KEY-PECK DURATIONS UNDER BEHAVIORAL CONTRAST AND DIFFERENTIAL REINFORCEMENT

WILLIAM R. WHIPPLE AND EDMUND FANTINO

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Pigeons were maintained on a multiple schedule in which both components were variable-interval one-minute schedules. When they were switched to a condition in which one component was extinction, behavioral contrast was observed. The median durations of the key pecks in the unchanged component did not decrease in size. The results are incompatible with a theory of behavioral contrast which considers the added pecks to be short-duration responses. In a second experiment, pigeons were required to emit short-duration key pecks in one component of a multiple schedule, and long-duration pecks in the other. Two of three pigeons learned to emit responses appropriate to the requirements of the component in effect, suggesting that the duration of the key-peck response is sensitive to differential reinforcement.

Key words: behavioral contrast, response duration, differential reinforcement, elicited responding, response topography as an operant, additivity theory, multiple schedules, key peck, pigeons

The phenomenon of behavioral contrast is manifested when reductions in the rate of reinforcement in one component of a multiple schedule lead to increased responding in the component whose rate of reinforcement is unaltered (Reynolds, 1961). In the case of pigeons, for example, there are more pecks directed at the response key in the unchanged component. One theory is that the extra pecks are elicited responses, qualitatively different from operant pecks (Gamzu & Schwartz, 1973; Rachlin, 1973; Schwartz & Gamzu, 1977). It is well established that when a stimulus change (especially one involving a keylight) regularly signals the availability of food, pigeons will come to peck at the key which provides this signal—a phenomenon known as autoshaping (Brown & Jenkins, 1968). This elicited responding will continue even if the procedure is altered so that the bird's pecking delays the presentation of food (Herrnstein & Loveland, 1972; Williams & Williams, 1969). The autoshaping procedure bears a close resemblance to Pavlovian conditioning, food being the unconditioned stimulus and the lighted key the conditioned stimu-

lus that comes to elicit conditioned responses (pecks) similar to the bird's unconditioned response to food (also a peck). The similarities between autoshaping and classical conditioning have led some theorists (e.g., Mackintosh, 1974) to suggest that they may be mediated by common processes.

Several lines of evidence, reviewed by Schwartz and Gamzu (1977), have supported the "additivity" theory of behavioral contrast which proposes that the additional pecks observed in the unchanged component are elicited ("autopecks"). For example, autopecking is readily observed only when the signal for food is a visual stimulus located on the response key (Wasserman, 1973). Similarly, behavioral contrast is most rapidly obtained when the discriminative stimulus is a visual one projected on the key (Redford & Perkins, 1974; Schwartz, 1974). Other contrast experiments (e.g., Keller, 1974) have shown that if the multiple-schedule signal is located on a key other than the operant key, substantial numbers of pecks occur to the signal key even though these responses are not reinforced. Addition of the signal-key pecks (presumably autopecks) to the operant-key pecks result in rates similar to those obtained in the usual contrast experiment.

Direct evidence bearing on the additivity hypothesis requires that operant pecks be distinguished from elicited pecks. Important

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in this regard is the report of Schwartz and Williams (1972) that the duration of autopecks is typically less than 20 ms, while operant pecks generally exceed 40 ms in duration. (The duration is the time which elapses from the bird's first measurable contact with the key until the key returns to its resting position.) This result was applied to the phenomenon of contrast by Schwartz, Hamilton, and Silberberg (1975). Using a two-key multiple-schedule procedure, they hypothesized that pecks directed at the signal key would be elicited pecks and should therefore have shorter durations than pecks to the operant key. The results were difficult to interpret. Although signal-key pecks were indeed of short duration, there were very few of them, so that the sum of signal-key pecks and operant-key pecks did not show behavioral contrast.¹

However, there is a potential problem in using the two-key multiple-schedule procedure when response duration is studied. Since the majority of responses are made to the operant key, the birds presumably stand closer to that key. Thus, it is possible that any differences observed are attributable to the bird's position in the chamber rather than to a difference between operant and elicited key pecking. The experiments reported here study the duration of pigeons' key pecks using single-key multiple-schedule procedures.

