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CHANGING THE RESPONSE UNIT FROM A SINGLE PECK TO A FIXED NUMBER OF PECKS IN FIXED-INTERVAL SCHEDULES[1]

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Each of three pigeons was studied first under a standard fixed-interval schedule. With the fixed interval held constant, the schedule was changed to a second-order schedule in which the response unit was the behavior on a small fixed-ratio schedule (first a fixed-ratio 10 and then a fixed-ratio 20 schedule). That is, every completion of the fixed-ratio schedule produced a 0.7-sec darkening of the key and reset the response count to zero for the next ratio. The first fixed-ratio completed after the fixed-interval schedule elapsed produced the 0.7-sec blackout followed immediately by food. These manipulations were carried out under two different fixed-interval durations for each bird ranging from 3 min to 12 min. The standard fixed-interval schedules produced the typical pause after reinforcement followed by responding at a moderate rate until the next reinforcement. The second-order schedules also engendered a pause after reinforcement, but responding occurred in bursts separated by brief pauses after each blackout. For a particular fixed-interval duration, post-reinforcement pauses increased slightly as the number of pecks in the response unit increased despite large differences in the rate and pattern of key pecking. Post-reinforcement pause increased with the fixed-interval duration under all response units. These data confirm that the allocation of time between pausing and responding is relatively independent of the rate and topography of responding after the pause.

On fixed-interval (FI) schedules of reinforcement, pigeons pause after reinforcement and then respond at a moderate rate until the next reinforcement. Recent data have demonstrated that it is possible to manipulate response rate without changing the duration of the post-reinforcement pause, as long as the time between reinforcements remain constant (Farmer and Schoenfeld, 1964; Neuringer and Schneider, 1968; Killeen, 1969; Morgan, 1970; Shull, 1970; Elsmore, 1971). This independence of post-reinforcement pause duration from response rate supports a two-process model of FI performance. One set of factors determines how much time the pigeon spends pausing after reinforcement and another set of factors determines the rate and patterning of responding after the post-reinforcement pause. The present experiment investigated whether the post-reinforcement pause would remain invariant for a particular FI duration even if the response unit was changed.

The logic of the study was to compare the performance on FI schedules in which the response unit was a single key peck with the performance under equivalent FI schedules using different response units. Specifically, the performance on a small fixed-ratio schedule (FR 10 or FR 20) was treated as a single response that was reinforced with food according to a FI schedule. Thus, the performance on a standard FI schedule was compared with the performance engendered by a second-order schedule [FI (FRx:S)] that arranged the same minimum interreinforcement interval. Each FRx completed before the FI elapsed darkened the key briefly and the first FRx completed after the FI elapsed produced the darkening of the key and then food (Kelleher, 1966; Davison, 1969).

METHOD

Subjects

Two adult male Silver King pigeons (BW 7 and BW 8) and one White Carneaux pigeon (BW 6) were obtained from the Palmetto Pigeon Plant. Birds BW 7 and BW 8 were ex-

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perimentally naive at the start of the experiment; BW 6 had been trained previously on variable-interval schedules of reinforcement. Each bird was maintained at approximately 80% of its free-feeding weight throughout the experiment.

Apparatus

The experimental chamber was a standard operant conditioning test chamber for pigeons (Lehigh Valley Electronics #1519). A ventilating fan and white noise helped mask extraneous sounds. One wall of the chamber contained openings for presenting grain and for a response key located directly above the feeder opening, which could be transilluminated with a white light. When the key was white, a peck with a force exceeding 0.18 N applied to the key closed an electrical contact that operated control and recording circuits and also produced a feedback click. Pecks when the key was darkened had no scheduled effect. The reinforcer consisted of a few seconds' access to grain. The reinforcer duration that would maintain the weight of each bird was determined at the beginning of the baseline FI schedules. During reinforcement the feeder opening was illuminated and the key darkened. The feeder light and the keylight were the only sources of illumination in the chamber.

Procedure

The basic design of the experiment involved studying each bird under a standard FI schedule with the single key peck as the response unit, and then changing the response unit to a FR schedule. Each bird was studied under two different FI durations making up Phase I and Phase II.

