RATE AND TEMPORAL PATTERN OF KEY PECKING UNDER AUTOSHAPING AND OMISSION SCHEDULES OF REINFORCEMENT¹

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The role of response-reinforcer contiguity on autoshaped key pecking in pigeons was studied by scheduling response-dependent nonreinforcement at the beginning or the end of brief (8-sec) discrete trials. Schedules that permitted chance conjunctions of key pecking and food sustained high rates of responding, whereas those that prevented the occurrence of key peck-food intervals shorter than 4 sec sustained low response rates. In addition, selective reinforcement schedules supported accelerating or decelerating rates of responding within individual trials. These effects were traceable to response-reinforcer (operant), but not stimulus-reinforcer (respondent) factors.

Key words: autoshaping, operant-respondent distinction, response-reinforcer contiguity, response differentiation, temporal control, key peck, pigeons

Contrary to a principal assumption of many "two-process" theories of learning—that a particular subset of an organism's behavioral repertoire is modifiable only by operant or respondent means—a single behavior may be directly affected by both response-reinforcer and stimulus-reinforcer relations (see Mackintosh, 1974 for a general review). The behavioral significance of these associative variables can be assessed in experiments that hold one set of factors constant or obtain results that are explicable in terms of only one set of variables.

Such experiments have been conducted on the bird's pecking response conditioned by the autoshaping procedure (see the recent review by Hearst and Jenkins, 1974). With reference to the role of the stimulus-reinforcer relation, Wasserman, Hunter, Gutowski, and Bader (1975) found that the very first key-peck response was a function of the frequency of prior pairings of a keylight stimulus and appe-

titive reinforcement (also see Brown and Jenkins, 1968). This functional relationship held both with conventional autoshaping procedures and with a special technique that prevented the subjects from contacting the response key during conditioning.

Not only may stimulus-reinforcer factors participate in the acquisition of the key-peck response, but they may also contribute to the maintenance of already-conditioned key pecking. The results of a two-phase experiment by Gamzu and Williams (1971, 1973) support this conclusion. First, pigeons were administered a procedure wherein response-key illumination signified an increase in the likelihood of food. Despite the acquisition of key pecking under these conditions, the increase in responding after the first peck to the lighted key could either have been due to the positive keylight-grain relation or to the positive, albeit adventitious, key peck-grain relation. Therefore, a second training phase was instituted. Here, the likelihood of food delivery in the absence of the keylight signal was set equal to the likelihood of food delivery in its presence. This procedure was suggested as a control for positive and negative stimulus-reinforcer relationships by Rescorla (1967). Gamzu and Williams argued that the failure of pigeons to maintain key pecking under these new conditions revealed the importance of the stimulus-reinforcer relation to autoshaped key pecking; the keylight-grain relation was reduced to zero,

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whereas the key peck-grain relation during the trials was unaffected when the schedule change was first instituted.²

Finally, the importance of the stimulus-reinforcer relation is underscored by the maintenance of key pecking under omission schedules of reinforcement (*e.g.*, Williams and Williams, 1969); these schedules maintain keylight-reinforcer pairings but prevent key peck-reinforcer pairings.

In an extension of this approach, Schwartz and Williams (1972) and Wasserman *et al.* (1975) isolated the involvement of a response-reinforcer factor in the maintenance of auto-shaped key pecking by using the yoked-control technique. In the latter study, for example, experimental chick subjects were administered keylight-heat pairings on trials when they did not peck the key, whereas yoked control subjects were administered the same sequence of keylight-heat pairings as their running mates, irrespective of key pecking. The greater responding that resulted under the yoked-control schedule is inexplicable in terms of a stimulus-reinforcer factor (since there was no difference in stimulus-reinforcer relations), but is interpretable in terms of response-reinforcer contiguity (since only the yoked-control subjects ever experienced conjunctions of key pecking and heat).

Despite the plausibility of response-reinforcer contiguity as a prominent factor in response maintenance during autoshaping, little direct evidence of the involvement of this factor is at hand, aside from the classical investigations of delay of reinforcement (see Mackintosh, 1974). Such studies usually entail positive response-reinforcer dependencies and different response-reinforcer delays, during which any discriminative stimuli are present for different time intervals. Both of these experimental features render especially hazardous extensions to autoshaping procedures in which no positive

response-reinforcer dependencies are in force and discriminative stimulus duration is independent of the subject's behavior.

