CONTEXT DEPENDENT CHANGES IN THE REINFORCING STRENGTH OF SCHEDULE-INDUCED DRINKING

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Previous experiments show that the opportunity to engage in schedule-induced responding is reinforcing. In this experiment, the reinforcing strength of schedule-induced drinking was measured. Four rats were trained on a concurrent-chain schedule. The two terminal links provided food pellets on identical fixed-time schedules. In addition, one terminal link also provided the opportunity to press a button that operated a water dipper. In this link, the rats showed polydipsic drinking. Button-pressing rate for polydipsic drinking was a bitonic function of pellet rate, and it was possible to describe the relationship with a slightly modified version of the matching equation for primary reinforcement. This equation also closely fit the data from other studies. Initial-link response rates, however, did not appear to be influenced by the availability of water in the terminal links. Control conditions suggested that the reinforcing strength of polydipsia was strongly bound to the context provided by periodic food reinforcement.

Key words: schedule-induced drinking, concurrent-chain schedule, reinforcement strength, matching law, drive, button press, lever press, rats

It is possible to arrange a contingency in which schedule-induced responding reinforces an instrumental response (Falk, 1966). For example, in one study pigeons were trained to work on a ratio schedule for the opportunity to engage in schedule-induced aggression against other pigeons (Cherek, Thompson, & Heisted, 1973); similarly rats can be trained to press a lever in order to engage in polydipsia (Killeen, 1975). These findings introduce the possibility that the quantitative theory that applies to primary reinforcers, the matching law (Herrnstein, 1970), may also apply to the reinforcing properties of schedule-induced responding. Cohen (1975) has tested this hypothesis. He trained rats on concurrent variable-interval, variable-interval (conc VI VI)

schedules that provided approximately equal rates of food reinforcement at each schedule. In addition, one schedule also supported polydipsic drinking. The rats spent more time at this alternative, and Cohen argued that the magnitude of the difference in time proportions was predicted by the matching law. (Up to then, the matching law had generally been restricted to describing the effects of food and shock on response rate.)

The study described below tests the generality of Cohen's findings. A concurrent-chain schedule was used to measure the reinforcing strength of polydipsia. This procedure provides a means for assessing the following issues. First, the difference in time proportions that Cohen observed may have occurred because the rats simply had one less activity at the food-only alternative. The structure of the chain procedure (see below) automatically removes this possible confound. Second, there is some reason to believe that the reinforcing strength of polydipsia will depend on whether the subjects are in the initial , choice, link or the terminal , consequence, link. For example, the temporal pattern of schedule-induced responding suggests that it depends on having recently eaten (e.g., Killeen, 1975; Staddon, 1977). If this is the case, the opportunity to engage in polydipsia may be reinforcing when

the subject is in the terminal link but not reinforcing when the subject is in the initial link. Alternatively, the reinforcing power of polydipsia may extend to both links as is commonly the case for primary reinforcers (e.g., Fantino, 1977). Third, the chain procedure provides a convenient way to measure the reinforcing strength of polydipsia in two different stimulus conditions, the initial and terminal links.

METHOD

Subjects

Four male Lashley-Black rats without previous experimental histories served. They were maintained at approximately 85% of their free-feeding body weights. Except for one control condition, described below, water was available in the home cages.

Apparatus

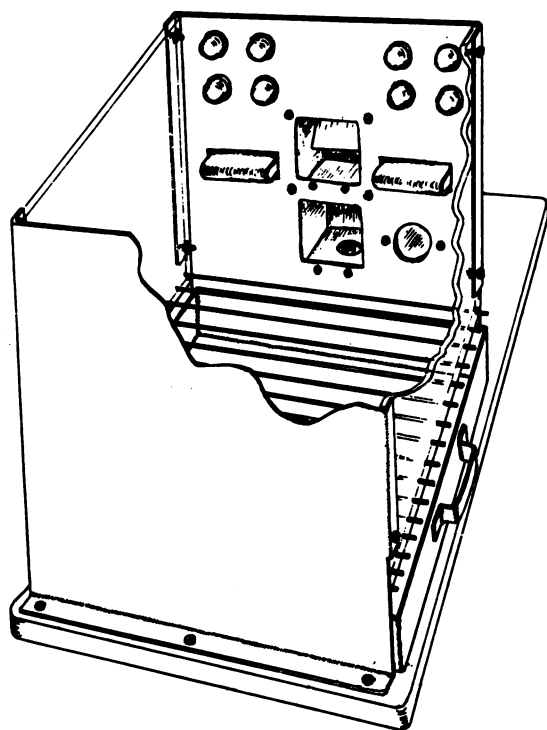A modified two-lever experimental chamber (20.5 cm by 23.5 cm by 19.5 cm) was enclosed