Phase I

Standard FI schedule. The baseline schedule was a standard fixed-interval (FI) schedule. That is, the first key peck after a fixed time interval had elapsed since the termination of the preceding reinforcement produced food. The first interval in each session started with the illumination of the key. After an initial training period of about 10 days, each bird was assigned to a different FI duration as indicated: Bird BW 6 (FI 3-min); BW 7 (FI 6-min); BW 8 (FI 12-min).

Second-order schedules [FI (FRx:S)]. After stabilization on the standard FI schedule, the schedule was changed to a second-order schedule [FI(FR 10:S)] with the response unit being 10 key pecks and reinforcement being assigned by the same FI schedule used in the baseline training. That is, every tenth peck during the FI produced a 0.7-sec darkening of the key and reset the accumulated response count to zero for the next ratio. The first FR 10 completed after the FI elapsed produced the 0.7-sec blackout followed immediately by food. The circuit ignored pecks during the blackouts. In casual observation the birds were never observed to peck during the blackouts.

After stabilization on the [FI (FR 10:S)] schedule, the response unit was increased from 10 to 20 pecks. Thus, the schedule was changed to a [FI (FR 20:S)] schedule.

The [FI (FR 10:S)] schedule and the FI schedule were reinstated in order to determine the recoverability of performances. Throughout Phase I the FI duration remained constant for each bird.

Phase II

For Phase II, each bird was shifted to a different baseline FI schedule as indicated: Bird BW 6 (FI 6-min); BW 7 (FI 12-min); BW 8 (FI 3-min). With the new baseline FI each bird was studied under the standard FI schedule, the [FI (FR 10:S)] schedule and the [FI (FR 20:S)] schedule.

Table 1 indicates the actual sequence of conditions and the number of sessions devoted to each condition for Phases I and II. Several other experimental treatments employing the Phase I baseline FI intervened between Phase I and Phase II. These are not considered here.

Sessions were conducted daily, each terminating after 50 reinforcements. Data were recorded from every interval in the session.

RESULTS

Figures 1 and 2 show selected cumulative records from one of the last 10 sessions of each condition in Phase I for BW 6 (baseline FI 3-min) and BW 8 (baseline FI 12-min). At a molar level of analysis, the temporal patterns of responses between reinforcements were similar among the three schedules. For a particular FI duration, all three schedules produced approximately equivalent interreinforcement

Table 1

The sequence of conditions, the number of sessions, the baseline FI duration, the mean post-reinforcement pause (PRP), and the mean observed interreinforcement interval (IRI) for each bird. All durations are in minutes.

			BW 6			*BW 8*			*BW 7*		
Condition	*Order*	*Sess*	*FI*	*PRP*	*IRI*	*FI*	*PRP*	*IRI*	*FI*	*PRP*	*IRI*
Phase I			3 min			12 min			6 min		
FI(a)	1	50		0.88	3.16		4.67	13.0		0.14	6.21
(b)	5	30		1.09	3.15		6.26	12.6		0.49	6.19
[FI(FR 10:S)] (a)	2	30		1.17	3.20		7.19	13.7		2.79	6.29
(b)	4	15		1.29	3.18		6.70	12.8		3.31	6.33
[FI(FR 20:S)]	3	40		1.34	3.27		7.59	13.7		3.88	6.67
Phase II			6 min			3 min			12 min		
FI(a)	7	70		2.06	6.05		1.10	3.10		3.36	12.2
(b)	10	20		2.77	6.10		1.49	3.10		2.74	12.3
[FI(FR 10:S)] (a)	6	30		2.90	6.16		1.78	3.22		6.02	12.5
(b)	8	20		2.96	6.29		1.35	3.16		7.01	13.6
[FI(FR 20:S)]	9	20		3.78	6.35		1.92	3.26		7.89	14.3

intervals. On the standard FI schedule, the birds most often displayed the typical pattern of pausing for about half the FI and then pecking at a fairly steady rate until reinforcement. On the second-order schedules, the birds likewise paused for about half the FI but then emitted bursts of responses separated by brief pauses. The number of pecks in a burst corresponded to the FR requirement of the second-order schedule. The duration of the brief pause separating bursts was shorter under the [FI (FR 10:S)] schedule than under the [FI (FR 20:S)] schedule. Although at a molecular level of analysis the pattern of key pecks dif-

