SIGNALLED FREE-OPERANT AVOIDANCE OF SHOCK BY PIGEONS PECKING A KEY¹

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Two pigeons were trained to peck a key under a free-operant avoidance schedule. Then, changes in key color signalled the beginning (safe period) and the end (warning period) of the response-shock interval, with a response required to change the key color. Finally, a change in key color signalled the warning period and either a response or a shock reinstated the safe stimulus. During signalled avoidance, response rate was higher during the warning stimulus than during the safe stimulus. More responding tended to occur in the warning stimulus when it was terminated by either a response or a shock than by only a response. In either procedure, response latency during the warning stimulus was a function of the duration of the warning stimulus. In general, response and shock rate were higher during unsignalled than during signalled avoidance. When the warning stimulus was brief, the results were similar to those of unsignalled avoidance. These results confirm previous findings with pigeons, are in general agreement with data provided by other species in studies of signalled avoidance, and thereby indicate the transituationality of the key-pecking operant.

Key words: avoidance, stimulus control, key pecking, pigeons

Signalled and discriminated avoidance designate experimental procedures in which a warning signal appears at a fixed time interval before a scheduled shock. Responses before the onset of the warning stimulus postpone its appearance and the scheduled shock; responses during the warning signal terminate it and postpone the shock. If a shock is not avoided, the shock may terminate the warning signal and initiate a new "trial" (Sidman, 1955), or the warning stimulus may be removed only by the next response (Ulrich, Holz, and Azrin, 1964). Frequent responding during the signal and a lower frequency in its absence occur when the subjects are rats (Keehn, 1959; Sidman, 1955; Sidman and Boren, 1957; Ulrich *et al.*, 1964), fish (Behrend and Bitterman, 1963), monkeys (Hyman, 1969; 1971; Sidman, Mason, Brady, and Thach, 1962), or pigeons (Foree and LoLordo, 1970; 1974). This phenomenon has been referred to as stimulus control of avoidance behavior (Ulrich *et al.*, 1964).

The procedures relate to the interpretation of a stimulus that precedes shock. If warning signals become conditioned aversive stimuli, responses in the presence of the warning stimulus are maintained because they terminate (escape from) an aversive stimulus and postpone or avoid shock. Responding during the safe stimulus is maintained because the warn-

ing stimulus is postponed or avoided. The procedures, then, permit analysis of whether the warning stimulus maintains escape and/or avoidance.

Other things being equal, the warning stimulus in the signalled avoidance procedure used by Ulrich *et al.* should be more aversive than that used by Sidman. A higher frequency of shocks in the absence of responding is associated with the warning signal when the shock-shock (S-S) interval is shorter than the response-shock (R-S) interval and only a response can terminate the warning signal. Thus, if responding during the safe period is maintained by postponement of the warning signal, more responding in the absence of the signal should be observed in the "response-only" than in the "response or shock" procedure.

However, more responding was observed during the safe period in Sidman's (1955) experiment than in Ulrich's *et al.* (1964) experiment. One possible explanation is that the warning signal was more aversive in Sidman's

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experiment. The second explanation refers to the modality of the stimulus used as a signal: Sidman used a flashing light, Ulrich *et al.* a buzzer. The greater stimulus control found by Ulrich *et al.* may reflect the greater effectiveness of auditory stimuli as a warning signal for rats (Bolles, 1967, p. 411).

One purpose of the present experiment was to compare the procedures when the same subject was exposed to both, and with a stimulus involving the same modality as the warning signal. Another purpose was to investigate the control of pigeon's key pecking under a signalled avoidance procedure. The difficulty in shaping and maintaining key pecking through negative reinforcement has been cited as one example of a special relation between some responses and some strong stimuli (Bolles, 1970; Seligman, 1970; Smith and Keller, 1970; Staddon and Simmelhag, 1971). Responses other than key pecking produce both discriminated and unsignalled avoidance behavior in pigeons (Macphail, 1968; Smith and Keller, 1970). Attempts to train and maintain key pecking through shock postponement have met with difficulties (Hoffman and Fleshler, 1959; Rachlin and Hineline, 1967). Hineline and Rachlin (1969) were successful only when pigeons were trained to escape a train of shocks of gradually increasing intensity. Combining Hineline and Rachlin's procedure with the method of successive approximations, Ferrari, Todorov, and Graeff (1973) and Todorov, Ferrari, and Souza (1974) were able to train key pecking. After the response was established, it was maintained by an unsignalled avoidance procedure in the same manner as other responses in the same or other species. Control by a signalled avoidance procedure would support the notion that once key pecking is established, it is controlled in the same way as other operants.