Fig. 1. The front panel of the experimental chamber. Pellets were delivered into the top opening; the water dipper was accessible through the bottom opening. Below the right lever was a Plexiglas button that operated the dipper.

in a sound attenuating box. Figure 1 presents a drawing of the front panel. Two sets of stimulus lights, left and right, could be illuminated from behind with white light. The response levers, one below each set of lights, were operated by a force of more than .20 N. A recessed receptacle for the delivery of food pellets (Noyes 45-mg chow bits) was located between the levers, 8 cm from the floor. Directly below the pellet window was a second opening which gave access to the water dipper. The dipper was operated by a Plexiglas button situated directly below the right lever. A houselight and buzzer (Sonalert) were attached to the roof of the chamber. White noise masked extraneous sounds, and a PDP-8E computer (Digital Equipment Corporation) controlled the sequence of experimental events and recorded data.

Procedure

Preexperimental training. The rats were water deprived for 24 hours and shaped to button press on a continuous reinforcement schedule for water. For each rat, only one session of training proved necessary.

Experimental sessions. The basic experimental procedure was a concurrent-chain schedule in which one terminal link provided access to water. In the initial link, left and right lever presses produced corresponding terminal-link states according to a *conc* VI 40-sec VI 40-sec schedule. The VI timer intervals were approximately exponentially distributed (Fleshler & Hoffman, 1962), and the schedule was arranged so that there was an approximately equal number of left and right terminal-link entries independent of the distribution of left and right initial-link responses (Stubbs & Pliskoff, 1969).

There were two types of terminal-link states: one for left-lever entries, the other for right-lever entries. In each, food pellets were delivered on identical, response-independent fixed-time (FT) schedules. In addition, one terminal link also provided access to water. In this link, a button press operated the dipper for 1.2 sec. The availability of water was signaled by an intermittent tone from the buzzer, and left and right terminal-link entries were further distinguished by the front panel lights. The initial link was signaled by the onset of the houselights and offset of the front panel lights.

Table 1

Summary of the initial-link relative response rates: *a* indicates baseline sessions; water was not available and left side response proportions are given; *b* indicates sessions that rats were water deprived; *c* indicates sessions in which a *conc* VR 40 VR 40 replaced *conc* VI 40-sec VI 40-sec schedule in the initial link.

Fixed-time interval (sec)	Water-available terminal link (left or right)	Percentage of initial-link responses to side associated with water-available terminal link Subjects:				Control condition
		1	2	3	4	
15	—	.52	.48	.45	.52	a
15	R	.46	.52	.57	.48	
15	L	.51	.49	.57	.60	
30	L	.53	.51	.51	.50	
30	R	.50	.52	.58	.53	
60	L	.53	.43	.51	.47	
60	R	.42	.54	.65	.59	
30	L	.67	.52	.57	.62	b
30	R	.61	.65	.63	.54	b
10	L	.55	.43	.47	.52	
10	R	.55	.57	.59	.52	
8	L	.49	.42	.45	.48	c
8	R	.47	.62	.59	.53	c
3.6	R	.48	.55	.57	.61	

Table 1 lists the sequence of conditions. The terminal-link FT values were varied from 3.6 sec to 60 sec, and the availability of water was alternated between the left and right sides to control for possible position preferences. Each FT value was generally run for 30 sessions: 15 sessions with water available in the left terminal link and 15 sessions with water available in the right terminal link. Additional control measures are coded by the lowercase letters in the rightmost column. They were as follows: In the initial experimental condition, *a,* water was not available in either terminal link. In the eighth and ninth conditions, *b,* the rats were water deprived. The water bottles were removed from the home cage, and the rats received their total water ration in the experimental sessions. In the twelfth and thirteenth conditions, *c,* a concurrent variable-ratio, variable-ratio (*conc* VR 40 VR 40) schedule replaced the *conc* VI 40-sec VI 40-sec schedule in the initial links.

One additional condition is not listed in Table 1. The rats were given a type of free-feeding condition in order to evaluate non-polydipsic drinking rates. In these sessions, no stimuli were presented, the water dipper was always available, and 150 pellets were delivered during the first 5 min of the session on an FT 2-sec schedule. This was the fastest rate of delivery at which the pellet dispenser reliably operated (and it took the rats longer than 5 min to eat the 150 pellets so that the free-feeding criterion was met).