EXPERIMENT 1

In Experiment 1 behavioral contrast was produced using the traditional one-key procedure, and the durations of key pecks in the two components were measured. If contrast results from the addition of short-duration autopecks to longer-duration operant pecks, the durations of pecks in the unchanged component (where contrast is evident) should be distributed about a median value shorter than that observed in a baseline condition. This prediction was tested by the present experiment.

Method

Subjects. Six adult male white Carneaux pigeons were maintained at approximately

80% of their free-feeding weights. All except Bird 206 had previously served in experiments involving multiple variable-interval schedules. Bird 206 had experience in experiments involving fixed-interval schedules but had never been exposed to multiple schedules. The birds were weighed after each experimental session and fed measured amounts of food so that their weight would remain constant. Water and grit were available in the home cages.

Procedure. The pigeons were tested in six identical chambers, measuring 36 cm in height and 35 cm in diameter. Each chamber had three response keys mounted 24 cm above the floor; rear-mounted projectors permitted various colors or patterns to be displayed on the keys. Only the left-hand key in each chamber was used; the others remained dark, and the few responses to them were not recorded. The force required to operate the left-hand key fell in the range (from chamber to chamber) .10 to .16 N, and key travel was within the range .8 to .9 mm. Each pigeon was always tested in the same chamber. Sessions were conducted daily.

Food hoppers were located 16 cm below the center key in each chamber. Reinforcement consisted of 4 sec access to Purina Pigeon Chow, which the birds were also fed in their home cages. While the hopper was raised, it was illuminated by a white light and other lights in the chamber were extinguished. A dim houselight, on the side of the chambers opposite the keys and hopper, was on at all times except during reinforcement. The dull black inside surfaces of the chambers eliminated any problem from houselight reflections off the walls (Hursh, Navarick, & Fantino, 1974). White noise was continuously present.

Scheduling of experimental events and recording of the data were performed by a PDP-8E computer under the control of the SYSTOL² software developed in our laboratory. The computer could control all six chambers independently, so the pigeons were studied simultaneously. A solid-state latching device served as an interface between the computer and the response keys. As soon as the micro-switch in the key was operated (i.e., when con-

¹The failure of Schwartz et al. to replicate the findings reported by Keller (1974) may have been related to the use of a changeover delay and is discussed in their article.

²SYSTOL is a general-purpose experimental control language particularly suited to operant research. Further details on the hardware and software used in these experiments are available from William R. Whipple.

tact was made with the normally open terminal), the electronic latch closed and remained closed until the microswitch returned to its original configuration (contact being made with the normally closed terminal). By providing positive signals for both the beginning and end of the measured key peck, we were able to eliminate artifacts caused by dust or contact bounce—a problem which had concerned Schwartz and Williams (1972)—and we could thus record peck-duration distributions by increments as small as 1 ms without difficulty.

The basic experimental paradigm was a two-component multiple schedule, each component being a variable-interval 1-min (*mult* VI 1-min VI 1-min). The two components were signaled by green and yellow keylights; components were 1 min long and were presented in alternating sequence. Experimental sessions consisted of 40 components. In the baseline condition (VI VI), both key colors signaled VI 1-min schedules; this condition was in force for 15 sessions. Beginning with Session 16, all birds were changed to a *mult* VI 1-min EXT schedule, in which the green key signaled an extinction component. This VI EXT condition remained in force for 11 sessions. Beginning with Session 27, baseline conditions were reinstated for 10 days.³

Results

Three sessions (A, B, and C) that typify performance in each condition (VI VI, VI EXT, VI VI) were selected for each bird. In the VI VI conditions, Points A and C were set where response rates in both components were nearly equal. In the VI EXT condition, Point B represented a session where enhanced responding in the VI component was clearly evident, but before responding in the EXT component had entirely ceased (so that durations of pecks in both components could be examined).