METHOD

Subjects

Two experimentally naive adult, male domestic pigeons (GE and CG) were used. The subjects were from uncontrolled derivations of the species *Columba livia*. Subjects were kept in individual home cages that provided free access to food and water. Electrodes implanted around the pubis bones were attached to a leather harness that was worn by the birds at all times (Azrin, 1959).

Apparatus

A standard experimental chamber for pigeons (33 by 30 by 32.5 cm), contained two translucent response keys that were 2 cm in diameter, 4 cm apart, and located 21 cm from the floor and 12.5 cm from the side walls. The left key was dark and inoperative. A minimum force of 0.01 N operated the response key and produced auditory feedback by operating a relay.

A mercury swivel with a plug was attached to the ceiling. Before each experimental session, the wires from the mercury swivel were connected to the electrodes fixed on the leather harness. The subjects could move freely inside the experimental chamber. Shock was produced with a modified Foringer shock source, equipped with a 40-K ohm series resistor. A pulse former controlled shock duration (35 msec); shock intensity (10 mA) was measured by using a 1-K ohm resistor in place of the birds.

Procedure

Subjects were trained to peck a transilluminated response key through negative reinforcement by the technique described by Ferrari *et al.* (1973). The room and the experimental chamber were darkened, the only illumination coming from a red light behind the response key. A train of 35-msec shocks was delivered at 0.5-sec intervals, with intensity gradually increasing from 0 to 10 mA. Any movement of the subject toward the response key stopped the shock for 15 sec. The response requirement was slowly changed by the method of successive approximations until the first effective key peck occurred. Any movement away from the response key was followed by an increase in shock intensity (up to 10 mA). After the first key peck, the response-shock interval was increased to 30 sec, and the session was continued until the one hundredth response was emitted. Both subjects emitted the first key peck and reached the one hundredth response criterion during the first experimental session (shaping session). The time required for the first and the one hundredth response was 70 and 107 sec for Subject GE and 17 and 122 sec for Subject CG. The experimental procedure was then divided in six phases:

Phase I. Unsignalled avoidance with R-S = 17 sec, S-S = 2 sec. Subjects had daily 2-hr ses-

Fig. 1. Schematic representation of the signalled avoidance conditions. (a) $R-S = 17$ sec, $S-S = 2$ sec. The warning signal (red) was terminated by a response only. Yellow signalled the safe period: in the example, safe-period duration was 10 sec, and the period between the onset of the warning stimulus and shock was 7 sec. (b) The same as a, but red signalled the safe period, green the warning period. (c) $R-S = S-S = 20$ sec. The warning signal (green) was terminated either by a response or a shock. The period between the onset of the warning stimulus and shock was 10 sec. Red signalled the safe period (10 sec).

sions in an unsignalled avoidance procedure until response rate stabilized. Response rate was considered stable when, after a minimum of 10 sessions, (a) cumulative response records indicated rate stability (through visual inspection) for at least six consecutive sessions, and (b) the difference between the average rate of responding of the first three and the last three of these sessions was less than 10% of the average rate in all six sessions. A red light transilluminated the response key throughout the session. Responses had only two scheduled

consequences in this phase: auditory feedback and shock postponement.

Phase II. Signalled avoidance with a new stimulus associated with a safe period in the R-S interval: warning stimulus termination by a response only. Phase II involved a signalled avoidance procedure similar to that used by Ulrich *et al.* (1964). The R-S and S-S intervals remained at 17 sec and 2 sec respectively. A session began with red light on the response key and shocks delivered at 2-sec intervals. A response changed the key color to yellow and

established a period of 17 sec free from shock (Figure 1a). In different conditions, the yellow light lasted 2, 5, 10, or 15 sec after a response. Each response in the presence of the yellow light reset the timer and also reset the response-shock interval. If no response was made after onset of the yellow light, the key color changed to red. A response in the presence of the red light changed the key to yellow and reset the response-shock interval. When no response occurred after onset of the red light and before 17 sec had elapsed since the last response, shock was delivered at 2-sec intervals until a response occurred.