The present investigation sought to provide more direct evidence concerning the role of response-reinforcer contiguity in behavior engendered by autoshaping procedures, while also minimizing the above methodological and analytical problems. As in previous autoshaping investigations, groups of pigeons were administered response-independent reinforcement (autoshaping) and response-dependent nonreinforcement (omission) schedules; key pecks during an 8-sec trial had no effect on food delivery in the response-independent condition, whereas any key pecks during the trial omitted food reinforcement at the end of the signal in the negative dependency condition. Of course, the response-independent schedule should promote much higher key-pecking rates than the omission schedule. Two other groups of subjects were administered selective reinforcement schedules that arranged response-dependent nonreinforcement during only 4 sec of the 8-sec trials. The two groups differed as to when the negative dependency was in effect. One condition arranged omission of reinforcement at the end of the trial when key pecks occurred during the first 4 sec of the trial. Since key pecks here could be followed by food at intervals shorter than 4 sec, it seemed possible that these subjects might respond on about as many trials as response-independent reinforcement subjects. The remaining condition arranged omission of reinforcement at the end of the trial when key pecks occurred during the last 4 sec of the trial. Since key pecks here could be followed by food only at intervals longer than 4 sec, it seemed possible that these subjects might respond as infrequently as omission subjects.

In addition to recording the number of trials with a key-peck response, the frequency of key pecking within individual trials was measured. Here, differences in the local rate of responding during the 8-sec trials might be revealed if the two selective reinforcement schedules were having an effect on patterns of key-pecking behavior (Hawkes and Shimp, 1975). Omission of reinforcement dependent on key pecking during the first half of the trial might accelerate key pecking as the end of the trial approaches; conversely, omission of reinforcement dependent on key pecking

²Gamzu and Williams (1971) asserted that the key peck-food relation during trials was not changed in the second phase of training. However, if one also considers the intertrial interval, then nonkey pecking behavior could have been contiguous with reinforcement when the schedule change was instituted. Behaviors other than key pecking could then have interfered with or otherwise reduced the frequency of key pecking (see Schoenfeld and Farmer, 1970). If so, the procedures of Gamzu and Williams would not successfully distinguish stimulus-reinforcer from response-reinforcer influences.

during the last half of the trial might decrease key pecking as the end of the trial draws near.

METHOD

Subjects

Thirty-two experimentally naive, adult homing pigeons were reduced to 80% of their free-feeding weights, were individually housed with water and grit always available in the home cages, and were tested daily when their weights did not exceed the 80% value by more than 10 g. Two birds were discarded early in training for failure to eat from the hopper on two consecutive days; two additional birds were discarded because of a procedural error. The resulting subject population was 28.

Apparatus

Four three-key pigeon conditioning chambers were used. In each chamber, only the center key was used to signal food presentation and to record key pecks. The 1.9-cm diameter clear plastic key required a force of at least 0.05 N for activation and was positioned 9.4 cm above the solenoid-operated grain feeder and 4.9 cm below the houselight. The key could be transilluminated with red light by a miniature display projector (IEE Series 10, 28 V dc, No. 1820 bulb). An ESB 24 bulb illuminated the food tray (LVE No. 114-10). The houselight (28 V dc, No. 1820 bulb) was encased in a black metal housing that continually directed light toward the ceiling during experimental sessions (see Wasserman 1973a). The interior walls of the box and the response panel (which contained the response keys, houselight, and food tray) were constructed of aluminum. Masking noise was continuously provided to the experimental room. In an adjoining room, scheduling and data collection were performed by a DEC PDP 8/I computer using the SKED software system (Snapper, Stephens, and Lee, 1974) and a relay interface.

Procedure

One day of feeder training was given as preliminary training (for details see Wasserman and Molina, 1975). Experimental training began the next day. All subjects received 40 trials per session for 28 sessions. Each trial consisted of an 8-sec illumination of the red key-light (CS) immediately followed by a 3-sec presentation of mixed grain (US), unless such a

presentation was cancelled by the occurrence of a key peck under an omission schedule. Reinforcement omission involved only the deletion of the scheduled food delivery; neither trial length nor the time until the next trial was altered by key pecking. The CS offset-CS onset interval was equiprobably set at 30, 60, or 90 sec.

