bevelled to an outer

diameter of 2.5 cm. The key required a force of approximately 10 g (0.098 N) to operate. An IEE projector behind the key allowed presentation of 12 colors and/or symbols onto the surface of the key. Two 6-cm diameter speaker holes, covered with white cloth, were centered on the right wall, 5 cm from the rear of the chamber. The top of the upper hole was flush with the ceiling and the lower hole was 2 cm below the upper one. The lower speaker was used to present continuous white noise throughout all experimental sessions. The upper speaker could be used to present a 400-Hz tone, which increased the sound level in the chamber by approximately 2 dB, from 85 to 87 dB SPL. Centered behind the translucent Plexiglas ceiling was a single #1820 pilot lamp that served as white houselight and was illuminated throughout all sessions. Four 110-V, 7-W red Christmas tree lamps were arranged in a circle around the houselight. They could be used to change the color of the illumination of the chamber. A one-way window was installed in the left wall. It was 8 cm high, extended from the front of the chamber 27 cm toward the rear, and was centered 18 cm from the chamber floor. Each chamber was housed in an insulated box that provided noise and light shielding and ventilation. Electromechanical control and recording equipment was located in an adjacent room.

Procedure

Trials were presented on a variable-time (VT) 30-sec schedule (range: 4 to 106 sec). Each trial was 12 sec long and consisted of CS1 presented for 4 sec, CS2 presented for 4 sec, and 4-sec access to grain. Except for the raising and illumination of the hopper, stimulus conditions during access to grain were identical to those during CS2. Figure 1 indicates the conditions for the first 32 birds, for which the key was illuminated white during the intertrial. There were eight birds in each of the four conditions. In the trace condition, the key was green during CS1 and white again during CS2. In the 8-sec delay condition, the key was green during both CS periods. In the 4-sec delay condition, the key remained white during CS1 and was illuminated red during CS2. In the serial condition, the key was green during CS1 and red during CS2.

Because the white key was much brighter than the red and green keys, 16 more birds

were included, eight each in a trace condition and an 8-sec delay condition with a red key during the intertrial (and the trace) and a green key during the signal. It should be noted that the trial stimuli for this trace group were identical to those for the serial group; only the intertrial stimuli differed.

On the day before the first autoshaping session, birds were allowed to approach and eat from the hopper as soon as it was raised. The key was not illuminated during hopper training. At the start of the first autoshaping session, birds were placed in the chamber with the hopper in the raised position. As soon as the bird began to eat, the hopper was lowered and the session begun. All sessions contained 60 trials. The first 32 birds were given 50 sessions, but since very few changes were observed after Session 25, the last 16 birds (with the red intertrial stimulus) were given 25 sessions. Key pecks had no scheduled consequences. They were recorded on counters and a four-pen event recorder. In addition, each bird was directly observed for a minimum of five trials each day, and notes were taken on behavior observed during all stimuli.

RESULTS

Figure 2 illustrates the number of trials to the acquisition of key pecking for each bird in each conditioning procedure, the groups being ordered by increasing mean trials. The trial on which acquisition occurred was defined as the first trial of a series of five trials in a row with at least one key peck. The circled *x*'s represent the geometric means, which are close to the medians and tend to be somewhat below the arithmetic means. Since the groups that received the red intertrial stimulus were not found to differ from those that received the white intertrial stimulus, these have been combined in the following analysis. The serial group conditioned fastest, with a median of 28 trials. The 4-sec delay group was next with a median of 58 trials. The 8-sec delay groups had an overall median of 73 trials, and the two trace groups had an overall median of 269 trials, or more than four sessions. One-tailed Mann-Whitney U tests were used to evaluate group differences. The 4-sec delay group did not differ significantly from either the serial group or the 8-sec delay group (p = 0.06 in both cases). All other differences were significant (p < 0.001 for each comparison).

Rates of key pecking varied widely between birds, and no consistent between-groups effects could be seen. This was due to individual differences in topography of the response, and to the fact that although most of the early pecks observed for all birds were pecks on the key, the location of many birds' pecks tended to drift over sessions so that most pecks fell near or just short of the key. For this reason, the proportion of within-trial key pecks that occur in each stimulus period, rather than rate, appears to be the most appropriate measure of the temporal distribution of pecks.

The next three figures show the changes over sessions in the proportion of within-trial pecks on the key that occurred during CS1 for the various groups. Sessions in which there were fewer than 25 total key pecks contributed no data to these figures. Figure 3 shows the proportion of key pecks in the first stimulus across 50 sessions for the eight pigeons that received the serial conditioning treatment. All pigeons initiated key pecking in CS2, but within a few trials key pecks were recorded in both CS1 and CS2. Over the next 10 sessions, three birds returned to a distribution markedly favoring CS2. On Day 25, all eight birds were key pecking. Direct observation of the birds revealed that for six of them, most of the pecks fell on the key; for two, most of the pecks fell near the key. Generally, these birds tended to peck faster and with a higher proportion of pecks hitting the key during CS2 than during CS1.

The results for the 4-sec delay group, for which CS1 was the same as the intertrial stimulus, are not presented in a figure, because all of these birds came to key peck exclusively in CS2. Direct observation indicated that all eight birds were pecking during the 4-sec conditioned stimulus in Session 25. Six of the eight were pecking primarily on the key, and two near the key.