Figure 1 illustrates the data of Bird 206. The upper left panel shows the response rates to the yellow (solid line) and green (dashed line) stimuli. The center segment of this panel represents the contrast manipulation, in

which the green stimulus signaled extinction. The left- and right-hand segments illustrate the VI VI condition. The letters A, B, and C indicate the sessions selected for analysis of peck durations. The three histograms show the distributions of key-peck durations at these three points. The solid bars refer to the unchanged component; the dashed bars to the component switched to extinction. Each bar indicates the percent of the total number of pecks falling in a particular bin; the bins were 5 ms in size, except for the last, which was an overflow bin containing all pecks whose duration exceeded 75 ms.

The additivity hypothesis as interpreted above would predict that the solid bars in Histogram B would be distributed about a shorter duration than in A or C. This prediction is not supported by the data. For this particular bird, behavioral contrast was accompanied by a substantial increase in the number of very long (greater than 75 ms) key pecks, but such pecks were given to both the VI and the EXT stimuli, a result not easily reconciled to any version of additivity theory.

Figures 2 and 3 give results for Birds 32 and 909 respectively. Note that since these birds emitted key pecks shorter than those of Bird 206, data were recorded using 2-ms bins. Here again the additivity prediction is unsupported; in these cases, however, no extremely long pecks occurred in the contrast condition.

Results for all six birds are contained in Table 1. For each bird, the table indicates the sessions selected to typify performance in the three conditions (VI VI, VI EXT, VI VI), and shows response rates observed in these sessions. The "index of contrast" provided for the VI EXT condition and for the return to VI VI baseline is simply the response rate for the condition in question divided by the rate observed in the original VI VI baseline. Following these figures, the table indicates the median duration of key pecks to the S+ and S−, respectively, at the three points selected. The additivity-based expectation that this median would be shorter in the VI EXT condition than in the VI VI baseline during the S+ component is not supported by data from any of the six birds. Birds 32, 909, 37, and especially 25 gave shorter pecks to the S− at the point when contrast was evident; but since additivity makes no prediction regarding the duration of pecks during EXT components,

³In the VI EXT condition, sessions were 50 components long, rather than 40. Data are expressed in terms of responses per minute to eliminate possible confusion from this source. The tenth session of the VI EXT condition (Session 25 of the experiment) was conducted as usual; but a computer error resulted in loss of the data for this one session.

Fig. 1. Response rates for the two components (upper left panel) and peck-duration histograms taken at three points for Bird 206. The solid line and solid bars in the histograms refer to the yellow key component; the dashed line and dashed bars refer to the green component. In the response-rate graph, the three segments represent baseline, contrast, and baseline respectively; capital letters identify the sessions selected for the histograms. The data for Session 25 were lost; see Note 3. In the histograms, each pair of bars (one solid, one dashed) represents one bin of the size indicated (5 ms for this subject). Representative points on the abscissa are marked. The last bin is an overflow bin; any peck duration too long to fit in any other bin is counted here.

this evidence neither supports nor challenges that hypothesis.

To demonstrate that the results are not an artifact of the particular sessions selected for analysis, Table 1 also shows median durations of key pecks averaged across the final five sessions in each condition, for both the S+ and S- components. These data are in general support of the results from the selected sessions. The only apparent exception is that of Bird 25, for whom this measure revealed somewhat shorter key pecks in the S+ component in the VI EXT condition. However, this change was not caused by an increase in very-short-duration pecks; the proportion of pecks shorter than 30 ms for this bird actually decreased from 15% in the VI VI condition to 13% in the VI EXT.

Discussion

The robust behavioral contrast observed in these birds makes this experiment a more appropriate test of the additivity hypothesis than

that of Schwartz et al. (1975), which yielded scant evidence of contrast. The prediction that key pecks during behavioral contrast should be distributed around a shorter median value owing to the increase in the proportion of short-duration pecks (relative to baseline conditions) was not supported by these data.