The duration of the terminal link and the number of terminal-link entries each session were varied from condition to condition so that the rats would earn approximately 100 pellets a session. For example, in the first 11 conditions, the duration of the terminal link was 104 sec. Thus, when the FT value was 30 sec, the rats received 3 pellets during the terminal-link state, and the session terminated after 33 terminal-link entries or 60 min, which ever came first. For the FT 8 sec condition, the terminal-link duration was 111 sec, and for the FT 3.6 condition, the terminal-link duration was 39 sec.

RESULTS

Terminal-Link Responding: Polydipsia.

Event recorder tracings showed that in most conditions, pellet delivery was followed by at least one button press for water, and we observed that each button press was followed by drinking from the dipper. The temporal pattern of button pressing for water and its rate relative to the free-feeding condition conforms to previous accounts of polydipsia (cf. Falk, 1971; Staddon, 1977). Rats 1, 2, and 3 developed polydipsic drinking within the first few sessions of the initial water-available condition, FT 15 sec, whereas Rat 4 did not develop polydipsia until the first FT 30-sec condition.

Figure 2 shows the temporal pattern of water-dipper operations and pellet deliveries for Rat 1 in the initial FT 30-sec condition. The perpendicular slashes on the upper line of the recorder tracing were triggered by the pellet dispenser; the rectangular excursions on the lower line were triggered by the 1.2-sec
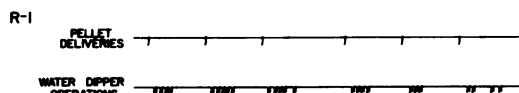

Fig. 2. The temporal pattern of pellet delivery and drinking for Rat 1 in the FT 30-sec condition. The pattern is the same as in studies in which water is directly available from a spout (cf. Staddon, 1977). All the rats showed a similar pattern.
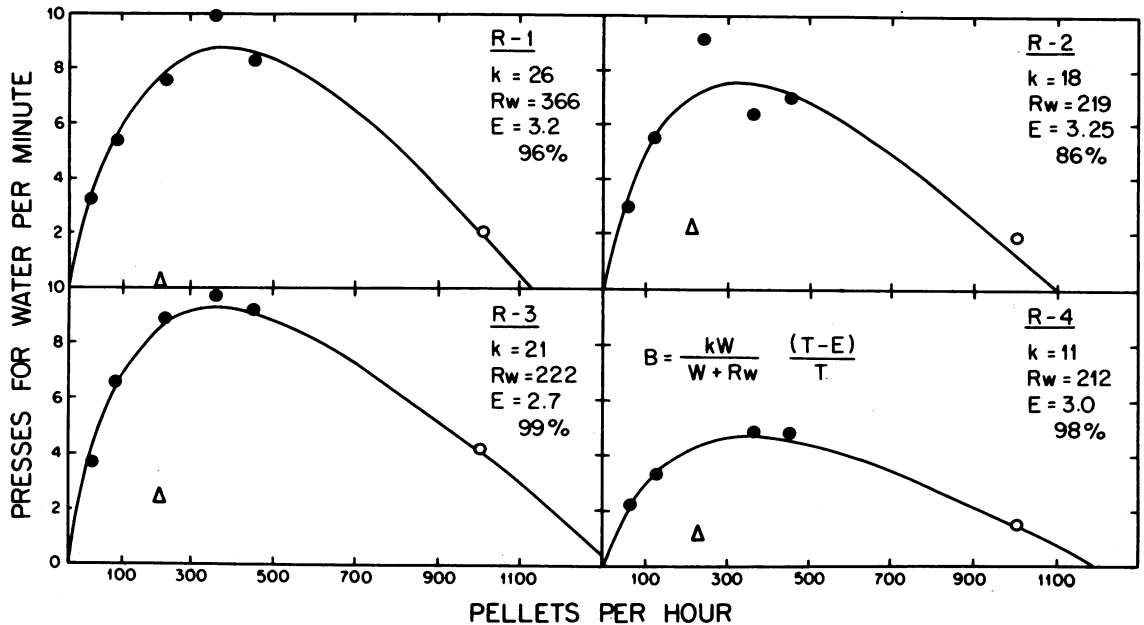
Fig. 3. The rate of button pressing for water as a function of pellet rate. Pellets were obtained on an FT schedule; each button press operated the dipper for 1.2 sec. The equation is a simple modification of the equation that describes the rate of instrumental responding as a function of rate of primary reinforcement (see text).

operation of the water dipper. As in previous studies of polydipsia, eating was closely followed by a burst of drinking, with the drinking usually occurring within the first half of the interpellet interval. All the rats showed a similar pattern.