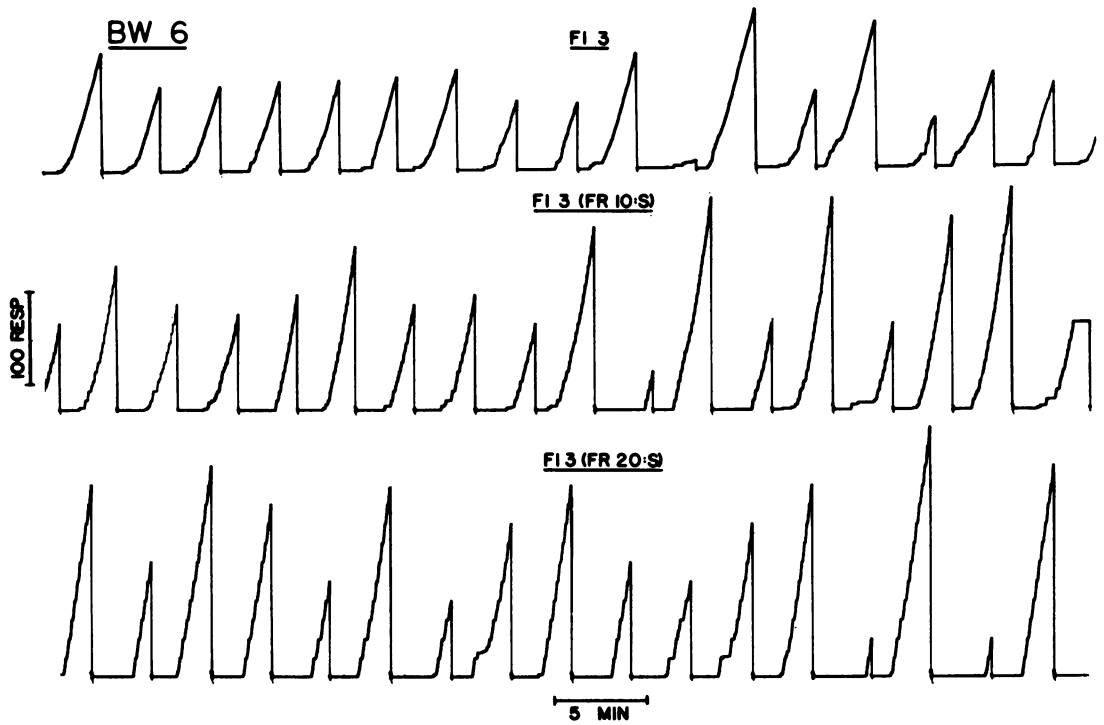

Fig. 1. Cumulative records for BW 6 under the standard FI 3-min schedule, the [FI 3-min (FR 10:S)] schedule, and the [FI 3-min (FR 20:S)] schedule. The records are from one of the last 10 sessions of a condition. The stepping pen reset to the baseline after each reinforcement.