Subjects were randomly assigned to one of four groups ($n = 7$) created by the presence of an omission dependency (O = Omission) or the lack of a dependency (N = No dependency) during each of two consecutive 4-sec subintervals of the 8-sec CS. (The subintervals of the CS were for scheduling purposes only; no correlated external changes occurred in the experimental chambers during these subintervals.) Subjects in condition NN had no dependency in effect during either subinterval of the CS and therefore received typical auto-shaping training, whereas subjects in condition OO had an omission dependency in effect during both subintervals of the CS, and therefore received typical omission training (see Schwartz, 1972; Wasserman, 1973b). The remaining two groups received selective omission schedules; response-dependent nonreinforcement was in effect during only one of the two consecutive 4-sec CS subintervals. Condition NO scheduled omission of food delivery if one or more key pecks occurred during the 4 sec immediately before food presentation; condition ON scheduled the omission dependency only during the first 4 sec of each trial. Note that both conditions NO and ON had the negative dependency in force during 4 sec of each individual 8-sec trial; the conditions differed only in terms of when the dependency was in effect.

Behavioral Measures

Total key pecks during the CS as well as total key pecks during the intertrial interval were recorded daily. In addition, key pecks during the CS were assigned to eight consecutive 1-sec bins, so that a representation of the temporal distribution of responding during trials was available. For purposes of reinforcement scheduling and data analysis, each trial was assigned to one of four types: an RR trial was one in which at least one key peck occurred in each 4-sec subinterval of the CS; an $\bar{R}R$ trial was one in which one or more responses occurred during the last 4 sec of the

trial, but none before then; conversely, an $\overline{RR}$ trial was one in which all key pecking was confined to the first 4 sec of the trial; and finally, $\overline{RR}$ indicated a trial with no responses.

Statistical Analysis

Since this experiment involved a factorial design of Reinforcement Schedule $\times$ CS Sub-interval, analyses of variance were performed on several of the behavioral measures. Other analyses are described in the Results section.

RESULTS

Acquisition

All subjects first key pecked within the initial 80 keylight-food pairings. Table 1 depicts the further course of key-peck acquisition for the four groups in terms of the total number of sessions necessary to reach a criterion percentage of trials with a key peck in a single, daily session (these arbitrarily selected criteria were 25%, 50%, 75%, and 100% trials with a key peck). At all criterion levels, birds in conditions that allowed key peck-food conjunctions (NN and ON) were reliably ($p < 0.05$) quicker in reaching criterion than were birds in conditions that did not allow key peck-food conjunctions (NO and OO); at 25%, $F(1, 24) = 8.25$, $p < 0.01$; at 50%, $F(1, 24) = 6.64$, $p < 0.05$; at 75%, $F(1, 24) = 12.94$, $p < 0.01$; and at 100%, $F(1, 24) = 23.86$, $p < 0.01$. At the 100% criterion, there was an additional reliable superiority of groups without a negative dependency during the first half of the trial (NN and NO) over groups with a negative dependency during the first half of the trial (ON and OO), $F(1, 24) = 5.56$, $p < 0.05$.

Postacquisition Performance

Eighty-six per cent of all subjects reached their highest performance criterion within the first two weeks of training. Therefore, the last two weeks of training may be considered to

reflect "postacquisition" performance. During the last two weeks of training, subjects in conditions that allowed key peck-food intervals shorter than 4 sec (NN and ON) responded on a reliably greater percentage of the trials than subjects in conditions that did not allow such short response-reinforcer intervals (NO and OO), $F(1, 24) = 22.23$, $p < 0.01$ (see Figure 1 and Table 2). Groups NN and ON also evidenced reliably higher mean rates of key pecking than Groups NO and OO, $F(1, 24) = 13.86$, $p < 0.01$: 1.31, 0.56, 0.07, and 0.09 key pecks per second, respectively.

Group NN subjects, of course, received more food presentations than any of the other subjects, since only in this condition did every trial always involve reinforcement. The three conditions that scheduled reinforcement omission (ON, NO, and OO) did not reliably differ in terms of the percentage of trials involving reinforcement, $F(2, 18) = 2.16$, $p > 0.10$, but did reliably differ in terms of the percentage of trials with a key peck, $F(2, 18) = 4.51$, $p < 0.05$. Therefore, differences in key pecking among these three groups are inexplicable in terms of the keylight-food relation. Furthermore, there was an insignificant ($p > 0.10$) negative correlation (Pearson $r = -0.20$) between percentage of trials involving reinforcement and the percentage of trials with a key peck in Groups NN, ON, and NO (Group OO was excluded from this analysis because of the necessary correlation of -1.00 here). Therefore, high levels of key pecking in Groups NN and ON cannot be attributed to these groups receiving a higher stimulus-reinforcer correlation than Groups NO and OO.

Examination of the temporal distributions of key pecking during the CS revealed that Groups NN and ON key pecked reliably more during the last half of the trial than did Groups NO and OO, $F(1, 24) = 10.55$, $p < 0.01$; the respective mean percentage of total key pecks during the last 4 sec of the trial was 54.0%, 77.4%, 31.3%, and 40.3%.

