

SCHEDULE-INDUCED LICKING DURING MULTIPLE SCHEDULES¹

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Schedule-induced polydipsia was studied in rats bar pressing under two-component multiple schedules of food reinforcement. The first component of the multiple schedule was a variable-interval 1-min schedule throughout the experiment. The schedule comprising the second component was varied over blocks of sessions in terms of rate and magnitude of reinforcement, and was either variable-interval 3-min (one pellet), variable-interval 3-min (three pellets), variable-interval 1-min (one pellet), or extinction. Water intake per session varied with the rate of reinforcement in the schedule comprising the second component and was highest when the schedule was variable-interval 1-min. Both bar-pressing behavior and licking behavior showed behavioral interactions between the two components of the multiple schedules. With magnitude of reinforcement held constant, a matching relationship was observed between lick rate and reinforcement rate; the relative frequency of licks in the constant component matched the relative frequency of reinforcement in that component. Bar pressing, however, showed only a moderate degree of relativity matching. During the schedule-induced licking, a burst of licking followed each delivery of a pellet (post-prandial drinking). The duration of these bursts of licking was observed to be a function of the inter-reinforcement interval.

Since Falk's original description of schedule-induced polydipsia (1961) numerous studies have investigated the conditions under which this phenomenon occurs. One requirement is that food be made available in small quantities at spaced intervals (Falk, 1969). Under these conditions, rats have been shown to drink huge amounts of water, often amounting to 50% of their body weight during a 3.5-hr session (Falk, 1967). Such polydipsic rats drink in the presence of considerable body fluid and tissue overhydration (Stricker and Adair, 1966). Various explanations have been advanced to account for this non-regulatory drinking; these include a dry-meal induced-thirst theory (Stein, 1964), an adventitious reinforcement theory (Clark, 1962), a displacement activity theory (Falk, 1969). However, these explanations do not encompass all of the data. It may be that the variables that initiate drinking behavior may not be the same variables that maintain the behavior.

In the present study, schedule-induced polydipsia was investigated in two-component

multiple schedules to see if drinking would vary as a function of the schedule of reinforcement, and whether licking behavior would show the interactions and relativity matching with reinforcement rate often found in operant behavior during multiple schedules.

Reynolds (1961) and others (Catania, 1961; Bloomfield, 1966) observed behavioral interactions of key pecking for food in pigeons during components of multiple schedules. Response rate during the constant component of a two-component multiple schedule was found to vary as a function of changes in the second component. When response rate in the constant component changed in the same direction as the response-rate change in the second component, the effect was termed induction; conversely, when the rate change in the constant component was in the opposite direction of the rate change in the second component, the effect was termed contrast. Contrast effects were observed in a limited number of studies in species other than the pigeon, such as the rat. Smith and Hoy (1954) and Herrick, Myers, and Korotkin (1959) found positive contrast, a response-rate rise in the constant component accompanied by a rate fall in the second component, during the formation of a stimulus discrimination in the rat. More recently, Pear

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and Wilkie (1971) found positive, but not negative, contrast (a fall in rate in the constant component accompanied by a rise in rate in the second component) in the bar-pressing behavior of rats. No studies have shown behavioral interactions in adjunctive behavior (*i.e.*, behavior for which reinforcement is not dependent) in rats during multiple schedules.

METHOD

Subjects

Three female albino Holtzman rats, approximately 75 days old, weighed approximately 200 g (85% of their free-feeding weights) at the start of the study. Their weights were gradually increased to about 300 g by the end of the experiment by feeding 12 to 15 g of food after daily sessions. Water was freely available at all times.

Apparatus

Two identical animal chambers measuring 10 by 6.5 by 9.75 in. (25.4 by 16.5 by 24.1 cm) (inner dimensions) were each enclosed in a sound-attenuating and light-shielded enclosure. Air blowers ventilated the enclosures. White noise and a dim houselight were on during sessions. A lever, operated by a force of approximately 15 g (0.14 N), and a food tray were located along one wall. The reinforcer was a 45-mg Noyes food pellet. On the opposing wall was a metal tube attached to a water bottle. Licks on the tube activated a contact-relay drinkometer (LeHigh Valley Electronics Model #221-05) connected to counters and a cumulative recorder in an adjacent room. Water intake was measured by differences in the weight of the water bottle before and after each session (with suitable adjustments

made for spillage and evaporation). The apparatus was not arranged to measure water intake separately for the two component schedules; however, number of licks in each component was recorded.