Figure 3 shows the rate of button pressing for water as a function of pellet rate. The filled circles are the average of two determinations, the open circles are a single determination, and the triangle is from the condition in which a meal of 150 pellets was delivered on an FT 2-sec schedule at the beginning of the session and water was available continuously. The data were averaged from the last 5 sessions of the included conditions.

The solid line is a modified version of the equation which describes the effect of primary reinforcement on instrumental behavior. The original equation (Herrnstein, 1970), is

$$B = \frac{kR}{R + R_e},   \quad (1)$$

where B is operant response rate, R is reinforcement rate, k is a fitted constant which estimates the asymptotic rate of B, and R_e is a second fitted constant which estimates the rate of unscheduled competing reinforcers, for example, those produced by grooming,

gnawing, etc. (for a fuller account, see Herrnstein, 1970). In words, Equation 1 says the rate of reinforced behavior is proportional to its relative reinforcement rate.

Equation 1 has been confirmed repeatedly for instrumental responding for primary reinforcement (de Villiers & Herrnstein, 1976). With a simple modification to account for the time spent eating, we found that it also described the relationship between the rate of button pressing in order to engage in polydipsia and the rate of primary reinforcement on the FT schedule. In addition (see below), this modified version of Equation 1 provided an equally good account of polydipsic licking for rats (Flory, 1971) and rhesus monkeys (Allen & Kenshalo, 1976).

First, assume that the reinforcing strength of polydipsia varies proportionally with the primary reinforcement rate on the supporting intermittent schedule. Second, take into account that polydipsia depends on prior eating and is thus constrained by the time spent eating. The simplest result is

$$B = \frac{kW}{W + R_W} \cdot [(T - E)/T]   \quad (2)$$

for $T \cong E$. For this study, the left side gives the rate of button pressing for the opportunity

to engage in polydipsic drinking. On the right side, k is the asymptotic button pressing rate, W is the reinforcing strength of polydipsia, which is assumed to vary proportionally with pellet rate, and in the denominator, R_W is the rate of competing, unscheduled reinforcers, measured in units of W. The second term on the right expresses the fact that polydipsia depends on prior eating and that the rats could not eat and button press simultaneously: T is the scheduled interpellet time, the FT value, and E is eating time, which was estimated from the data. In words, Equation 2 says that in between bouts of eating on a periodic food schedule, the reinforcing strength of polydipsia is proportional to the relative rate of food reinforcement. Therefore, the overall rate of polydipsic drinking will not necessarily be a monotonic function of food reinforcement rate: when the interreinforcement intervals are relatively long compared to the eating time, an increase in reinforcement rate will produce an increase in schedule-induced drinking rate; but when the interreinforcement intervals approach the eating time, there will be little time available for drinking.

Figure 3 shows that Equation 2 described button pressing for polydipsia about as well, or better, than Equation 1 does for instrumental behavior (cf. de Villiers & Herrnstein, 1976). The parameters k, R_W, and E were fit by the method of least squares, and the median amount of variance accounted for was .98. The new parameter, E, for eating time was about the same for each rat, which agrees with the observation that for rats such behaviors as licking and wheel running occur at constant rates (see, e.g., Premack, 1965), and the absolute values, 2.70 to 3.25 sec, agree with our observations of the interruption of button pressing due to eating. (Note, it can be shown that the additional parameter, E, does not account for the quality of the fit for the left leg of the functions.)

The open triangles indicate the rate of button pressing in the condition that 150 pellets were delivered on an FT 2-sec schedule during the first 5 min of the session. As noted above, this rate of delivery produced a free-feeding situation, with pellets quickly piling up in the tray. Correspondingly, drinking did not show the polydipsic pattern produced by periodic reinforcement. In fact, event recorder tracings and observation indicated that drinking did

not occur until all 150 pellets had been consumed, and even though the rats obtained at least 50% more pellets in the free-feeding condition than in any other, the drinking rate was the minimum observed.

Initial-Link Results

Figure 4 shows the individual and average initial-link relative response frequencies for entering the terminal link with water available as a function of pellet rate. Except for the baseline condition, each point is the average of two determinations: one when water was associated with the left terminal link; the other when the water was associated with the right terminal link. (Recall that, in baseline, water was not available in either terminal link.) The vertical bars show a standard deviation unit. The data were averaged from the last 5 sessions of each condition.