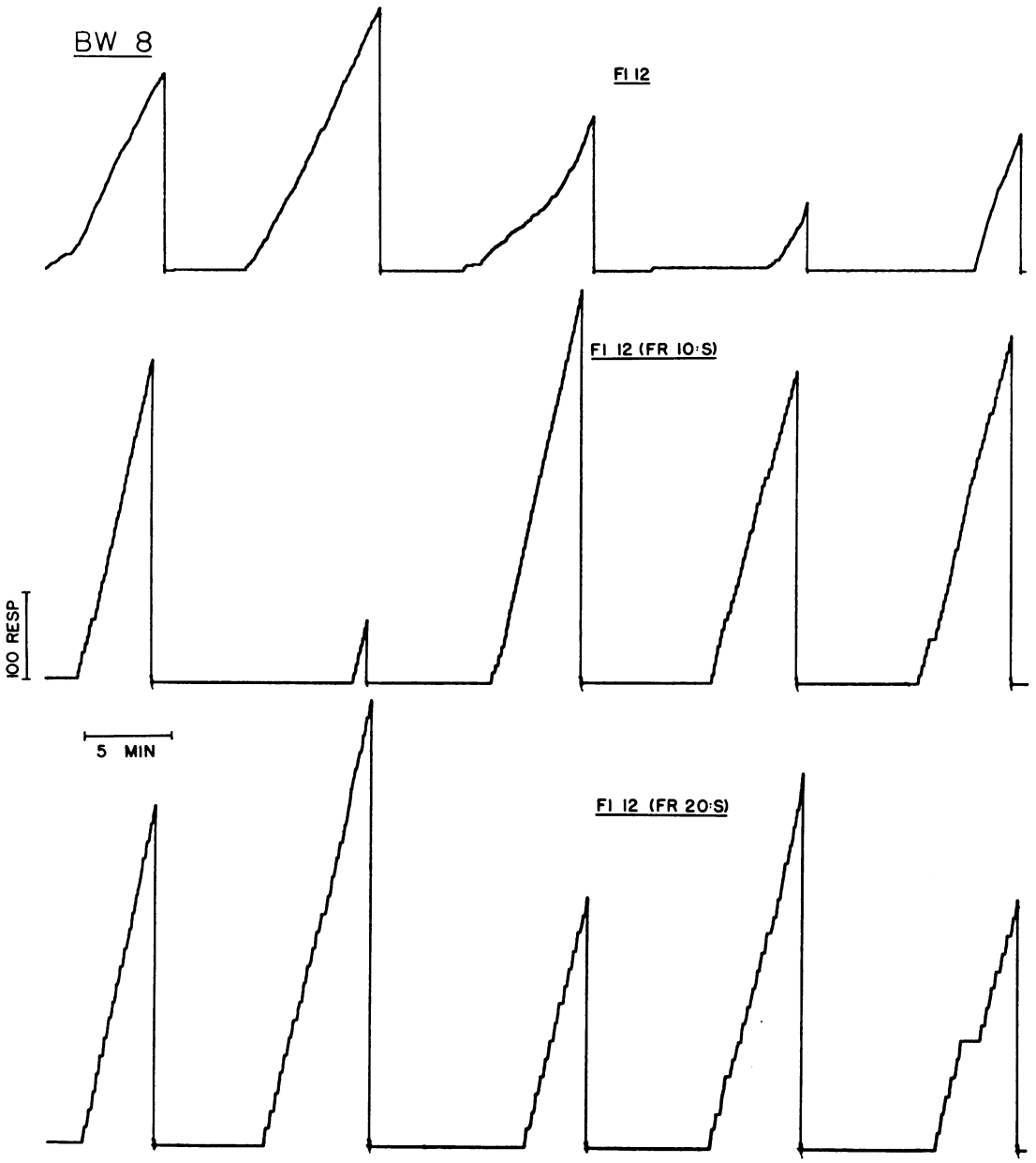

Fig. 2. Cumulative records for BW 8 under the standard FI 12-min schedule, the [FI 12-min (FR 10:S)] schedule, and the [FI 12-min (FR 20:S)] schedule. The records are from one of the last 10 sessions of a condition. The stepping pen reset to the baseline after each reinforcement.

fered markedly between the standard FI schedule and the second-order schedules, the temporal distribution of FR bursts on the second-order schedules resembled the pattern of key pecks under the standard FI schedule, confirming Kelleher's (1966) and Davison's (1969) observations with similar schedules. However, the transition from pausing to responding tended to be more abrupt on the second-order schedules than on the standard FI schedules.

In most respects, the performance of BW 7 (Figure 3) resembled the performance of the other two birds. However, on the standard FI 6-min schedule, the typical pause-and-respond pattern was often preceded by responding for a brief period immediately after reinforce-

ment. Because of these post-reinforcement response bursts, the post-reinforcement pause measured from reinforcement to the first key peck after reinforcement was much shorter on the standard FI 6-min schedule than on the two second-order schedules. The second-order schedules apparently did not have a large effect on the time to the terminal response run, but, instead, eliminated the burst of responding immediately after reinforcement.