Procedure

After initial bar-press training, a multiple variable-interval 1-min variable-interval 3-min (*mult VI 1-min VI 3-min*) schedule was in effect. Reinforcement for the two components of the multiple schedule was arranged on two separate tapes and was dependent on the first bar-press occurring after variable periods of time. All tapes had 20 intervals, the intervals being chosen from a table of random numbers with the restriction that the mean of these numbers be 60 (for the VI 1-min tape) and 180 (for the VI 3-min tape). When a food delivery became due, the tape was stopped until the next bar press occurred. The subjects had free access to the water tube throughout the session. Food delivery occurred independently of licks on the tube.

Subjects were studied individually in 60-min sessions at approximately the same time daily (except for weekends). The sequence of treatments is shown in Table 1. The two components of the multiple schedule alternated at 10-min intervals. The session always commenced with Component 1 and each component occurred three times during the 60-min session. A yellow light above the lever was illuminated during Component 2. Component 1 was always a VI 1-min schedule throughout the experiment, while Component 2 changed after every block of 27 sessions. During the first, third, and fifth stages of the experiment, Component 2 was VI 3-min. During the second stage, Component 2 was also VI 3-min,

Table 1
Order of Presentation of Reinforcement Schedules for Three Rats

Stage	Multiple Schedules		No. Sessions	Subjects
	Component 1	Component 2		
I	VI 1-min (1 pellet)*	VI 3-min (1 pellet)	27	S-1, S-2, S-3
II (a)	VI 1-min (1 pellet)	VI 3-min (3 pellets)	27	S-1, S-2,
II (b)	VI 1-min (1 pellet)	VI 3-min (3 FR 1 1-pellet)	27	S-3
III	VI 1-min (1 pellet)	VI 3-min (1 pellet)	27	S-1, S-2, S-3
IV	VI 1-min (1 pellet)	VI 1-min (1 pellet)	27	S-1, S-2, S-3
V	VI 1-min (1 pellet)	VI 3-min (1 pellet)	27	S-1, S-2, S-3
VI	VI 1-min (1 pellet)	Extinction	27	S-1, S-2, S-3

*All 45-mg Noyes food pellets.