Figure 4 presents the proportion of responding in the first half of the signal (corresponding to CS1) for the 8-sec delay group. Both the first few key pecks and subsequent responding were distributed fairly evenly between the two halves (CS1 and CS2) of the signal. In later sessions, three birds began to peck on the key more early (CS1) than late (CS2), five birds tended to key peck more late (CS2), and eight remained close to even. All 16 of these pigeons were observed to be pecking in Session 25.
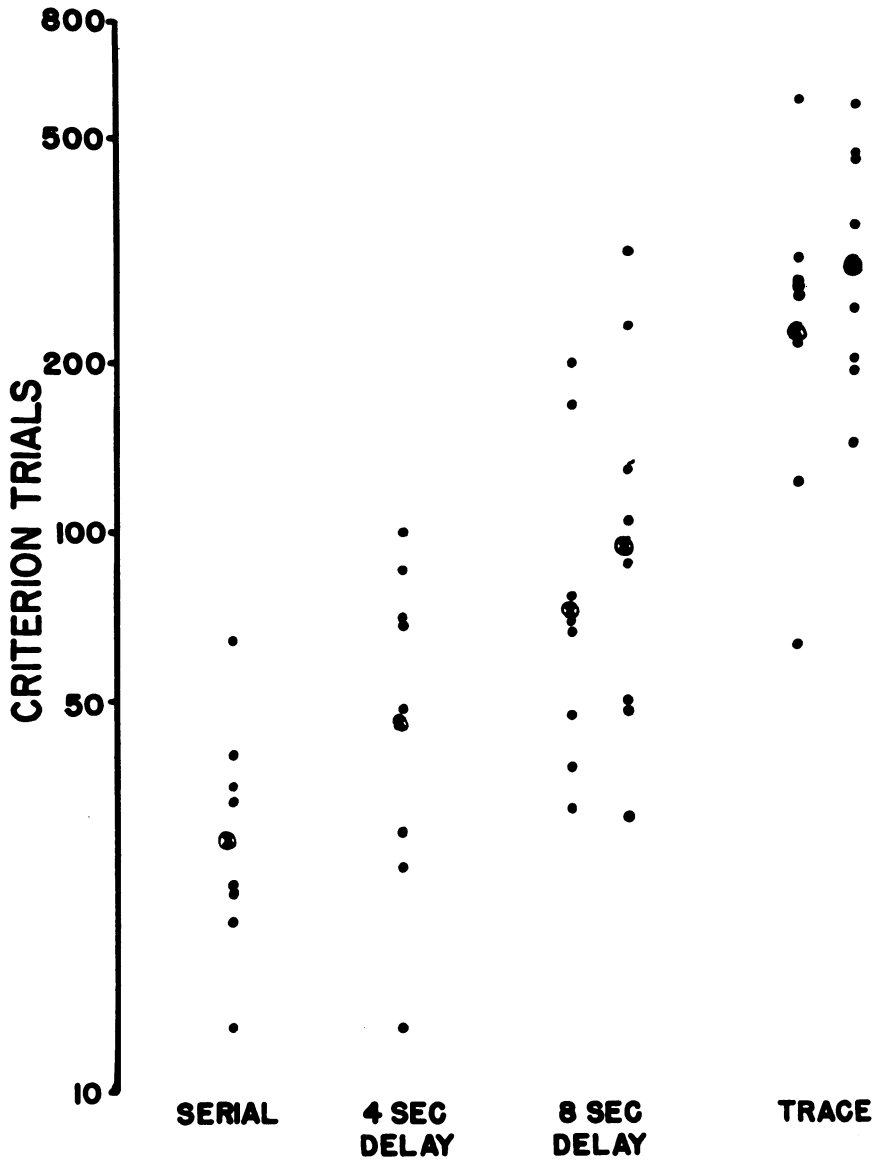
Fig. 2. Trials to criterion of acquisition of the key peck for individual pigeons in the four groups of Experiment I. The criterion trial was the first of five consecutive trials on which at least one key peck occurred. Trials are on a logarithmic scale. Ⓧ represents the geometric mean of each group. Subgroups of the 8-sec delay and trace groups are plotted in adjacent columns.

Twelve of them were pecking primarily on the key. The other four birds were all pecking near the key at a relatively constant rate.

To summarize, of 32 birds in the serial, 4-sec delay, and 8-sec delay procedures, all pecked on or near the key in Session 25.

The results for the trace group were distinctly different, as Figure 5 illustrates. In the early sessions all 16 birds made most of their key pecks during the first stimulus (*i.e.*, the signal period, CS1). The four birds that made more pecks during the trace (CS2) than during the signal only developed this pattern 10 or more sessions after acquiring the key peck. In Session 25, 15 birds remained in the experiment. One had been dropped when it stopped eating. All 15 pecked during the signal (CS1). Eight of the 15 were pecking primarily on the key, and the others were pecking short of, or near the key. During the trace (CS2), only 10 of
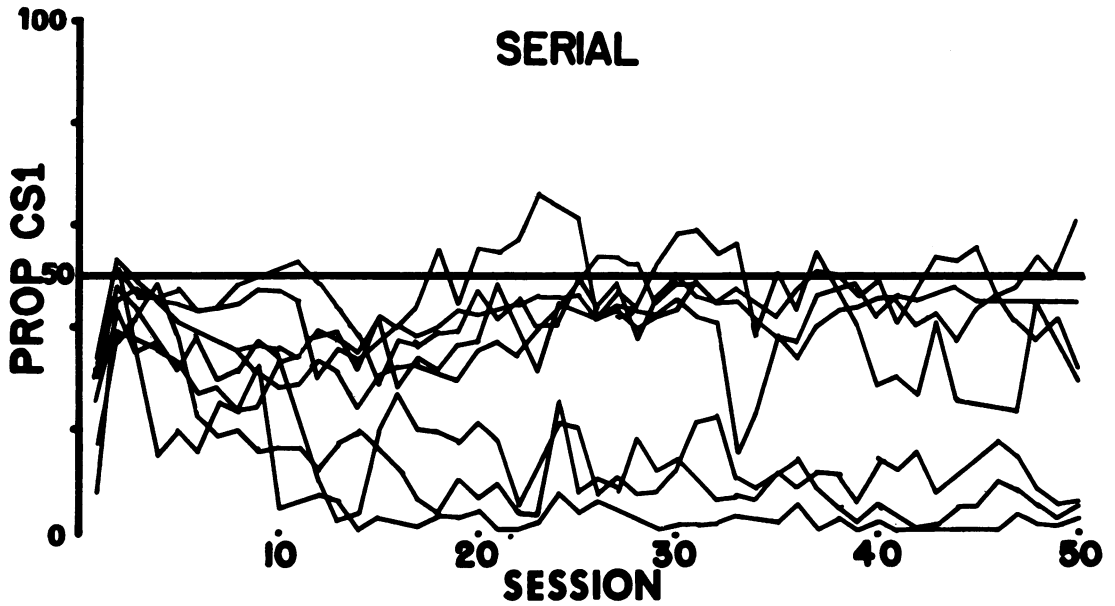
Fig. 3. Proportion of all within-trial key pecks that occurred during CS1 for individual birds in the serial conditioning procedure. Only sessions with at least 25 key pecks are plotted.
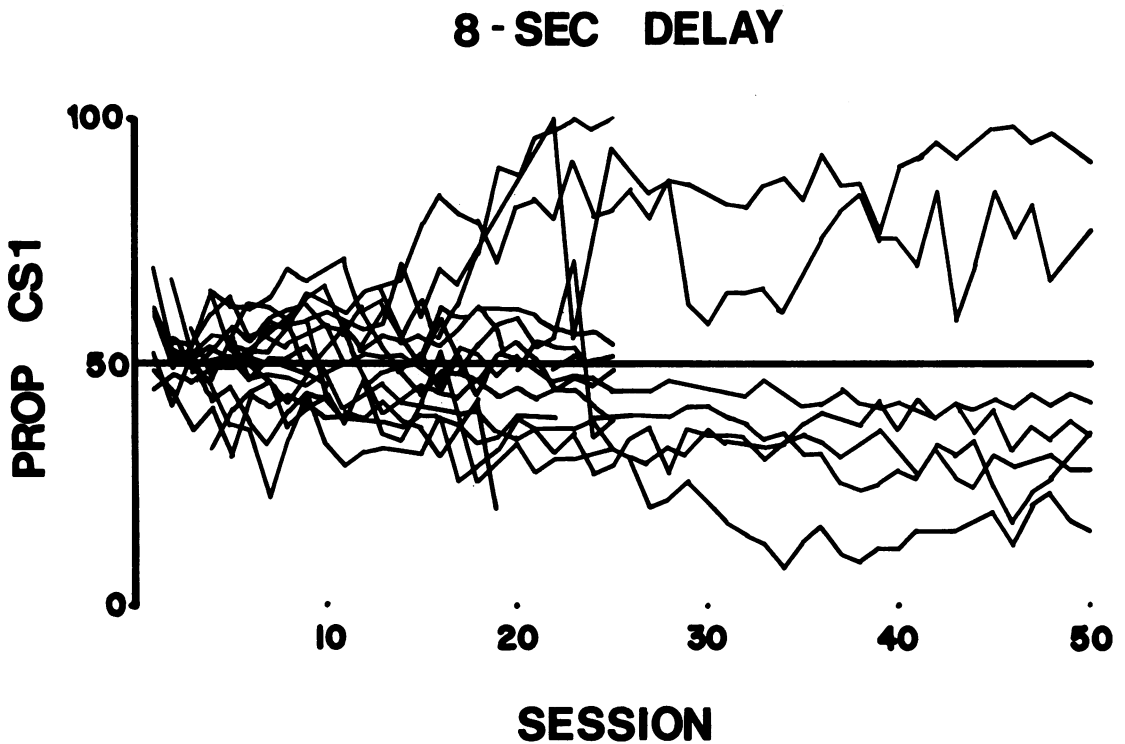