To evaluate the extent to which the performance of individual subjects in the four groups was influenced by the prevailing schedule of reinforcement, each pigeon was classified according to its most frequently performed type of trial during the last two weeks of training (see Table 2). This analysis revealed that the majority of subjects (5/7) in Group NN responded most with the RR pattern, the ma-

Table 1

Mean and Standard Deviation of Days to Criterion

Condi- tion	Criterion			
	25%	50%	75%	100%
NN	1.00 $\pm$ 0.00	1.29 $\pm$ 0.49	1.71 $\pm$ 0.49	3.86 $\pm$ 1.07
ON	1.00 $\pm$ 0.00	1.29 $\pm$ 0.76	2.29 $\pm$ 0.49	15.00 $\pm$ 9.43
NO	1.43 $\pm$ 0.79	3.57 $\pm$ 3.87	11.29 $\pm$ 10.90	22.43 $\pm$ 9.73
OO	2.14 $\pm$ 1.22	4.43 $\pm$ 3.91	14.86 $\pm$ 12.08	25.14 $\pm$ 7.56

Fig. 1. Mean percentage of trials with a key peck (cross-hatched bars) and mean percentage of trials with food (open bars) over Days 15 to 28.

jority (4/7) in Group ON responded with the $\overline{RR}$ pattern, and the majority (6/7) in Groups NO and OO responded with the $\overline{RR}$ pattern.

The preceding analysis cannot reveal any systematic character to a pigeon's response tendency when the most frequent type of trial is $\overline{RR}$. Therefore, subjects were reclassified on the basis of the most frequent type of trial, on trials when a response occurred. Again, the majority of subjects (6/7) in Group NN responded most with the $\overline{RR}$ pattern, the majority (5/7) in Group ON responded with the $\overline{RR}$ pattern, and the majority in Groups NO (6/7) and OO (5/7) responded with the $\overline{RR}$ pattern.

DISCUSSION

The results of the present experiment, entailing autoshaping and omission schedules of reinforcement, agree with those of prior omission-yoked control studies (Schwartz and Williams, 1972; Wasserman *et al.*, 1975) in reveal-

ing that response-reinforcer factors participate in the maintenance of autoshaped key pecking—even when the involvement of stimulus-reinforcer factors is excluded. Here, the overall rate of key pecking as well as the within-trial pattern of responding were a function of the prevailing schedule of reinforcement. Reinforcement schedules that permitted conjunctions of key pecking and food (NN and ON) sustained higher rates of responding than those that did not (NO and OO). Furthermore, within individual trials, increasing and decreasing patterns of key pecking resulted in Groups ON and NO, respectively: patterns of responding appropriate to the schedule of reinforcement. The within-trial patterns of key pecking under NN and OO schedules were generally more constant than under the selective schedules, although birds in Group OO often evidenced decreasing rates of responding. Much unpublished and unreported evidence from our laboratory, however, has revealed other temporal patterns of responding

Table 2
Last Two Weeks' Performance of Individual Subjects

Condition	Bird	Per cent Trials with a Peck	Per cent Trials with Food	Per cent of Total Trials of Each Type			
				RR	R $\bar{R}$	$\bar{R}R$	$\bar{R}\bar{R}$
NN	136	100.00	100.00	98.39	0.00	1.61	0.00
	137	80.71	100.00	0.36	79.64	0.71	19.29
	153	99.64	100.00	98.57	0.00	1.07	0.36
	139	79.64	100.00	41.61	32.32	5.71	20.36
	1	82.68	100.00	44.29	1.43	36.96	17.32
	2	100.00	100.00	99.11	0.00	0.89	0.00
	3	51.96	100.00	27.32	8.39	16.25	48.04
	Mean	84.95	100.00	58.52	17.40	9.03	15.05
ON	140	85.36	82.32	17.68	0.00	67.68	14.64
	141	20.89	92.32	1.43	6.25	13.21	79.11
	143	83.39	59.46	31.79	8.75	42.86	16.61
	144	73.04	88.75	10.71	0.54	61.79	26.96
	13	99.29	66.61	33.21	0.18	65.89	0.71
	5	37.50	68.75	2.68	28.57	6.25	62.50
	6	99.82	21.25	78.57	0.18	21.07	0.18
	Mean	71.33	68.49	25.15	6.35	39.82	28.67
NO	155	34.46	87.50	4.46	21.96	8.04	65.54
	146	47.32	68.93	8.75	16.25	22.32	52.68
	147	63.57	66.96	15.54	30.54	17.50	36.43
	148	16.96	94.46	1.25	11.43	4.29	83.04
	7	29.29	98.21	0.36	27.50	1.43	70.71
	8	55.36	99.82	0.00	55.18	0.18	44.64
	23	21.43	90.89	1.79	12.32	7.32	78.57
	Mean	38.34	86.68	4.59	25.03	8.73	61.66
OO	149	25.89	74.11	3.21	14.64	8.04	74.11
	150	15.54	84.46	0.71	12.86	1.96	84.46
	151	30.54	69.46	2.50	23.04	5.00	69.46
	152	47.68	52.32	5.36	32.14	10.18	52.32
	24	46.25	53.75	7.50	32.14	6.61	53.75
	11	78.57	21.43	16.96	0.54	61.07	21.43
	12	4.28	95.71	0.00	1.96	2.32	95.71
	Mean	35.54	64.46	5.18	16.76	13.60	64.46