Shock occurred only in the presence of the red light, and always after a fixed time (2, 7, 12, or 15 sec). The red light was called the warning signal, the period between its onset and the first shock was designated the warning period, the yellow light was called the safe signal, and the period between a response and the red light was called the safe period.

Changes from one experimental condition to the next occurred when response rate reached the stability criterion described for Phase I. The order of conditions is given in Table 1.

Phase III. Unsignalled avoidance. In Phase III, the unsignalled avoidance procedure was re-instated. The red light was on throughout the session and no exteroceptive stimulus signalled impending shock. Response-shock and shock-shock intervals remained at 17 and 2 sec respectively.

Phase IV. Signalled avoidance with a new stimulus associated with a warning period in the R-S interval: warning stimulus termination by a response only. As shown in Figure 1b, the procedure of Phase IV was the same as Phase II, except that a green light signalled the warning period. The safe period was signalled by a red light (the same color present in unsignalled avoidance). Subject GE was tested with safe-signal duration of 15 sec and warning-signal duration of 2 sec. Subject CG had safe-signal durations of 15 and 10 sec.

Phase V. Signalled avoidance with warning stimulus termination by either a response or a shock. The R-S and S-S intervals both equalled 20 sec. The warning stimulus was terminated by a response or a shock, whichever occurred first (Figure 1c). Colors signalling the safe (red) and warning (green) periods were the same as in Phase IV. Table 1 shows that each subject

Table 1
Response-shock and shock-shock intervals, duration and color of safe and warning stimuli, number of sessions, and order of presentation of all experimental conditions for both subjects.

Phases	Safe Signal		Warning Signal				Subject GE		Subject CG	
	RS	SS	Duration		Duration		Sessions		Sessions	
	(sec)	(sec)	(sec)	Color	(sec)	Color	Order	Order	Order	Order
I	17	2		Unsignalled (red)			94	1	56	1
II	17	2	15	yellow	2	red	57	5	19	2
	17	2	10	yellow	7	red	22	4	32	5
	17	2	5	yellow	12	red	23	2	23	3
	17	2	2	yellow	15	red	23	3	21	4
	17	2	15	yellow	2	red	—	—	21	6
III	17	2		Unsignalled (red)			31	6	23	7
IV	17	2	15	red	2	green	51	7	18	8
	17	2	10	red	7	green	—	—	25	9
V	20	20	15	red	5	green	17	8	20	10
	20	20	10	red	10	green	16	10	19	12
	20	20	5	red	15	green	28	9	24	11
	20	20	15	red	5	green	24	11	18	13
	20	20	10	red	10	green	16	12	17	14
	20	20	5	red	15	green	25	13	17	15
VI	20	20		Unsignalled (red)			10	14	16	16

had three different values of warning-signal duration, each value occurring twice (5, 15, 10, 5, 10, 15 sec, in that order).

Phase VI. Unsignalled avoidance. The red light was on throughout the session and no exteroceptive stimulus signalled impending shock. The R-S and S-S intervals were 20 sec, as in Phase V.

RESULTS

Response Rates

The last six sessions of each condition were considered. Figure 2 shows the overall rate of key pecks in the six phases. In Phases I and II, the change from unsignalled to signalled avoidance with a new stimulus (yellow light) associated with the safe period had little effect on response rate. The rate of responding of Subject GE was 10.0 responses per minute in unsignalled avoidance, and varied from 7.2 to 11.3 responses per minute when the time between onset of the warning stimulus and shock delivery was changed from 2 to 15 sec. For Subject CG, response rate in unsignalled avoidance was 8.0 responses per minute, varying from 6.7 to 9.5 in signalled avoidance. For both subjects, response rate when the warning-signal duration was 2 sec was higher than in the previous conditions of unsignalled avoidance. (Here and in subsequent Figures the conditions within phases are not presented in order of occurrence. See Table 1 for sequence of conditions.)

The return to unsignalled avoidance (Phase III) increased response rates of both subjects. The rate of responding from Subject GE increased from 11.0 responses per minute in the last condition in signalled avoidance to 19.7 responses per minute in unsignalled avoidance. For Subject CG, the change was not as drastic (from 9.5 to 11.4 responses per minute) as it was for Subject GE.