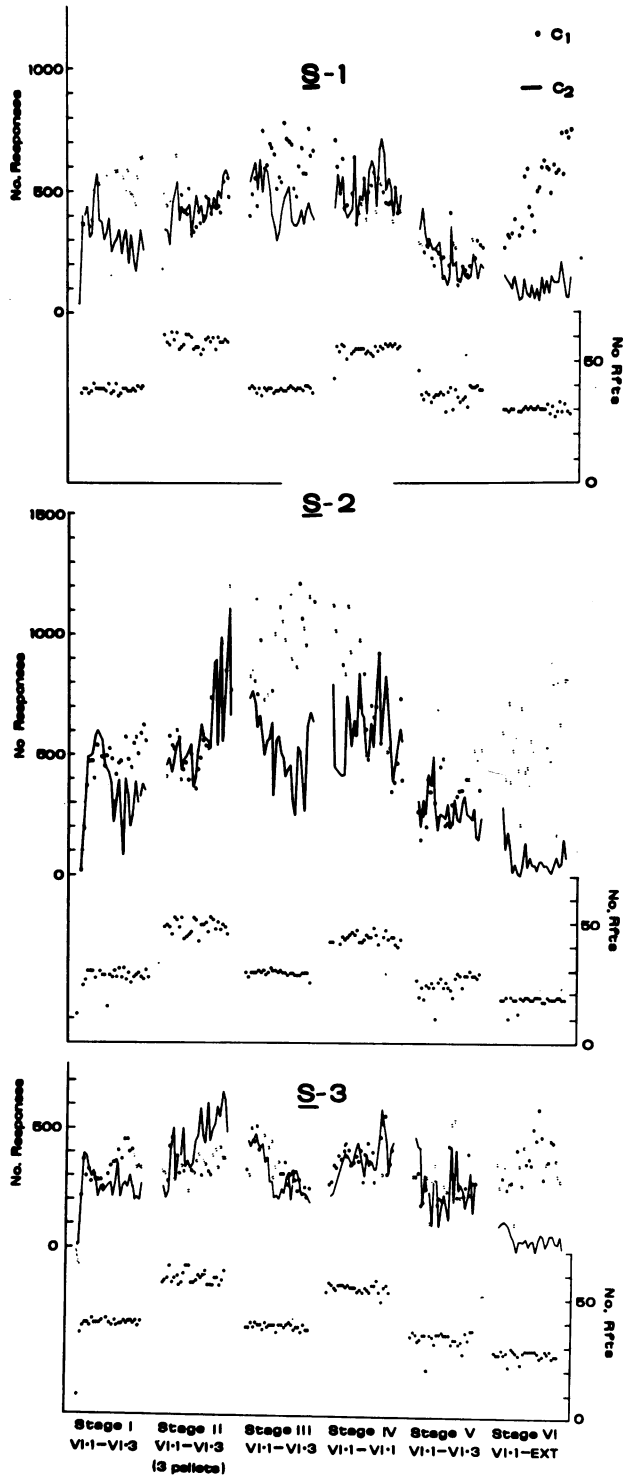


Fig. 1. Number of bar presses and number of reinforcements in three rats during Component 1 (C_1) and Component 2 (C_2) during six stages. Each stage consisted of 27 sessions. Component 1 remained VI 1-min throughout, while Component 2 was either VI 3-min, VI 3-min (three pellets), VI 3-min, VI 1-min, VI 3-min, or extinction (EXT) as described in Table 1.

but the number of pellets delivered at each reinforcement was three 45-mg pellets for Rats S-1 and S-2, while for Rat S-3, the VI 3-min reinforcement was by one 45-mg pellet for each of three consecutive bar presses [VI 3-min (3 FR 1 45-mg)]. During Stage IV, Component 2 was VI 1-min and during Stage VI, Component 2 was extinction. The three subjects underwent the same sequence of treatment with the exception of Stage II (as explained above).

RESULTS

Bar-presses. Figure 1 shows that bar-pressing rates in Component 2 varied with the rate and magnitude of reinforcement in Component 2. Absolute (Figure 1) and relative (Table 2) rates of bar pressing during Component 1 (which was VI 1-min throughout) also varied with the rate and magnitude of reinforcement of the schedule in effect in Component 2. Such interactions in bar-pressing behavior between the two components could be seen most clearly in Stage V, when all three subjects showed negative induction, *i.e.*, a decline in Component 1 bar pressing accompanying a decline in Component 2 bar pressing when the reinforcement schedule in Component 2 was changed from VI 1-min to VI 3-min. During Stage VI, all three subjects showed positive contrast; *i.e.*, a rise in Component 1 bar pressing accompanying a decline in Component 2 bar pressing when the schedule in Component 2 was changed from VI 3-min to extinction. However, behavioral interactions were not always uniform. During Stage III, Rats S-1 and S-2 showed positive contrast while Rat S-3 showed negative induction in Component 1 bar pressing.

When the reinforcement schedules in the two components were both VI 1-min (as in Stage IV), bar-pressing rates in the two components were approximately the same. Also, when total number of pellets in each component was the same, although delivered at different frequencies (as in Stage II when Component 2 was VI 3-min (three pellets)), bar-pressing rates were approximately the same.

When relative frequency of bar pressing in Component 1 was plotted against the relative frequency of reinforcement in Component 1, as in Figure 2, a moderate degree of matching

was seen between the two relative frequencies. The 45-degree line with the intercept at zero indicates perfect matching; the obtained deviations from this line in Figure 2 would better fit a line with slope less than 1.0 and the intercept at a positive value. These results are similar to those of Reynolds (1963), who found an approximate proportionality between relative rate of key pecking and relative rate of reinforcement in pigeons using multiple schedules.

Water intake and licks. Within the first three to nine sessions of the experiment, all three subjects showed drinking at polydipsic levels comparable to those reported by Stein (1964) and Falk (1967). The ease with which polydipsia was established supports the observation that time-dependent reinforcement schedules, such as the VI schedules used in the present multiple schedules, easily induce polydipsia (Falk, 1961).

Figure 3 and Table 2 show that water intake varied with the rate of reinforcement in the schedule comprising Component 2, with the highest intake occurring during Stage IV when the schedule in Component 2 was VI 1-min, the schedule with the highest rate of reinforcement. Increasing the magnitude of reinforcement, however, did not elevate water intake; Stage II, when Component 2 was VI 3-min (three pellets) and Stage III when Component 2 was VI 3-min (one pellet) showed equivalent levels of water intake.

Licking during Component 2 varied with the rate and magnitude of reinforcement of the schedule comprising Component 2 (Figure 3). Lick rates during Component 2 were highest when the schedule in Component 2 was VI 1-min (Stage IV). There was also a moderate increase when the schedule in Component 2 was changed from VI 3-min (one pellet) to VI 3-min (three pellets) (Stage I and Stage II).

During Stage II, there was little difference in the licking pattern of Rats S-1 and S-2, which received three pellets after a single response on each reinforcement occasion, and Rat S-3, which received a single pellet for each of three consecutive bar presses on each reinforcement occasion. Initially, Rat S-3 showed a burst of licking following each pellet delivery during Component 2; however, by the fourth session, this behavior pattern changed so that when a reinforcement oc-

Table 2
 Relative frequency of bar presses and licks in Component 1, mean water intake per session and mean licks/pellet for each component during the six stages of the experiment for each subject.