It is interesting to observe that several birds in the present experiment, after extended training on *mult* VI VI schedules, emitted key pecks which were almost exclusively of short duration. By comparison, Schwartz and Williams (1972) found that extended training under an operant schedule led to a predominance of long-duration pecks. However, it is important to note that their apparatus did not register responses with durations shorter than 8 ms (a precaution against spurious responses caused by contact bounce or dust). This meant that in their experiment, under response-dependent conditions, responses shorter than 8 ms were never reinforced. In response-independent schedules, however, re-

Fig. 2. Response rates and peck-duration histograms for Bird 32. Bin size is 2 ms. See caption of Figure 1 for details. (A version of this figure has also appeared in Fantino & Logan, 1979, p. 132.)

Fig. 3. Response rates and peck-duration histograms for Bird 909. Bin size is 2 ms. See caption of Figure 1 for details.

Table 1

Measures of behavioral contrast and median key-peck durations for pigeons exposed to multiple schedules. Figures in parentheses are quartile deviations of the distributions of key peck durations.^a

Measure	VI VI	VI EXT	VI VI
<i>Bird 206</i>			
Session number	15	26	36
Resp/min during S+	14.5	30.7	14.5
Index of contrast	—	2.12	1.00
Median peck duration in ms during S+	27(5)	39(14)	39(8)
Median peck duration in ms during S-	28(6)	28(26)	39(9)
Median duration during S+ averaged over final five sessions	25(5)	35(9)	32(9)
Median duration during S- averaged over final five sessions	26(5)	28(15)	30(8)
<i>Bird 32</i>			
Session number	11	26	35
Resp/min during S+	22.1	34.4	24.6
Index of contrast	—	1.56	1.11
Median peck duration in ms during S+	6(1)	7(1)	5(2)
Median peck duration in ms during S-	7(1)	6(2)	4(2)
Median duration during S+ averaged over final five sessions	6(1)	7(1)	5(2)
Median duration during S- averaged over final five sessions	6(1)	6(2)	4(1)
<i>Bird 909</i>			
Session number	15	19	29
Resp/min in S+	18.9	31.5	22.3
Index of contrast	—	1.67	1.18
Median duration in ms during S+	6(1)	6(1)	4(1)
Median duration in ms during S-	6(2)	5(1)	4(1)
Median duration during S+ averaged over final five sessions	5(1)	5(1)	4(1)
Median duration during S- averaged over final five sessions	5(1)	5(1)	4(1)
<i>Bird 25</i>			
Session number	15	21	35
Resp/min in S+	18.9	24.1	23.0
Index of contrast	—	1.28	1.21
Median duration in ms during S+	117(48)	122(48)	128(45)
Median duration in ms during S-	110(46)	46(28) ^a	127(47)
Median duration during S+ averaged over final five sessions	112(44)	92(48)	122(45)
Median duration during S- averaged over final five sessions	100(46)	67(47)	130(48)

Measure	VI VI	VI EXT	VI VI
<i>Bird 49</i>			
Session number	11	19	35
Resp/min during S+	14.5	30.7	30.3
Index of contrast	—	2.11	2.09
Median duration in ms during S+	13(2)	15(2)	14(2)
Median duration in ms during S-	11(2)	13(2)	14(2)
Median duration during S+ averaged over final five sessions	13(2)	14(2)	14(2)
Median duration during S- averaged over final five sessions	12(2)	13(3)	14(2)
<i>Bird 37</i>			
Session number	14	19	30
Resp/min during S+	29.8	36.8	29.7
Index of contrast	—	1.23	1.00
Median duration in ms during S+	15(3)	18(5)	16(3)
Median duration in ms during S-	14(3)	13(4)	14(4)
Median duration during S+ averaged over final five sessions	14(3)	14(4)	17(4)
Median duration during S- averaged over final five sessions	13(3)	10(4)	16(4)

^aThe quartile deviation (or semi-interquartile range) is half the quantity (Q3-Q1) where Q1 and Q3 represent the 1st and 3rd quartiles. For asymmetric distributions, the quartile deviation may be greater than the median. If more than 25% of the key pecks fall in the last (overflow) bin, the value cannot be calculated accurately. This was the case for Bird 25 and (in the VI EXT condition only) Bird 206; the figures shown for these birds are estimated by treating the last bin as though it were of the same size as the other bins.

inforcement followed any peck with equal probability, regardless of duration. Thus, the procedure of Schwartz and Williams implied differential reinforcement of short- and long-duration key pecks when response-dependent schedules were involved. Recent research by Ziriaux and Silberberg (1978) has suggested that peck durations may be sensitive to such differential reinforcement; this might explain the difference between the findings of Schwartz and Williams and those reported here (since our procedure did not exclude very short-duration pecks). A second experiment was performed to explore this possibility.