When a new stimulus (green light) was introduced to signal the warning period in Phase IV, response rates decreased to levels comparable to those of Phase II. The only differences between signalled avoidance in Phases II and IV were the color on the response key (yellow-red and red-green, respectively) and the part of the response-shock interval with which the new stimulus was associated (yellow with the safe period in Phase II and green with the warning period in Phase IV). In Phase V, the

data from the first three experimental conditions showed different effects for the two subjects. Subject GE had lower response rates than in any previous condition. Subject CG had response rates in the same range as that in previous signalled avoidance conditions. In Phase V, the colors were the same as in Phase IV, with green signalling the warning period, but (a) the response-shock and shock-shock intervals were changed from R-S = 17 sec and S-S = 2 sec to R-S = S-S = 20 sec; and (b) the conditions for terminating the warning stimulus and re-instating the safe stimulus were changed from a response to either a response or a shock. Replication of the three experimental conditions in Phase V revealed lower response rates than in any previous condition.

When the unsignalled avoidance procedure was re-instated (Phase VI), now with R-S = S-S = 20 sec, response rates increased. For Subject GE, the increase was from 5.0 responses per minute in signalled avoidance to 8.7 responses per minute in unsignalled avoidance. For Subject CG, the increase was from 5.4 to 8.8 responses per minute.

Shock Rates

Figure 3 shows rates of shock delivery for the same sessions. In Phase II, for both subjects, shock rate decreased under the signalled avoidance procedure. The return to unsignalled avoidance in Phase III increased shock rates of both subjects (considering only the last condition of signalled avoidance).

A new stimulus (green light on the response key) signalling the 2-sec warning period in Phase IV increased rate of shocks for both subjects, with a greater increase for Subject GE. When the warning period was increased to 7 sec for Subject CG, shock rate decreased to the lowest rate emitted by this subject throughout the experiment.

Rates of shocks in the signalled avoidance conditions of Phase V were generally low for both subjects, varying from 0.05 to 0.29 and from 0.11 to 0.22 shocks per minute for Subjects GE and CG respectively. A direct comparison of these shock rates with those of Phases II and IV is not possible, because the rate of shocks scheduled by the conditions in Phase V (R-S = S-S = 20 sec) was lower than those scheduled in Phases II and IV (R-S = 17 sec and S-S = 2 sec). Shock rates in Phase V can be evaluated when compared to Phase VI.

Fig. 2. Overall response rates in the six phases. Filled columns indicate rate of responding in the unsignalled avoidance conditions. Unfilled columns indicate response rates in the signalled avoidance conditions. Numbers refer to length of time (in seconds) between onset of the warning signal (S_w) and shock. In this and subsequent Figures, Table 1 should be consulted for the sequence of conditions within phases.

Shock rates increased when the unsignalled avoidance procedure was re-introduced.

Stimulus Control

Figure 4 shows response rates during the safe and warning periods of the response-shock interval. Response rate in the warning period was obtained by dividing the number of responses emitted in the presence of the warning stimulus by the time the warning stimulus was

on. Rate of responding during the safe period is the number of responses in that period divided by the time the safe signal was on. Figure 4 shows that rate of responding during the warning stimulus was higher than responding in the presence of the safe stimulus, with only two exceptions.

Stimulus control of avoidance defined only in terms of different rates under the safe and warning stimuli may be misleading. A sub-

Fig. 3. Shocks delivered per minute in the six phases. Filled columns indicate shocks per minute in the unsigalled avoidance conditions. Unfilled columns indicate shocks per minute in signalled avoidance. Numbers refer to length of time (in seconds) between onset of the warning signal (S_w) and shock.

ject may respond at a lower rate during the safe stimulus and avoid the warning stimulus consistently. Another measure is allocation of the total number to the safe signal and the warning signal. In Figure 5, the y-axis shows responses during the warning signal as a proportion of the total number of responses. The x-axis shows warning-signal duration as a proportion of the duration of the response-shock interval. With perfect stimulus control, all responses would occur during the warning stimulus irrespective of its duration. The diagonal line with zero intercept and slope of one indicates a warning signal ineffective in controlling response distribution over the length of the response-shock interval. Because the pro-

portion of responses in the presence of the warning stimulus would depend on its relative duration, rather than its function as a signal for shock, stimulus control would not be manifested.