Stage	Reinforcement Schedules		Relative Frequency of Bar Pressing During Component 1			Relative Frequency of Licking During Component 1			Mean Water Intake (ml)			Mean Licks/Pellet						
	Component 2		S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3	S-1	C ₁	C ₂	C ₃	C ₁	C ₂	C ₃
	Component 1	Component 2																
I	VI 1-min	VI 3-min	0.62	0.55	0.55	0.68	0.67	0.70	19.4	15.0	15.8	46	64	79	111	79	97	97
II	VI 1-min	VI 3(3 pellets)	0.51	0.51	0.44	0.58	0.61	0.66	20.8	19.9	25.7	62	41	99	62	142	71	71
III	VI 1-min	VI 3	0.57	0.64	0.52	0.68	0.69	0.74	20.0	19.9	24.1	71	95	108	139	177	168	168
IV	VI 1-min	VI 1	0.49	0.53	0.50	0.48	0.48	0.51	29.7	25.0	28.7	99	99	110	114	126	114	114
V	VI 1-min	VI 3	0.53	0.57	0.52	0.69	0.70	0.75	17.4	13.1	21.3	82	88	73	81	133	113	113
VI	VI 1-min	EXT	0.83	0.91	0.86	0.96	0.98	0.96	17.3	15.5	18.8	97	-	117	-	154	-	-