by birds that were administered schedules of reinforcement quite similar to the present OO schedule.

In this report, we have emphasized response-reinforcer contiguity as an important parameter contributing to the earlier results of omission *versus* yoked control comparisons and to the present experimental outcomes. Two prominent views of how this parameter affects behavior may be noted. First, by positive reinforcement, individual discrete responses or groups of responses may be rendered increasingly likely by the contiguous presentation of reinforcement (also see Hawkes and Shimp, 1975). Alternately, by the punishment of responding due to the omission of scheduled reinforcers, individual discrete responses or groups of responses may be decreased in likelihood. Neither of these two possibilities has

yet been excluded; indeed, both may actually be involved (see Wasserman *et al.*, 1975).

Nonetheless, available evidence supports the proposal that, subsequent to the emergence of autoshaped key pecking (which may be principally or even exclusively the result of stimulus-reinforcer relations) responding is maintained by both stimulus-reinforcer and response-reinforcer relations.

REFERENCES

- 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.
- Gamzu, E. and Williams, D. R. Classical conditioning of a complex skeletal response. *Science*, 1971, 171, 923-925.
- Gamzu, E. R. and Williams, D. R. Associative factors underlying the pigeon's key pecking in autoshaping

- procedures. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 225-232.
- Hawkes, L. and Shimp, C. P. Reinforcement of behavioral patterns: shaping a scallop. *Journal of the Experimental Analysis of Behavior*, 1975, 23, 3-16.
- Hearst, E. and Jenkins, H. M. *Sign-tracking: The stimulus-reinforcer relation and directed action*. Austin, Texas: The Psychonomic Society, 1974.
- Mackintosh, N. J. *The psychology of animal learning*. London: Academic Press, 1974.
- Rescorla, R. A. Pavlovian conditioning and its proper control procedures. *Psychological Review*, 1967, 74, 71-80.
- Schoenfeld, W. N. and Farmer, J. Reinforcement schedules and the "behavior stream." In W. N. Schoenfeld (Ed), *The theory of reinforcement schedules*. New York: Appleton-Century-Crofts, 1970. Pp. 215-245.
- Schwartz, B. The role of positive conditioned reinforcement in the maintenance of keypecking which prevents delivery of primary reinforcement. *Psychonomic Science*, 1972, 28, 277-278.
- Schwartz, B. and Williams, D. R. The role of the response-reinforcer contingency in negative auto-maintenance. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 351-357.
- Snapper, A. G., Stephens, K. R., and Lee, D. M. The SKED software system. Kalamazoo: The SKED Users Group, 1974.
- Wasserman, E. A. The effect of redundant contextual stimuli on autoshaping the pigeon's keypeck. *Animal Learning and Behavior*, 1973, 1, 198-206. (a)
- Wasserman, E. A. Key-peck persistence on autoshaping procedures. *Proceedings, 81st Annual Convention, American Psychological Association*, 1973, 881-882. (b)
- Wasserman, E. A., Hunter, N. B., Gutowski, K. A., and Bader, S. A. Autoshaping chicks with heat reinforcement: The role of stimulus-reinforcer and response-reinforcer relations. *Journal of Experimental Psychology: Animal Behavior Processes*, 1975, 1, 158-169.
- Wasserman, E. A. and Molina, E. J. Explicitly unpaired keylight and food presentations: interference with subsequent auto-shaped key pecking in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 1975, 1, 30-38.
- Williams, D. R. and Williams, H. Auto-maintenance in the pigeon: sustained pecking despite contingent non-reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 511-520.

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