Cumulative records from the second FI duration for each bird (Phase II) were essentially similar to those from Phase I. To a great extent, BW 7 persisted in responding immediately after reinforcement on the standard FI schedules throughout the whole experiment.

In general, the pattern of key pecking after the post-reinforcement pause on the second-order schedules was very different from the pattern on the standard FI schedule. Despite these differences, BW 6 and BW 8 appeared to pause about as long on the standard FI schedule as on the second-order schedules. The remainder of the data analyses provide some quantitative support for these generalizations.

For all conditions, post-reinforcement pause was measured from reinforcement to the first key peck after reinforcement. Table 1 shows for each bird the average post-reinforcement pause for the three response units under both FI schedule durations. Each duration represents the mean of the last 10 sessions of a condition. For any particular FI duration there was a small but systematic increase in post-reinforcement pause duration as the number of pecks making up a response unit was increased for BW 6 and BW 8. For BW 7, the post-reinforcement pauses were much longer on the second-order schedules than on the standard FI schedules in part because the second-order schedules eliminated the post-reinforcement response bursts. Although BW 6 and BW 8 almost never responded immediately after reinforcement on the standard FI schedules, they occasionally made a few responses early in the interval and then paused again before making the transition to the terminal rate. These early responses (termed "probes" by Cumming and Schoenfeld, 1958) almost never occurred on the second-order schedules.

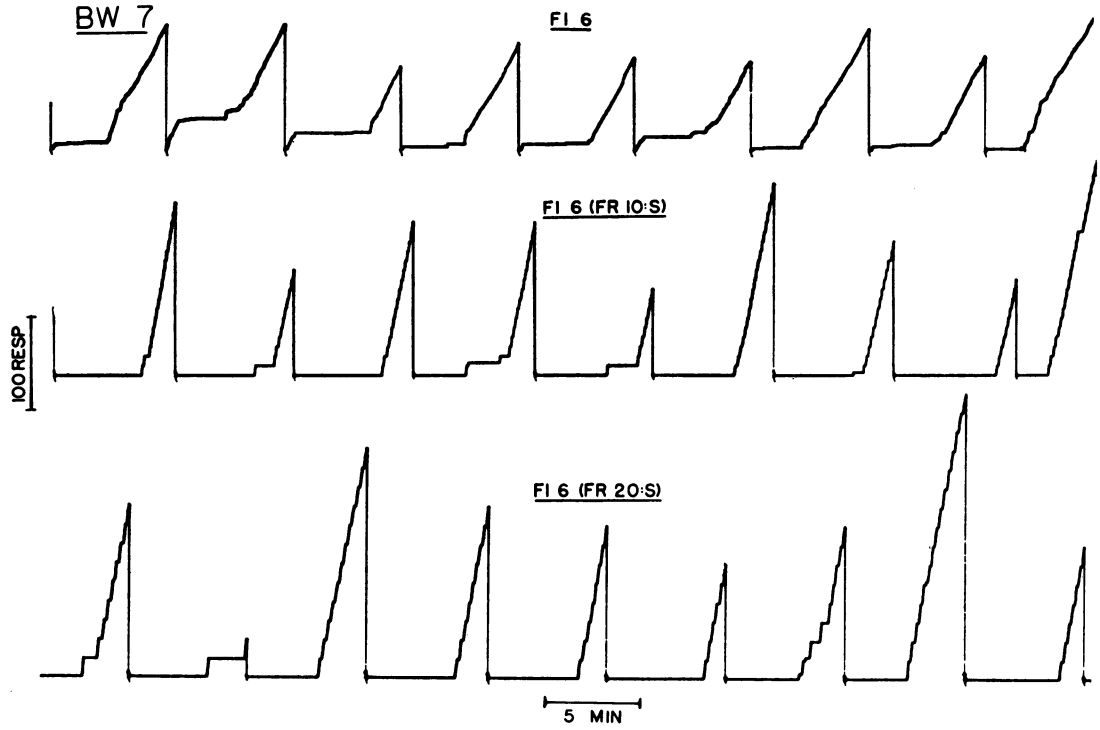

Fig. 3. Cumulative records for BW 7 under the standard FI 6-min schedule, the [FI 6-min (FR 10:S)] schedule, and the [FI 6-min (FR 20:S)] schedule. The records are from one of the last 10 sessions of a condition. The stepping pen reset to the baseline after each reinforcement.