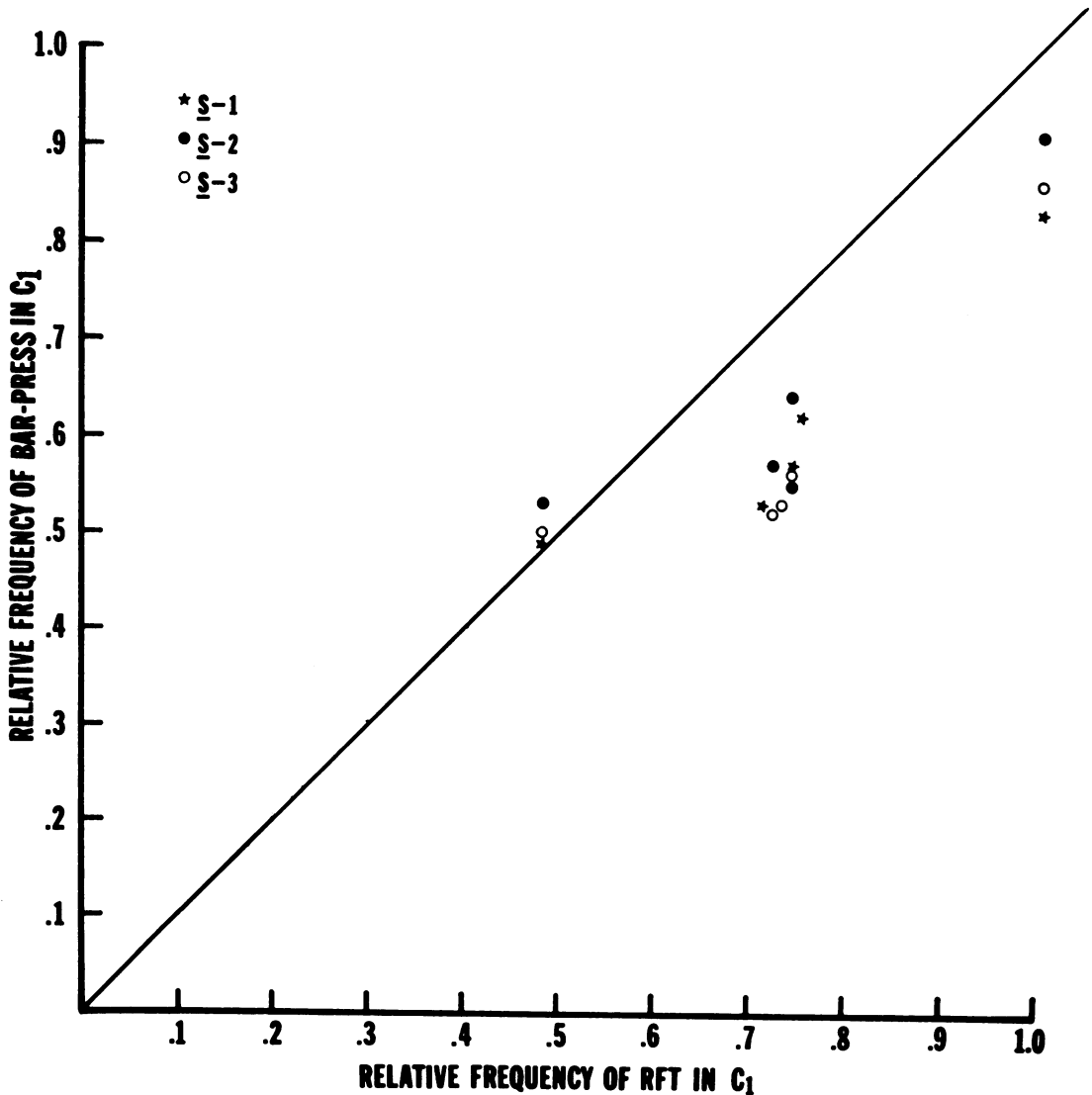


Fig. 2. Relative frequency of bar presses in Component 1 plotted against relative frequency of reinforcements in Component 1. Data points were derived from means of the 27 sessions during each of the five stages (excluding Stage II when magnitude of reinforcement was changed).

curred, Rat S-3 quickly bar pressed twice more and obtained all three pellets in one response burst before commencing licking. This agrees with Keehn and Colotla's observation (1970) that continuously reinforced responses are rarely interrupted by bursts of licking.

Lick rates in Component 1, the constant component, also varied with the rate and magnitude of reinforcement of the schedule comprising Component 2. Such behavioral interactions between the two components could be seen clearly in Stage II when a rise in Component 2 licks was accompanied by a rise in

Component 1 licks (positive induction) in all three subjects. Figure 3 shows that increasing magnitude of reinforcement in Component 2 from VI 3-min (one pellet) during Stage I to VI 3-min (three pellets) in Stage II resulted in increasing both Component 1 and Component 2 lick rates proportionally in Stage II; the difference in lick rates of the two components previously seen in Stage I continued into Stage II, even though the two schedules in Stage II delivered the same total number of pellets, albeit at different frequencies. When frequency of reinforcement in the two compo-