Fig. 4. Proportion of all within-trial key pecks that occurred during CS1 (the first half of the delay) for individual birds in the 8-sec delay conditioning procedure. Only sessions with at least 25 key pecks are plotted.
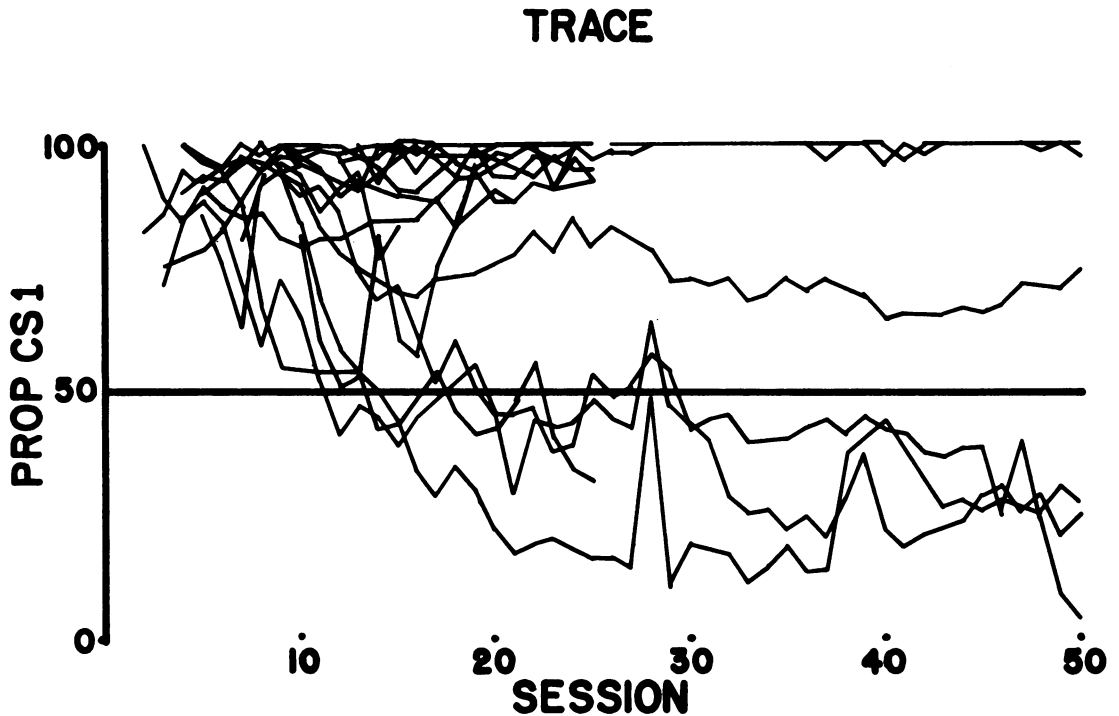
TRACE

Fig. 5. Proportion of all within-trial key pecks that occurred during CS1 (the signal period) for individual birds in the trace conditioning procedure. Only sessions with at least 25 key pecks are plotted.

the 15 were observed to be pecking. Four of the 10 were pecking on the key, four near the key, one in the lower-left front corner, and one pecked the floor in front of the hopper. Of the other five, two simply stopped directly before the key and waited, two bobbed up and down before the front wall (and therefore before key and hopper), and one turned to the left wall and shook its head left and right, a movement that looked somewhat like that used by pigeons to throw grit out of a food tray. None of these behaviors was seen during intertrial periods, even though the key color was the same as during the trace period.

Shortly after beginning to peck the key during the trial, virtually all birds made a large number of intertrial pecks over some period of time within the next two sessions. None of the birds maintained intertrial pecking for any sustained period.

DISCUSSION

The relative rates of acquisition of key pecking in the various conditions of Experiment I tended to be in agreement with data from other autoshaping studies, where such exist (Baldock, 1974; Groves, 1974; Ricci, 1973). No autoshaping studies compare trace and delay procedures with identical CS-UCS intervals. Even in this comparison, the present outcome, much faster acquisition of key pecking by the 8-sec delay group than by the trace group, is consonant with the literature on Pavlovian conditioning (*e.g.,* Ellison, 1964; Kamin, 1965).