EXPERIMENT 2

In addition to examining the susceptibility of key-peck duration to differential reinforce-

Table 2

Median key peck durations and response rates in each component, averaged over the last five sessions of each phase in Experiment 2. Figures in parentheses are quartile deviations.^a

Phase (sessions)	Component	Duration required	Median response duration in ms			Responses/minute		
			Bird 57	Bird 36	Bird 35	Bird 57	Bird 36	Bird 35
1 (50)	H	long	29 (17)	27 (24)	14 (5)	40	51	46
	V	short	22 (3)	23 (23)	12 (7)	39	49	21
2 (59)	H	short	13 (4)	26 (15)	4 (2)	35	46	19
	V	long	37 (18)	23 (16)	16 (6)	35	51	41
3 (38)	H	long	36 (18)	37 (25)	13 (5)	38	33	24
	V	short	28 (8)	43 (24)	6 (2)	49	52	12
4 (51) ^b	H	short	15 (9)	21 (19)	4 (1)	35	29	14
	V	long	21 (14)	20 (19)	7 (8)	39	38	20

^aIn the case of Bird 36, the last (overflow) bin of the peck duration distribution frequently contained more than 25% of the total number of pecks. The quartile distributions indicated for this bird are estimated. See Note a to Table 1.

^bDuring Sessions 48 of Phase 4, Bird 35's response key became jammed. The problem was subsequently corrected; however, data from this and the following session were not counted for this bird. The values given for Bird 35 in Phase 4 are averaged over Sessions 45, 46, 47, 50, and 51.

ment, Experiment 2 was designed to serve as a control for Experiment 1. Since the results of that experiment were essentially negative (we had failed to find shorter duration key pecks during contrast as anticipated by additivity theory), it seemed desirable to demonstrate that our apparatus was capable of making reliable differentiation between short- and long-duration pecks when these differences were actually present. In this experiment we sought to induce differences in peck duration by differential reinforcement using the same apparatus employed in Experiment 1.

Method

A multiple-schedule procedure was employed. Two components alternated every 60 sec. Each component was associated with a VI 30-sec schedule of reinforcement, which was halted when the other component was in effect. In one component (designated H), a horizontal line was projected on the response key, and the chamber was illuminated by a red houselight. During the other component (V), the key stimulus was a vertical line, and the houselight was blue. Rates of scheduled reinforcement were identical between the two components throughout the experiment.

Initially, during one component (H), only key pecks whose duration exceeded 36 ms qualified as responses. These pecks were followed by a brief (200 ms) green flash on the key. The first such response after the VI sched-

ule had timed out led immediately to reinforcement (3.5-sec operation of the food hopper, during which time the magazine was illuminated by green light). Nonqualifying key pecks (those less than 36 ms in duration) had no scheduled consequences. In the alternate (V) component, the situation was reversed; only pecks shorter than 36 ms produced feedback and qualified for reinforcement.

Sessions lasted 50 min. Three birds were studied; all were experimentally experienced, but none had served in Experiment 1. From time to time as the experiment progressed, duration requirements for the two components were reversed, so that long-duration key pecks were required in the component in which short pecks had previously been reinforced, and vice versa. Table 2 indicates the number of training sessions and the response requirements for each component in each phase of the experiment. The criterion by which long key pecks were differentiated from short ones was always 36 ms, a value which effectively discriminated between the "elicited" (signal-key) pecks and the "operant" pecks in the experiment of Schwartz et al. (1975).