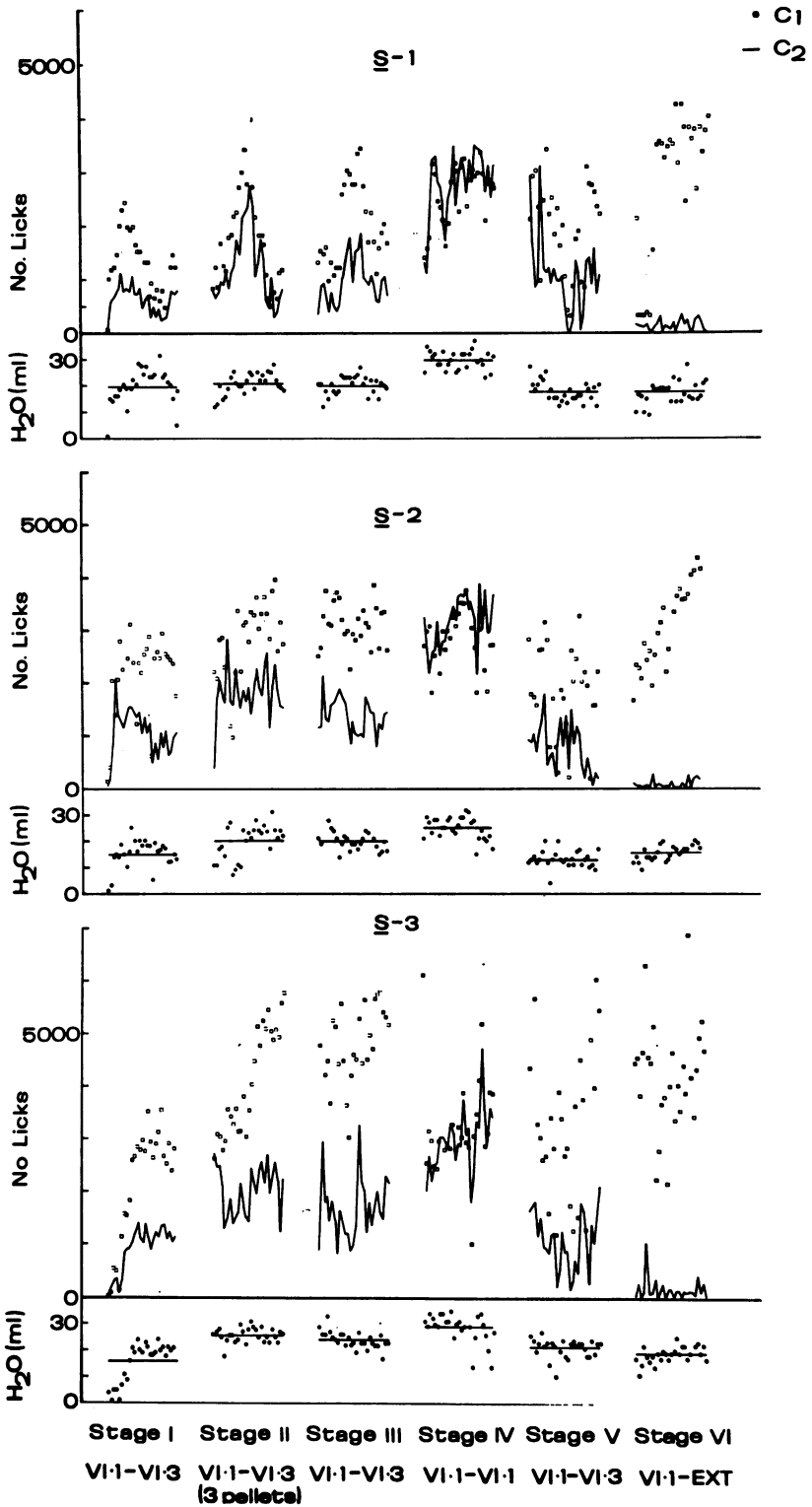


Fig. 3. Number of licks during Component 1 (C₁) and Component 2 (C₂) and total water intake in three rats during the six stages. The data were taken from the same sessions as shown in Figure 1.

nents was identical, as in Stage IV, lick rates in the two components were the same. This would indicate that rate of reinforcement determined lick rates in both Components 1 and 2 in Stage II.

During Stage VI, all three subjects showed positive contrast, *i.e.*, a marked and persistent increase in Component 1 licks while Component 2 licks decreased as the schedule in Component 2 was changed from VI 3-min to extinction.

When relative frequencies of Component 1

licks were plotted against relative frequencies of Component 1 reinforcements, all three subjects showed close matching (Figure 4). This matching between relative licks and relative reinforcements was better than that observed for relative bar pressing and relative reinforcements (*cf.* Figure 2).

Licking occurred typically in a burst immediately following pellet delivery (Figure 5). When there was no pellet delivery, as in extinction, this burst of licking did not occur. This pattern of post-pellet bursts of licking is