Most of the present findings regarding the temporal distribution of pecks within trials also seem in accord with other data, *e.g.,* the higher rate of responding in CS2 than in CS1 in the serial conditioning procedure was also observed by Ricci (1973), and by Williams (1965). A variety of different trends in the temporal distribution of key pecks across delay autoshaping trials has been observed (Baldock, 1974; Gardner, 1969; Moore, 1971; Ricci, 1973; Wasserman, 1973). Some pigeons in the 8-sec delay group of Experiment I exhibited each of these trends, and no particular trend represented the group.

The temporal distribution of key pecks in the trace autoshaping procedure differs from the pattern most often reported in Pavlovian conditioning, *i.e.,* most of the (excitatory) conditioned responding during the trace period (Pavlov, 1927; Rescorla, 1968). In the present

study, 11 of 15 birds key pecked, and 15 of 15 pecked, during CS1, but only four of 15 key pecked and 10 of 15 pecked anywhere during the trace period.

EXPERIMENT II

Perhaps we failed to obtain a consistent increase in the rate of key pecking within each trial in the 8-sec delay autoshaping procedure because the CS-UCS interval was too short. Experiment II therefore included delay and trace autoshaping groups that received 28-sec CS-UCS intervals. Ricci (1973) conducted a delay autoshaping experiment with a 30-sec CS-UCS interval, and found no consistent pattern of responding within trials. However, Ricci administered only 600 trials, not an enormous number considering the slow development of certain patterns of responding in Experiment I. For example, key pecking in the trace interval of the 8-sec trace procedure developed only after more than 600 trials. Consequently, pigeons in Experiment II received from 1500 to 4000 autoshaping trials. To compensate for the increased CS-UCS interval, the average intertrial interval of Experiment II was increased to 2 min. Groups of pigeons that received 8-sec delay and 8-sec trace autoshaping treatments, but with a 2-min intertrial interval, were also included in Experiment II.

Because the short-trace autoshaping procedure of Experiment I produced off-key pecking in some birds, direct observations were continued in Experiment II, and an attempt was made to record some of the pecking that did not actuate the key in the long-trace procedure. Further, a more detailed description of the temporal distribution of pecks within trials was made possible by the use of computer analysis.

METHOD

Subjects and Apparatus

Subjects were 32 experimentally naive pigeons, and one pigeon (Bird 57) that had 12 days of the 28-sec trace procedure, then 10 days of the 8-sec trace procedure, then 13 more days of the 28-sec trace procedure (procedures to be described below). All subjects were male, retired breeders of the White Carneaux strain, and all were maintained as in Experiment I. The apparatus used was as described in Experiment I, except that in place of the four-

pen event recorder, a Friden Flexowriter was modified to punch the data, in 1-sec intervals, onto eight-track paper tape for computer analysis.

Procedure

Two trial lengths, 12 sec and 32 sec, and two procedures, delay and trace, were combined to yield four conditions: (1) 8-sec delay; (2) 8-sec trace, *i.e.*, a 4-sec signal followed by 4-sec trace; (3) 28-sec delay; and (4) 28-sec trace, *i.e.*, a 4-sec signal followed by 24-sec trace. The first two conditions were identical to the 8-sec delay and 8-sec trace conditions of Experiment I, except for the length of the intertrial interval. A VT 2-min intertrial interval (range: 1 to 510 sec), during which the key was white, was used. The signal (CS) was a green key, and white light again illuminated the key during the trace period. Key colors were maintained through the 4-sec food presentation.

Eight naive birds were assigned to each condition; however, one bird assigned to the 28-sec trace procedure died shortly after the experiment began, and the bird with previous experience on this schedule (Bird 57) was assigned to replace it. As in Experiment I, hopper training was conducted on the day preceding the first autoshaping session.

The birds in the 8-sec delay and 8-sec trace conditions received 25 sessions of 60 trials each. The birds in the 28-sec delay condition received 50 sessions of 50 trials each. The birds in the 28-sec trace condition received 80 sessions of 50 trials each. Number of sessions was determined on the basis of pilot studies and analysis of daily changes in performance.

All birds were directly observed on a minimum of five trials every fifth session, and notes were taken on the behaviors observed in all stimuli. Key pecks were recorded but had no scheduled consequences. Upon observation, it became apparent that for no bird in the 28-sec trace procedure did key pecking provide an accurate index of pecking. Therefore, in Sessions 76 through 80, the experimenter observed these birds on 20 trials during each session and operated a hand switch each time a clearly defined peck occurred. To establish the reliability of the procedure, the experimenter pressed a hand switch to record a pigeon's pecks on 20, 8-sec delay autoshaping trials. On consecutive five-trial blocks within the 20 trials, four other people recorded pecks

by operating a second hand switch. These people were given no further instructions or description of pecking. The procedure was repeated until distributions of pecks had been obtained from eight birds. The correlation, for all birds, of the experimenter's distribution of pecks across 2-sec intervals summed across 20 trials for a given bird with the composite distribution obtained from the other people was 0.98.

RESULTS

The 8-sec delay group conditioned faster (median = 18.0 trials to the acquisition criterion) than the comparable group (median = 73.0 trials) in Experiment I (p < 0.001). During the last five conditioning sessions, there were marked individual differences in the within-trials patterns of key pecking, as in the analogous condition of Experiment I. Five birds attained their maximum rate of key pecking within the first 2 sec of the trial, but three others showed an increase in rate across the trial. The continued increase for two of these birds occurred because they pecked the key early, but nibbled on it late, causing a high rate of key actuations. The mean latency for this group, calculated on those trials on which a key peck was actually recorded, was 1.79 sec.

The 8-sec trace group also conditioned more rapidly (median = 103 trials) than its counterpart in Experiment I (median = 269 trials, p < 0.05). Further, the 8-sec trace group conditioned more slowly than the 8-sec delay group (p < 0.01). One bird in the 8-sec trace group (#40) failed to eat regularly from the hopper and was dropped from the analysis. During the last five conditioning sessions, two of the seven remaining birds maintained key pecking throughout the trace period. Two others pecked the key briefly during the signal and then pecked rapidly in the air near the hopper opening during the rest of the trial. A fifth bird pecked at a rate of about two per second, but most of the pecks fell short of the key during CS1, and all were short during the trace. The sixth bird made a quick peck, usually short of the key, then pecked the floor in the left corner until the hopper operated. The seventh bird did not peck, simply moving to the key when CS1 occurred, and remaining there until food was presented. Mean latency of the key peck for this group was 1.46 sec. Finally, more than 30% of the trials analyzed

for the six birds that were observed to be pecking somewhere were without a single key peck.