Part of the increase in post-reinforcement pause duration resulted from the elimination of probes. In addition, increasing the number of pecks required for a response unit resulted in a small increase in the mean interreinforcement interval, which might have contributed to the differences in post-reinforcement pause duration among the response unit conditions. Table 1 shows the mean observed interreinforcement interval for each bird.

To adjust for changes in the observed interreinforcement interval, post-reinforcement pause durations were expressed as a proportion of the observed interreinforcement interval for each condition. Figure 4 shows the mean (based on the last 10 sessions) relative post-reinforcement pauses for each bird under each condition. For all birds and for each FI duration the relative post-reinforcement pause increased as the number of pecks for a response unit was increased from 1 to 20. However, considering the data from both determinations at the standard FI and [FI (FR 10:S)] schedules, the effect of response unit size on relative post-reinforcement pause was small for BW 6 and BW 8. Considering second determinations only for these birds, the difference in relative post-reinforcement pause between the standard FI and the [FI (FR 10:S)] schedules never exceeded 0.05. For BW 7, the increase in the size of the response unit from 1 to 10 pecks produced a large increase in relative post-reinforcement pause by eliminating the post-reinforcement response burst. When the response unit was 10 or 20 pecks, the relative post-reinforcement pause was approximately half the interreinforcement interval for BW 7.

In contrast to the small effect of response unit size on post-reinforcement pause duration was the large effect of FI duration on post-reinforcement pause. Regardless of the response unit, post-reinforcement pause increased with the FI duration, ranging from about one-third to one-half of each FI for BW 6 and BW 8.

DISCUSSION

The main purpose of this experiment was to examine the effect of the response unit size on post-reinforcement pause duration in FI schedules. The logic of the experiment required that the response unit affect the patterning of key pecks without markedly altering the temporal patterning of reinforcements. This requirement was satisfied. The response unit had a minimal effect on the interreinforcement interval, but exerted powerful control over the pattern of key pecking. When the unit was 10 or 20 pecks, responding oc-

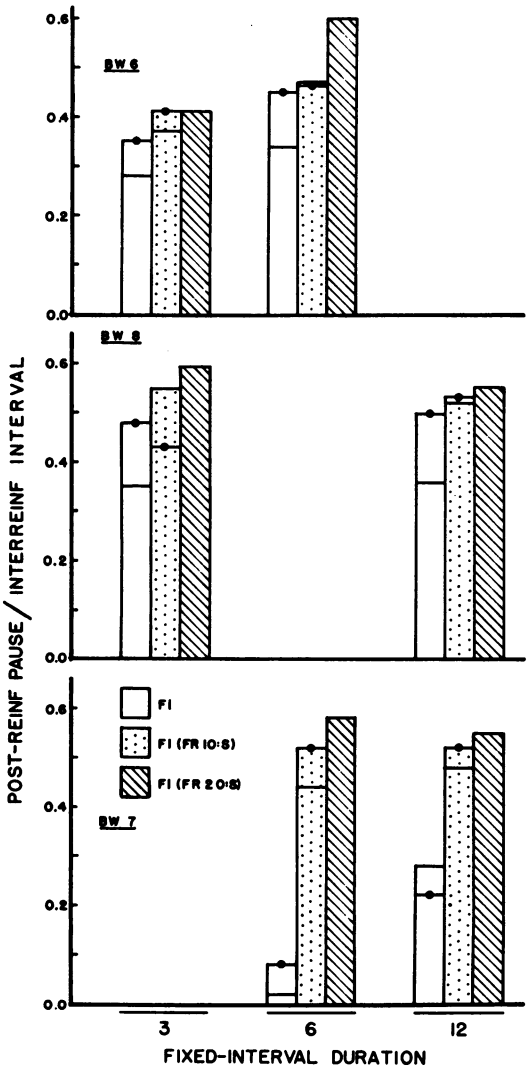

Fig. 4. Post-reinforcement pause duration expressed as a proportion of the observed interreinforcement interval for the three pigeons. Each fixed-interval duration is represented by a group of three bars. The bars within a group represent the different response units with a particular FI duration. From left to right the three bars represent respectively the mean post-reinforcement pause from the standard FI schedule, from the [FI (FR 10:S)] schedule and from the [FI (FR 20:S)] schedule. The large dots indicate redeterminations. Each point is the mean of the last 10 sessions of a condition.

curred in bursts of 10 or 20 pecks respectively, suggesting that the FR components indeed functioned as unitary responses.