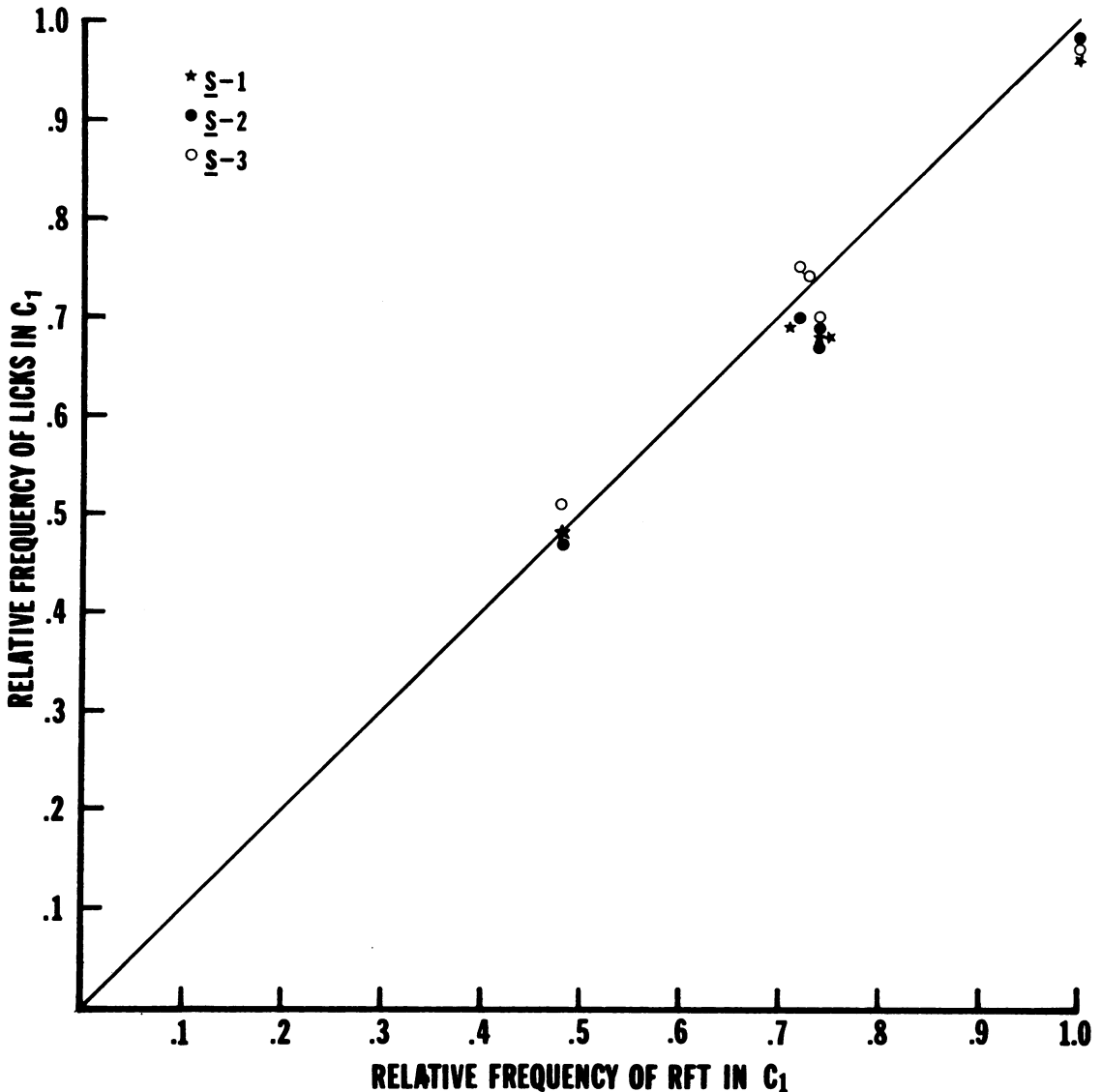


Fig. 4. Relative frequency of licks in Component 1 plotted against relative frequency of reinforcements in Component 1. Data points were derived from means of the 27 sessions during each of the five stages, excluding Stage II when magnitude of reinforcement was different.