In experimental conditions, the first four points, relative response frequencies were approximately .50. Rats 1 and 2 pressed the levers independently of the location of water, even though they engaged in polydipsia. Rats 3 and 4 showed a slight preference to enter the water-available terminal link. However, for Rat 4 the difference between responding on the two levers was never greater than one standard deviation unit. Consequently, there was no trend as a function of pellet rate, and collapsing across conditions and subjects, there was an average bias of 2% to respond at the lever associated with the water-available terminal link.

The fifth point in Figure 4 (control 1) shows the effect of replacing the initial-link *conc* VI VI schedule with a *conc* VR VR schedule. This change was made because it has been reported that concurrent ratio schedules amplify relative response rate differences (e.g., Rachlin & Green, 1972). However, for the opportunity to engage in polydipsia, the concurrent ratio schedule did not increase preference. In fact, the average difference in first-link response frequencies decreased to about 1%.

The sixth point in Figure 4 (control 2) shows the effect of water deprivation on first-link relative response rates. We removed the water bottles from the home cages so that experimental sessions provided the rats their only access to water. When water deprived, all the rats showed a clear preference to enter the water-available terminal link. This establishes
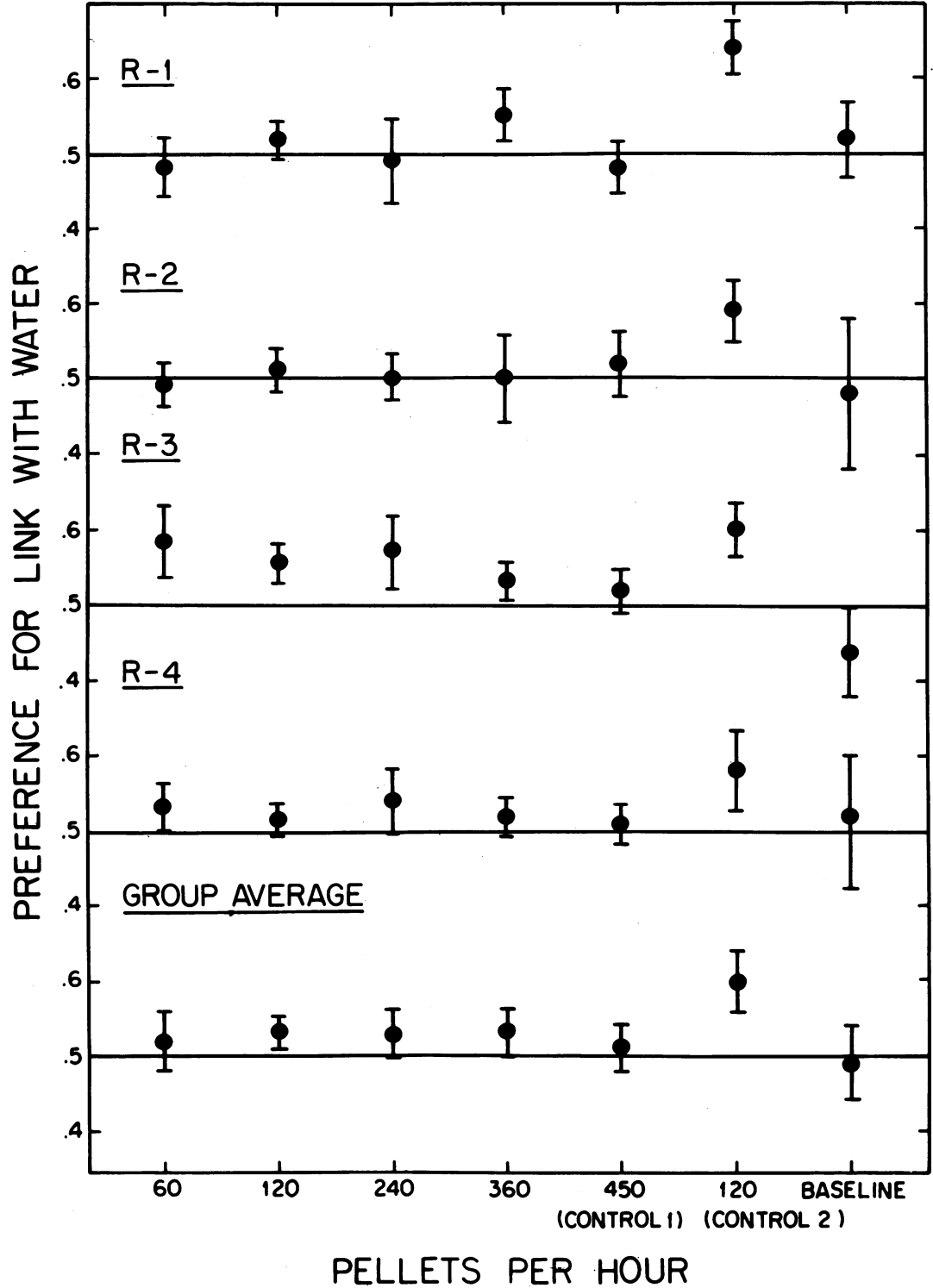
Fig. 4. Relative response rates for entering the terminal link that provided access to the water dipper. The data were averaged from the last 5 sessions of a condition. The bars indicate a standard deviation unit. In control 1, a *conc* VR VR schedule was substituted for a *conc* VI VI schedule in the initial link. In control 2, the rats were water deprived in the home cage.