The 28-sec delay group reached the acquisition criterion in a median of 71 trials, almost identical to that of the 8-sec delay group of Experiment I. Figure 6 shows the rate of key pecking for the 28-sec delay group for Days 8 through 12 (trials 351 through 600). The points are plotted for every 2 sec through food presentation. Most birds showed a large increase in rate of pecking over the first 4 sec, and then a more gradual increase or even some decrease across the remainder of the CS-UCS interval. The birds with a low rate of key pecking were observed to alternate key pecking with bobbing left and right before the key, rather than pecking off the key. The mean latency of the key peck was 5.02 sec, although approach to the key was almost always observed to be very rapid upon signal onset. The longer latencies were observed to be correlated with preening or facing away from the key at the onset of the trial, although a few of the birds with low rates would either miss the key, then bob, or bob and then peck, adding to their latencies.

Figure 7 shows the rates of key pecking for the pigeons in the 28-sec delay group on the last five days of training (Days 46 through 50 or trials 2251 through 2500). At this point in training, the rate of key pecking rose gradually for the six birds shown here, then declined again for three of those birds. Birds 11 and 373 had a rate of key pecking too low to make graphing practical. The latency data revealed that the onsets of key pecking were spread over the first third of the delay interval. The mean latency of the key peck had increased to 6.61 sec by this time. Observation showed that the birds were moving more slowly to the key than on earlier trials, although they usually began their movement at the onset of the signal. Once at the key, key pecking tended to be only one of the behaviors in which they engaged. Bobbing, pecking a corner of the front wall, or running the beak along the edge of the ceiling (each bird had its own idiosyncratic pattern) tended to be interspersed with key pecking. About halfway through the delay period a marked increase in rate of pecking was usually observed, but the proportion of all pecks that were on the key increased for some birds, decreased for others, and was unchanged for some.
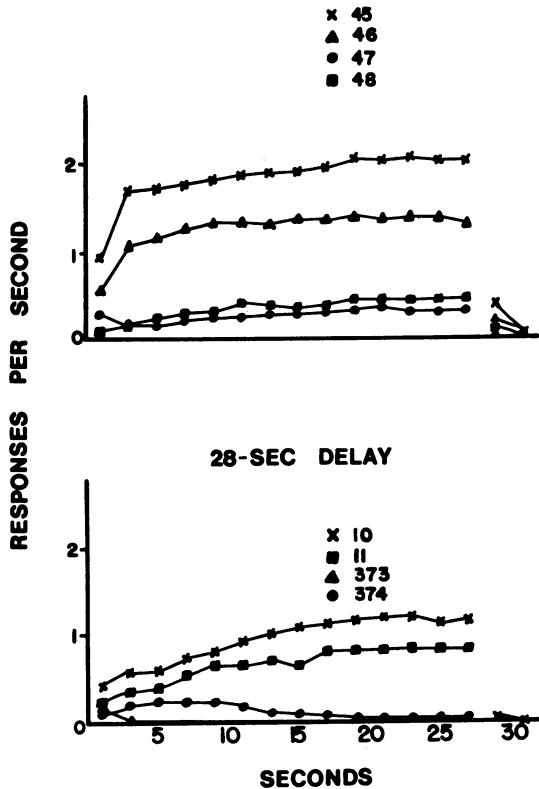
Fig. 6. Rate of key pecking across the 32-sec trial for individual pigeons in the 28-sec delay conditioning group of Experiment II. Data are from trials 351 through 600 (Sessions 8 through 12).
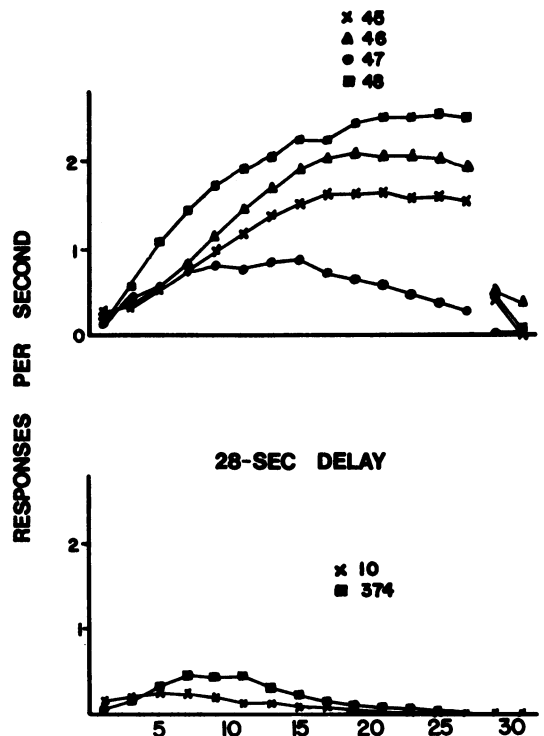
Fig. 7. Rate of key pecking across the 32-sec trial for individual pigeons in the 28-sec delay conditioning group of Experiment II. Data are from the last 250 trials of training, trials 2251 through 2500 (Sessions 46 through 50).

The 28-sec trace group did very little key pecking. If the first trial on which a key peck occurred is used as a measure of acquisition, the birds acquired key pecking in a median of eight sessions (range: 1 to 33 sessions). Key pecking, however, was irregular and rarely occurred on more than 10 trials in a session. The most normal occurrence was for key pecking to occur during the CS on from three to 10 trials in a session for about three to 10 sessions and then to cease. Observations showed a consistent pattern in the development of behavior of all birds, although the time parameters of this development varied greatly between birds. By Session 30, all birds developed an approach to the key during the signal. Within a session or two of their development, these approaches to the key developed into weak pecks that seldom operated the key. During the trace period, the birds would pace away from the key and return to their respective intertrial behaviors. Over the 10 to 20

sessions after approach to the key developed, behavior in the trace period became differentiated from the intertrial behavior. Somewhere around the thirtieth to the sixtieth session (depending on the individual bird) pecking began to develop near the *end* of the trace period. At about the same time, approaches to the key, and for some birds even orienting to the key, during the CS, diminished. The pecking at the end of the trace period tended to increase for some birds until it occupied a large fraction of the trace interval. The location of the pecks tended to be highly variable both between and within birds. Virtually every location in the front third of the chamber was sometimes occupied by a bird that stood there and pecked.

Figure 8 shows the rate of pecking at all locations, as recorded by the experimenter, for seven of the eight birds. The function for Bird 62 was similar to that of Bird 57, but the rate of pecking was lower than any shown. It is clear that the end of the signal and beginning

of the trace period did not cause a break in behavior. As noted above, approaches to the key were not observed during the CS; usually only a brief (about 1- or 2-sec) orientation toward the key was noted. After orienting to the key, the bird would immediately begin a pattern of behavior of which pecking gradually became a part. The mean latency of the peck was 8.73 sec.