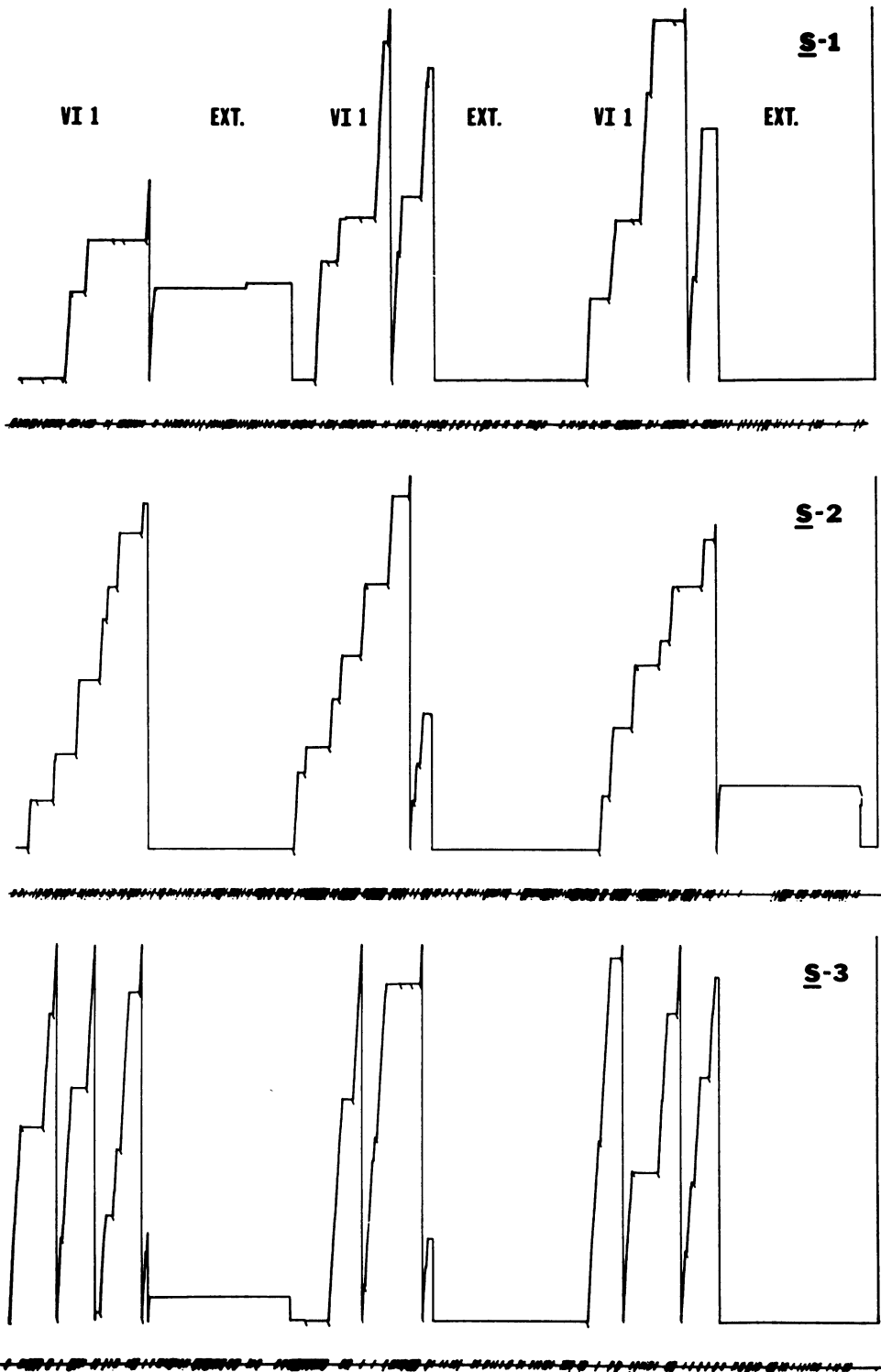


Fig. 5. Individual cumulative records of the first day of *mult* VI 1-min EXT. Each lick moved the response pen upward; the pen reset to baseline when the component schedules changed. Diagonal marks of the response pen indicate reinforcement. Diagonal marks of the event pen (the lower horizontal line) indicate individual bar presses.

typical of polydipsia in rats (Falk, 1961; Stein, 1964). Thus, during extinction, Component 2 licks declined immediately, whereas bar pressing decreased more slowly.

DISCUSSION

Falk (1969) hypothesized that drinking was related to rate of reinforcement in a bell-shaped function, with the mode at approximately VI 2-min. According to this formulation, VI 1-min (one pellet) would induce more drinking than VI 1-min (two pellets), and VI 2-min (one pellet) more than VI 2-min (two pellets). Also, VI 2-min would induce more drinking than VI 1-min. Since Falk held total number of pellets constant in his studies, it was clear that Falk's measure was drinking/pellet rather than drinking/time (as in Figure 3). When the present results were analyzed in terms of licks/pellet (Table 2), licks/pellet during the VI 1-min schedule were approximately 75% of that of the VI 3-min schedule. When magnitude of reinforcement was increased three-fold [from Stage I, VI 3-min (one pellet) to Stage II, VI 3-min (three pellets)], licks/pellet decreased to 60% of the former. That is, VI 3-min (one pellet) induced more licks/pellet than VI 3-min (three pellets), but VI 3-min (one pellet) induced a higher licks/pellet than VI 1-min (one pellet). These findings are consistent with those of Stein (1964), who reported smallest values of licks/pellet for VI 1-min, intermediate values for VI 2-min, and the highest for VI 3-min with all three schedules using one pellet per reinforcement.

When session length, rather than total number of pellets delivered, was held constant in the present study, water intake and total licks per 60-min sessions showed the opposite from above, *i.e.*, more water intake and licks during VI 1-min than during VI 3-min, and more Component 2 licks during Stage II, VI 3-min (three pellets) than during Stage I, VI 3-min (one pellet). This was due to the greater frequency of reinforcements in the higher density reinforcement schedules compensating for its smaller licks/pellet.

To summarize, both food-reinforced bar-pressing behavior, and the adjunctive behavior of licking at a water spout showed behavioral interactions during multiple schedules typically seen with operant food-reinforced behavior.

Bar pressing in rats during multiple schedules showed an approximate matching between relative rates of bar pressing and relative rates of reinforcement similar to that observed by Reynolds (1961) in pigeons key pecking to obtain food. Reynolds observed that induction from the constant component and the persistence of some responding in the extinction component kept the slope of the curve less than 1.0, and the intercept a positive value rather than zero; therefore, a rough, rather than exact, proportionality between responding and reinforcement was maintained.

Licking, however, showed a closer matching with relative rates of reinforcement. This closer matching was due mainly to the fact that licking was almost invariably initiated by delivery of food pellets. Thus, when the schedule in Component 2 was changed to extinction, licking in this component was immediately reduced to near-zero levels. Therefore, the relative rate of licking in Component 1 approached 1.0. The slight deviation from the plotted slope is due to the fact that the chain of licking, once initiated, varied according to the relative interreinforcement interval. Reinforcements during the VI 1-min schedule initiated a slightly shorter chain of licking (licks/pellet) than did reinforcements during VI 3-min. If licks/pellet had remained constant for all reinforcement schedules, then an exact matching would have been obtained.

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