Results

Table 2 shows, for each phase of the experiment, the duration of the median key peck and the rate of responding in both components; values are averaged over the final five sessions of each condition. The only differences

Fig. 4. Median duration of key pecks for each component in Experiment 2 during transition from Phase 3 to Phase 4. Units on the x-axis are blocks of three sessions. The left panel shows the last 15 sessions of Phase 3; the right panel shows data from the beginning of Phase 4, continuing until discrimination of the two components is clearly evident (no reversals of trend for four consecutive data points).

between the phases were reversals in response requirements; thus Phase 3 was identical to Phase 1, and 4 was identical to 2.

Birds 57 and 35 both came to emit key pecks of relatively long or short duration, according to the requirements of the particular component in effect. As may be seen in Table 2, the pecks emitted by these birds in the component requiring long-duration key pecks were longer than those in the short-duration component in all four phases. The differentiation of response duration is particularly clear in Phases 2 and 3; in Phases 1 and 4, the differences are smaller (especially for Bird 35), but in every case the differences were in the direction required by the schedule. Bird 36 did not appear to acquire the discrimination; throughout the ex-

periment, differences in median peck duration between components were small and not systematically related to experimental manipulations.

To illustrate the performance of the birds during reversal of schedule requirements, Figure 4 shows durations of median key pecks for Birds 57 (upper panel) and 35 (lower panel) beginning 15 sessions before the end of Phase 3, and continuing until differentiation of the two components in Phase 4 was clearly evident. Solid lines refer to Component H, dashed lines to Component V. Median durations of key pecks are plotted in blocks of three sessions. The bird-to-bird differences in overall distribution of peck durations that were observed in Experiment 1 were evident in

this case as well; for this reason, different scales are used on the two graphs. Bird 35 illustrates an interesting point: discrimination of duration requirements in the two components may occur even when only a small proportion of pecks meet the criterion in one of them. In the final sessions of Phase 3 shown in Figure 4, key pecks longer than 36 ms (which were required for Component H) accounted for only 18% of Bird 35's responses in that component. Yet, as Figure 4 shows, this bird was clearly sensitive to the differential peck-duration requirement, and reversal was accomplished nearly as readily as with Bird 57.

Discussion

The finding that key-peck duration could be brought under stimulus control for two subjects indicates that the apparatus is sensitive to differences in peck duration where these differences exist. It is unlikely, then, that our failure to observe reductions in the duration of key pecks in connection with behavioral contrast in Experiment 1 was due to insensitivity of our apparatus.

The results of Experiment 2 suggest that at least one aspect of the topography of the key-peck response (the duration) may be modified by differential reinforcement and brought under stimulus control. To consider the topography of responding as an operant is not a new idea; Skinner (1938) successfully modified both force and duration of lever presses by rats through differential reinforcement. Ziriaux and Silberberg (1978) trained pigeons to emit either short- or long-duration key pecks through differential reinforcement, although their procedure was more complex than that used here. Although Schwartz and Williams (1972) were unable to increase the rate of very short key pecks (under 16 ms) by differential reinforcement, this may have been due to a procedural artifact. Unlike the apparatus used in the present study, which recorded all pecks regardless of duration, the apparatus in the Schwartz and Williams experiment did not register responses with durations shorter than 8 ms, assuming these to be contact bounce. Thus, in differentially reinforcing pecks shorter than 16 ms they restricted reinforcement to responses longer than 8 ms but shorter than 16 ms—possibly a discrimination too fine for pigeons to make. When Schwartz and Wil-

liams adjusted the upper limit of the reinforced range to 26 ms, the proportion of key pecks which fell in the specified range increased dramatically.

The findings reported here, like those of Ziriaux and Silberberg (1978), suggest that the duration of the pigeon's key-peck response may be influenced by differential reinforcement, at least in some cases. This possibility creates complications for theoretical formulations which seek to differentiate between "elicited" and "emitted" behavior through measures of duration. Tests of such formulations would seem to require stringent controls to insure that any differences observed are not the result of inadvertent differential reinforcement.

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