DISCUSSION

The increase in rate of acquisition for the two groups given 12-sec trials and VT 2-min intertrial intervals over the analogous groups in Experiment I given VT 30-sec intertrial intervals, as well as the similar rates of acquisition of the 28-sec delay group of Experiment II and the 8-sec delay group of Experiment I, are in accord with the data of Baldock (1974), Groves (1974), and Terrace *et al.* (1975), who found that the number of trials to criterion was inversely related to the ratio of intertrial interval duration to trial duration.

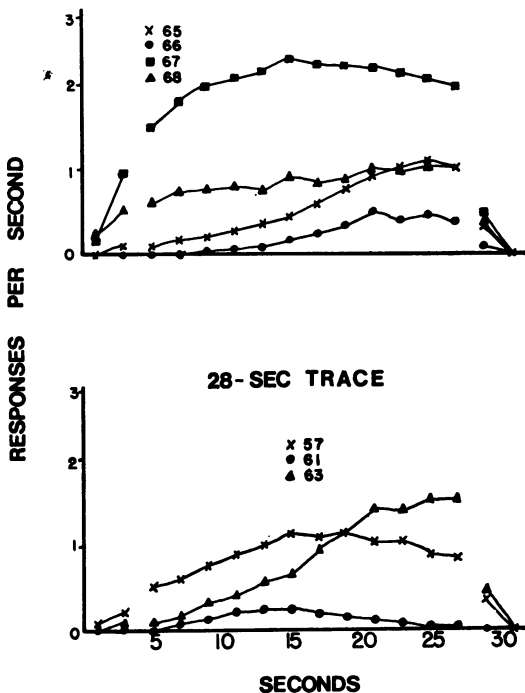It is clear that key pecking was representa-

Fig. 8. Rate of all pecking, as observed by the experimenter, across the signal, trace, and reinforcement periods for individual pigeons in the 28-sec trace conditioning group of Experiment II. Data are from 20 trials from each of the last five sessions of conditioning (Sessions 76 through 80).

tive of pecking in general only in the 8-sec delay condition and for the early trials in the 28-sec delay condition. These conditions were marked by almost immediate onset of highly directed, high-rate pecking. In the 8-sec trace condition, the first pecks within a trial were usually also directed onto the key. However, pecking left the location of the key even before the end of the signal. After extended training in the 28-sec delay condition, the onset of pecking tended to occur later and the behavior was less reliably directed toward the key. Finally, in the 28-sec trace condition, very little pecking, even that which appeared to be directed at the key, resulted in key actuations. The pecking behavior tended to begin later in the interval, often substantially after the signal had terminated, and to be diffusely directed over relatively large areas near the front of the chamber.

It seems that early in conditioning, or when the trial length is short, the key serves as an object at which pecking is directed. When there is no signal on the key or when the trial is relatively long, pecking is no longer as precisely directed, nor is it initiated soon after the onset of the signal. A pattern of behavior that is initiated by the onset of the signal includes pecking, especially near the time when food is normally presented. All this might look very Pavlovian, with the orienting and approach responses to the CS early in training and the more temporally controlled behavior later, if the length of the training needed were different. Konorski (1967) and Pavlov (1927) typically dealt with tens of trials to produce their effects; the present effects, especially when the CS-UCS interval was 28 sec, took thousands of trials.

EXPERIMENT III

The serial conditioning procedure of Experiment I, which produced rapid acquisition of key pecking, used keylight stimuli as both CS1 and CS2. Experiment III extended the serial procedure to the case where CS1 is not located on the key, but is a tone or a change in color of the general illumination in the chamber. The modality and localizability of the CS are important determinants of the outcome of an autoshaping experiment. Several authors (*e.g.*, Bilbrey and Winokur, 1973; Gamzu, 1968) have presented tones that pre-

ceded food while a key elsewhere was constantly illuminated or flashed irregularly, and have reported that no key pecking was obtained. Schwartz (1973) obtained some pecking at a constantly illuminated key during a tone that preceded food, but only when a compound of the tone and a change in the keylight had previously preceded food. Of course, in such a procedure the tone had been paired with reinforced key pecking, permitting the operation of contingencies other than the stimulus-stimulus (CS-UCS) one that characterizes classical conditioning. Jenkins (in Hearst and Jenkins, 1974) reported some pecks at an illuminated disc covering a loudspeaker through which an auditory signal for food was presented, but there was considerable variability. Further, Farthing (1971) reported that two of eight pigeons sometimes "pecked at" a speaker that emitted a tone CS that reliably preceded food, but six of the birds oriented to and pecked near the hopper during tone. Thus, it is not clear whether the lack of consistent autoshaping to auditory stimuli occurs because such stimuli may be difficult to localize and "peck at", or because birds fail to associate auditory stimuli with food. Foree and LoLordo (1973) showed that, given a history of treadle pressing for food in the presence of a compound houselight-tone stimulus, pigeons' responding was controlled by the houselight, but not by the tone, when it was presented alone, suggesting that the salience of tones may be very low in food situations.

Wasserman (1973) exposed pigeons to keylight changes preceding food under two conditions: houselight always or never illuminated. The birds with the houselight pecked the key, and those without failed to peck the key. Wasserman took this to mean that an effective CS in autoshaping must be a localizable stimulus. In the no-houselight condition, illumination of the key produced general illumination that could be detected from any part of the chamber. Therefore, the keylight was a redundant CS, and birds did not approach or peck the key. We do not know whether they were pecking elsewhere or not. On the basis of these data, a houselight CS would not be expected to elicit pecking on a constant key, though individual pigeons might be expected to peck distinctive features of the chamber during the CS.

A serial conditioning procedure that sub-

stitutes tone or houselight for the green keylight CS1 of Experiment I allows us to examine some of the effects of different CSs. If either tone or green houselight fails to become associated with food, then pigeons receiving this stimulus should behave like those in the 4-sec delay group of Experiment I. If tone or houselight is associated with food, but does not itself elicit key pecking, and the informativeness of the keylight CS2 is an important determinant of acquisition of the key peck (Allaway, 1971; Schwartz and Gamzu, *in press;* Wasserman, 1973), then CS2 could be considered a redundant stimulus in these serial procedures, and the key peck should be acquired more slowly than in the 4-sec delay group of Experiment I. In Experiment I, the serial conditioning group did acquire the key peck to CS2 rapidly, but that outcome might have depended on the use of a keylight change, which elicited pecking, as CS1.