Figure 5 shows that when only a response could terminate the warning stimulus, the data from Subject GE tended to cluster around the diagonal line. The proportion of responses during the warning stimulus approximately matched the proportion of the warning signal to the total response-shock interval. With the exception of the point referring to the warning-stimulus duration of 7 sec (0.41 on the abscissa), all points from Subject CG fell below the diagonal.

Fig. 4. Rate of responding during the safe (unfilled columns) and warning (filled columns) periods in the signalled avoidance conditions. Numbers refer to length of time (in seconds) between onset of the warning signal and shock.

The data for Subject GE fell above the diagonal line, indicating a proportion of responses during the warning stimulus greater than its relative duration. The only exception is the point referring to warning-stimulus duration of 15 sec in its first determination. Subject CG, however, responded proportionally more during the warning stimulus on the replication series only.

Response Latencies

Figure 6 shows response latency during the warning signal as a function of warning-signal duration. For both subjects, response latency

always was an approximately linear function of warning-stimulus duration.

DISCUSSION

The key-peck response of pigeons came under the control of signalled avoidance. Response and shock rates were generally lower under signalled avoidance than under unsignalled avoidance. Response rate was generally higher under the warning signal than in its absence, but did not show a clear difference between the procedures for signalled avoidance. Stimulus control was seen in the distribution

Fig. 5. Proportion of total responses occurring during the warning stimulus as a function of warning-stimulus duration taken as a proportion of the response-shock interval length.

of responses between the warning and the safe periods. Under the "response-only" procedure, the proportion of total responses that occurred in the presence of the warning signal approximately matched the relative length of the signal. Under the "response or shock" termination procedure, responses tended to be channelled into the warning period. The third measure, response latency, revealed no difference between the procedures.

The greater stimulus control with the response or shock termination procedure may be explained in terms of schedule parameters.

When only a response terminated the warning stimulus, the S-S interval was 2 sec. When the S-S interval elapsed without a response, the bird would receive a shock every 2 sec. This means that in Phases II and IV, the frequency of shocks in the presence of the warning stimulus was higher than that scheduled when a response or a shock was necessary to terminate the warning signal. The warning signal was a sufficiently strong conditioned aversive stimulus to maintain both escape (responding during the warning signal) and avoidance (responding during the safe period).

Fig. 6. Response latency during the warning signal as a function of the interval (in seconds) between warning stimulus onset and shock. Filled circles refer to data from Phase II, unfilled circles from Phase IV. Triangles refer to data from Phase V, first exposure (filled) and replication (unfilled).

The direct relationship between response latency and duration of the warning signal agrees with results reported by Hyman (1969; 1971) and studies of classical (discriminated) avoidance (Berger and Brush, 1975; Jones, 1961; Weisman, Zerbolio, and Denny, 1965). The similar response latencies in the presence of the warning signal in both procedures, combined with changes in responding during the safe period, relates to the role of the warning stimulus in signalled avoidance. The signal clearly had two functions. Responding in its presence was a function of the length of time between signal onset and the next shock, irrespective of whether only one shock or a train of shocks was scheduled. Responding in its absence depended on what was being signalled by the warning stimulus: it tended to be lower when only one shock would be delivered per warning-signal presentation (response or shock

termination procedure) than when the warning stimulus signalled a train of shocks (response-only termination procedure).

The stimulus control of key-peck avoidance of shock confirms and extends the findings of Ferrari *et al.* (1973) and Todorov *et al.* (1974). Key pecking was maintained even when both the R-S and S-S intervals were equal to 20 sec. This response was maintained under stimulus control in a way similar to other operants (Behrend and Bitterman, 1963; Graf and Bitterman, 1963; Hyman, 1969; 1971; Keehn, 1959; Sidman, 1955; Sidman and Boren, 1957; Ulrich *et al.*, 1964). Such findings are evidence of the transituationality of the key-pecking operant (Schick, 1971; Schwartz, 1974). Key pecking showed the same orderliness as other operants in avoidance procedures. It remains to be seen if key pecking maintained through negative reinforcement is under the control of stimulus-stimulus contingencies also, in a way similar to key pecking maintained by positive reinforcement (*e.g.*, Gamzu and Schwartz, 1973; Jenkins and Moore, 1973). Results of Rachlin (1969) suggest that that may be the case.

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