For a particular FI duration, post-reinforcement pause also depended on the response unit, increasing with the number of pecks in the unit. This was true even when the small changes in the interreinforcement interval were taken into account (Figure 4). Part of the increase in post-reinforcement pause duration with increasing size of the response unit was due to the decreased frequency of "probes" on the second-order schedules compared with the standard FI schedules. This was most apparent in the case of BW 7. The time to the first peck after reinforcement might not be the best estimate of the latency of the transition point between the pausing and responding states (Schneider, 1969). Other estimates of post-reinforcement pause duration that eliminate the small artifact of occasional "probes" would have revealed smaller differences in post-reinforcement pause durations among the three response units. In view of these considerations, the most reasonable interpretation of the data is that changing the number of pecks for a response unit from 1 to 20 has a rather small effect on post-reinforcement pause duration. In contrast, the interreinforcement interval has a large effect. It is unlikely that these generalizations would apply if the response unit were a much larger number of pecks than used here. Large FR schedule components would interact with the interreinforcement interval in complex ways (Herrnstein and Morse, 1958).

Previous reports have shown post-reinforcement pause to be an increasing function of FI duration (Sherman, 1959; Schneider, 1969; Harzem, 1969; Innis and Staddon, 1971; Shull, 1971). The present data confirm this relation and extend it to second-order schedules where the response unit is the behavior on a small FR schedule.

The relative independence of the post-reinforcement pause from the response unit has implications for theories of FI responding. The performance on FI schedules can be considered as two behavior states—a variable-duration post-reinforcement pause and a variable-duration terminal or "work" state (Sherman, 1959; Schneider, 1969; Shull, 1970; Staddon and Simmelhag, 1971). The designation "work state" and "pause state" are only with respect to the measured operant and do not imply that behavior is absent during the post-reinforcement pause (*cf.* Falk, 1969; Staddon and Simmelhag, 1971). One set of factors determines how the animal allocates its time between the two states, another set of factors determines the rate and topography of behavior in the terminal work state (Farmer and Schoenfeld, 1964; Neuringer and Schneider, 1968; Killeen, 1969; Morgan, 1970; Shull, 1970; Elsmore, 1971). The present study further supports this two-factor model of FI performance by showing post-reinforcement pause duration to be largely independent of the response unit (and also the rate and pattern of key pecking) occurring after the post-reinforcement pause. Recent data permit a more detailed specification of this two-factor model. The factors determining what the animal does in the work state, *i.e.*, the rate and topography of behavior in the responding state, include (a) the response unit required for reinforcement (the present data; Zeiler, 1968; Morgan, 1970; and Shull, 1970), (b) the response rate prevailing at the moment of reinforcement, *i.e.*, the reinforced interresponse time, (Farmer and Schoenfeld, 1964; Killeen, 1969; Elsmore, 1971), and (c) the rate of reinforcement in the terminal state (Schneider, 1969). Factors correlated with the interreinforcement interval determine the animal's time allocation between pausing and working. Such factors could include (a) the rate of reinforcement (Catania and Reynolds, 1968), (b) temporal discrimination based on the stimulus marking the beginning of the interval (Skinner, 1938; Schneider, 1969), and (c) the delay from the transition into the work state to the next reinforcement (Shull, 1971). This last possibility suggests that the transition is a different operant from behavior in the work state, *i.e.*, that it is functionally a changeover operant. Variations in properties of the stimulus marking the beginning of the interval also affect mainly the pause before responding (Staddon and Innis, 1966; 1969; Byrd and Marr, 1969).

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