METHOD

Subjects and Apparatus

Sixteen experimentally naive, male White Carneaux retired breeders were maintained as in Experiment I. The apparatus used was the same as in Experiment I.

Procedure

The procedure was identical to that given to the serial autoshaping group of Experiment I, except that for eight birds, CS1 was the addition of a 400-Hz tone to the existing white noise and for eight birds CS1 was the addition of the green houselight to the existing white houselight. The keylight remained white during CS1; CS1 lasted for 4 sec, and CS2 (a red keylight) lasted for 8 sec, the last 4 sec of which overlapped 4-sec access to grain. The intertrial interval averaged 30 sec, during which the keylight was white, the white noise was on, and the houselight was white. All birds were manually hopper trained on the day preceding the first autoshaping session. Each bird was watched for a minimum of five trials each session and notes were taken on its behavior in all stimuli. Key pecks were recorded, but had no scheduled consequences. There were 25 sessions of 60 trials each.

RESULTS

The tone group reached the acquisition criterion, five trials in a row with at least one

peck, in a median of 33.5 trials, or slightly faster than the 4-sec delay group of Experiment I (median = 58 trials). The houselight group reached criterion in a median of 68 trials, and was significantly slower than the tone group (p < 0.05, two-tailed Mann-Whitney U Test). Both groups reached criterion more slowly than the serial group of Experiment I (median = 28 trials). This difference was not significant for the tone group, but was for the houselight group (p < 0.01, two-tailed Mann-Whitney U Test). All birds began pecking the key during the red keylight (CS2) substantially before any pecking, either on or off the key, was observed during either houselight or tone.

Figure 9 shows the proportion of key pecks during CS1 for the houselight group. Within very few sessions, most birds were pecking the key during the houselight signal. Observation revealed that the first few presentations of the houselight elicited mild alerting responses (*i.e.*, the birds looked about a little), which rapidly disappeared (before key-peck conditioning occurred). There followed a time, usually one-half to two sessions, during which the houselight produced no noticeable changes in behavior. During this time, the birds began to peck the key during the red keylight component (CS2). Finally, during the houselight (CS1), a rapid transition from orientation and a few pecks *near* the key to pecking on or near the key on every trial was noted. By Session 25, all six of the remaining birds (two were dropped when they stopped eating from the hopper) were consistently pecking on or near the key during the houselight and during the keylight signals, though when the green houselight was illuminated there was a marked tendency to bob or run the beak over a wall or the ceiling or peck somewhere away from the key before moving to the key. Each bird had its own idiosyncratic performance. In Experiment I, on the other hand, the birds approached the key rapidly as soon as the color changed.

The tone group (Figure 10) showed much the same effect as the houselight group, but the effect developed much more slowly. At the beginning of training, the tone caused a strong alerting response. The birds stopped, looked around, but were not noted to look particularly at the speaker near the rear of the chamber. The birds were usually still reacting in this way to the tone after they began to peck the key. This reaction to the tone gradually disappeared, but in contrast to the houselight group, the period during which no reactions were observed during the tone lasted from six to 10 sessions. Gradually, a peck response and a key-orienting response emerged together during the tone. For most birds, this consisted of alternating between stopping wherever they

Fig. 9. Proportion of all within-trial key pecks that occurred during CS1 (the green houselight) for individual pigeons in the green houselight group of Experiment III. Only sessions with at least 25 key pecks are plotted.
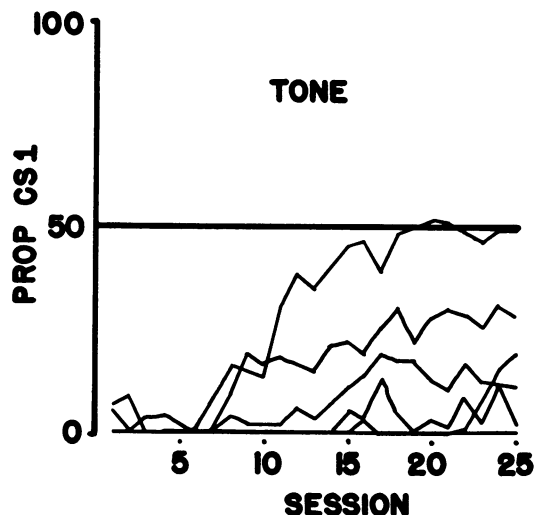
Fig. 10. Proportion of all within-trial key pecks that occurred during CS1 (the tone) for individual pigeons in the tone group of Experiment III. Only sessions with at least 25 key pecks are plotted.

were and pecking, and moving to the key, often pecking on the way. By Session 25, all eight birds were consistently pecking on the front wall during the tone and on or near the key during the keylight signal. In this group too, during the tone each bird seemed to have a brief pattern of other behavior that occurred just before pecking. The tone group, unlike any other group reported thus far, maintained a consistent although low rate of intertrial pecking, which never exceeded 20% of the rate during the tone.

DISCUSSION

Acquisition in each group proceeded during CS2 much as it did in the 4-sec delay group. The more rapid acquisition of key pecking in the tone group than in the green houselight group was probably due to the stronger alerting responses to the tone, leading to more effective keylight-food pairings early in training, but not to a specific effect of tone pairings with either keylight or food. It is not clear whether the tone and houselight pairings with keylight or with food were the critical variables determining pecking during CS1. But the fact that pecking took much longer to develop during the tone than during the green houselight may be related to the findings of Foree and LoLordo (1973) for discriminated operant treadle pressing. They found that a houselight element of a compound stimulus signalling the availability of food overshadowed an auditory element, but the reverse was true when the compound signalled avoidable shock. This outcome suggests that houselight stimuli are more easily associated with food than are tones.

Allaway (1971) found that the rate of autoshaping to a 6-sec keylight CS was significantly retarded if a tone preceded illumination of the key by 2 sec on each trial and overlapped it, suggesting the importance of the informativeness of CS2. Neither of the serial conditioning procedures of Experiment II produced such an outcome, relative to the 4-sec delay group of Experiment I. Perhaps the retardation observed by Allaway depended on the overlap of CS1 and CS2, so that the (tone) CS1 was contiguous with food reinforcement.

The first pecks observed in the presence of the tone or green houselight did not occur on the key nor in any consistent location, but appeared to be "elicited" by the tone or the houselight at the location the bird happened to occupy at the time. Only later was pecking "withheld" until the bird reached a specific location, usually near the key. Even after 25 days of training most of the systematic behavior, including most of the pecking, that occurred during CS1 was not being reflected by key pecking. The final distribution of key pecks during the trial was similar to that of the serial group in Experiment I, i.e., pecking during both CS1 and CS2, and more pecking during CS2.

GENERAL DISCUSSION

In the present experiments, where the CS was a change of illumination on the pigeon key and when data reported were from early in the training of experimentally naive pigeons, key pecking, or responding directed to the CS, appeared to be a good measure of conditioning. However, either after a large number of pairings of a keylight and food, or when the CS was relatively diffuse, key pecking no longer provided orderly measures of conditioning. Under all circumstances, however, pecking (all pecks including key pecks) appeared to provide orderly data. Comparisons of off-key pecking and key pecking revealed a number of differences that changed depending on the situation. The key peck occurred most frequently early in training, was directed toward a small area, and began with a short latency after the onset of the signal regardless of CS length. The peck that occurred most frequently late in training and with diffuse stimuli was directed across a much larger area, usually near the location of the UCS, and began to occur substantially after onset of the stimulus.

The temporal distribution of pecks and their nondirectedness late in training or with diffuse stimuli is in line with the findings of Konorski (1967), Pavlov (1927), and others as regards location of classically conditioned responses in both space and time. The temporal distribution and directedness of key pecks is consistent with the results of autoshaping experiments. This outcome leads to the conclusion that specific attributes of responses contribute importantly to the results and interpretations of experiments that use classical conditioning procedures (cf. Schneiderman, 1972). "Autoshaping", "sign-tracking", and

"directed respondent" seem to describe adequately the outcome of experiments in which key pecking is found to be an orderly response. On the other hand, Pavlovian or temporal respondent seems to provide a better description of the outcome of experiments in which pecking other than key pecking is found to be an orderly response. As with most divisions of behavior, this one is relatively arbitrary. Its appropriateness will depend on whether it is useful in helping to organize the results of conditioning experiments.

REFERENCES

Allaway, T. A. *Attention, information, and autoshaping.* Unpublished Ph.D. dissertation, University of Pennsylvania, 1971.

Baldock, M. D. *The effects of trial and intertrial durations upon the acquisition and maintenance of the autoshaped keypeck.* Unpublished Ph.D. dissertation, Columbia University, 1974.

Bilbrey, J. and Winokur, S. Controls for and constraints on autoshaping. *Journal of the Experimental Analysis of Behavior,* 1973, 20, 323-332.

Brown, P. L. and Jenkins, H. M. Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior,* 1968, 11, 1-8.

Church, R. M. and Black, A. H. Conditioned heart rate and CS-UCS interval. *Journal of Comparative and Physiological Psychology,* 1958, 51, 478-482.

Ellison, G. D. Differential salivary conditioning to traces. *Journal of Comparative and Physiological Psychology,* 1964, 57, 373-380.

Farthing, G. W. Effect of a signal previously paired with free food on operant response rate in pigeons. *Psychonomic Science,* 1971, 23, 343-344.

Foree, D. D. and LoLordo, V. M. Attention in the pigeon: The differential effects of food-getting *vs.* shock-avoidance procedures. *Journal of Comparative and Physiological Psychology,* 1973, 85, 551-558.

Frey, P. W., Englander, S., and Roman, A. Interstimulus interval analysis of sequential CS compounds in rabbit eyelid conditioning. *Journal of Comparative and Physiological Psychology,* 1971, 77, 439-446.

Gamzu, E. *The classical conditioning paradigm in the "autoshaping" of the pigeon's key-peck.* Unpublished Master's thesis, University of Pennsylvania, 1968.

Gardner, W. M. *An analysis of auto-shaping.* Unpublished Ph.D. dissertation, University of Alabama, 1969.

Groves, L. C. *The effects of trial and cycle durations on automaintenance in the pigeon.* Unpublished Ph.D. dissertation, University of North Carolina at Greensboro, 1974.

Hearst, E. and Jenkins, H. M. *Sign-tracking: the stimulus-reinforcer relation and directed action.* Austin, Texas: The Psychonomic Society, 1974.

Kamin, L. J. Temporal and intensity characteristics of the conditioned stimulus. In W. F. Prokasy (Ed.), *Classical conditioning.* New York: Appleton-Century-Crofts, 1965. Pp. 118-147.

Kharchenko, P. D. *Delayed conditioned reflexes.* Kiev: Kiev University Press, 1960.

Konorski, J. *Integrative activity of the brain.* Chicago: University of Chicago Press, 1967.

Longo, N., Klempay, S., and Bitterman, M. E. Classical appetitive conditioning in the pigeon. *Psychonomic Science,* 1964, 1, 19-20.

Moore, B. R. *On directed respondents.* Unpublished Ph.D. dissertation, Stanford University, 1971.

Newlin, R. J. *The relation of Pavlovian and autoshaping outcomes.* Unpublished Ph.D. dissertation, University of North Carolina at Chapel Hill, 1974.

Pavlov, I. P. *Conditioned reflexes.* (Trans. by C. V. Anrep). London: Oxford University Press, 1927.

Razran, G. *Mind in evolution.* Boston: Houghton Mifflin, 1971.

Rescorla, R. A. Pavlovian conditioned fear in Sidman avoidance learning. *Journal of Comparative and Physiological Psychology,* 1968, 65, 55-60.

Ricci, J. A. Key pecking under response-independent food presentation after long simple and compound stimuli. *Journal of the Experimental Analysis of Behavior,* 1973, 19, 509-516.

Schneiderman, N. Response system divergencies in aversive classical conditioning. In A. H. Black and W. F. Prokasy (Eds.), *Classical conditioning II.* New York: Appleton-Century-Crofts, 1972. Pp. 341-378.

Schwartz, B. Maintenance of key pecking by response-independent food presentation: the role of the modality of the signal for food. *Journal of the Experimental Analysis of Behavior,* 1973, 20, 17-22.

Schwartz, B. and Gamzu, E. Pavlovian control of operant behavior: An analysis of autoshaping and of interactions between multiple schedules of reinforcement. In W. K. Honig and J. E. R. Staddon (Eds.), *Handbook of operant behavior.* Englewood Cliffs, N.J.: Prentice-Hall, in press.

Terrace, H. S., Gibbon, J., Farrell, L., and Baldock, M. D. Temporal factors influencing the acquisition of an autoshaped response. *Animal Learning and Behavior,* 1975, 3, 53-62.

Wasserman, E. A. The effect of redundant contextual stimuli on autoshaping the pigeon's keypeck. *Animal Learning and Behavior,* 1973, 1, 198-206.

Williams, D. R. Classical conditioning and incentive motivation. In W. F. Prokasy (Ed.), *Classical conditioning.* New York: Appleton-Century-Crofts, 1965. Pp. 340-357.