that it was possible for the rats' behavior in the initial , choice, link to come under control of consequences in the terminal links. It also should be noted that other aspects of the results indicated that the rats discriminated between the two terminal links. In the terminal link which did not provide water, which was signaled by the absence of the intermittent tone, the rats rarely pressed the button for water.

Figure 5 shows the temporal pattern of button pressing for water for Rat 1 when it was water deprived in the home cage. The upper tracing is from the first two water side terminal-link entries of the session. Rat 1 began drinking as soon as it entered the terminal link and continued to do so independently of pellet deliveries. That is, unlike polydipsic drinking, see Figure 2, water-deprived drinking did not show a temporal dependency on eating. The lower tracing shows the temporal pattern of button pressing in the last two water side terminal-link entries from this same session. Near the end of the session, Rat 1 resumed the polydipsic pattern it had shown when not water deprived. Presumably, drinking early in the session was motivated by thirst, whereas drinking late in the session was polydipsic. This apparent change in drive states suggests that in condition *c* even greater initial link preferences would have occurred had it been possible to maintain water deprivation throughout each session. To our knowledge, these are the first data that give evidence of two modes of drinking within a single, relatively brief period (not greater than 60 min).

DISCUSSION

Context dependent changes in polydipsia's reinforcing strength. The view that there was a link-correlated change in drive state is consistent with the major findings. Assume that the drive to engage in polydipsia depends on the following factors: (a) food deprivation, (b) having recently eaten, and (c) cues that signal the unavailability of food (cf. Staddon, 1977). Consequently, the terminal link would activate the drive and empower polydipsia with reinforcing strength (Brown & Herrnstein, 1975), but the initial link would not since food pellets were not obtained there.

However, there is the possible objection that the rats actually preferred to enter the ter-
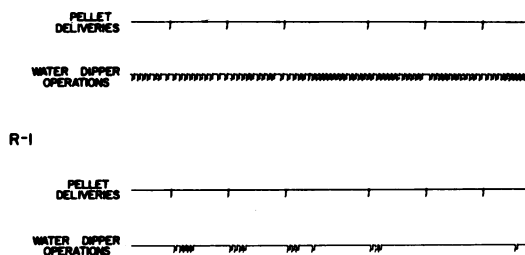

Fig. 5. The temporal pattern of drinking for Rat 1 when it was water deprived. The upper tracing is from the beginning of the session. Drinking was independent of eating. The bottom tracing is from the end of the same session. The difference is apparently due to the satiation of thirst.

minal link with water available, but that the procedure did not provide a sensitive enough measure. This criticism is answered in part, at least, by the results from the condition in which the rats were water deprived in the home cages. First-link response proportions shifted in favor of the water-available link (see Figure 4). In addition, it is well established that concurrent-chain procedures produce systematic initial-link preferences (Fantino, 1977; Herrnstein, 1964). Other accounts (e.g., Falk, 1977) may also be relevant, but whatever the etiology of the reinforcing power of polydipsia, once released it controls responding in the way described by the relative law of effect (Herrnstein, 1970).

The quantitative relationship between rate of schedule-induced drinking and rate of primary reinforcement. The rate of schedule-induced drinking is approximately constant (e.g., Allen & Kenshalo, 1976; Flory, 1971). This suggests that Equation 2 would have predicted the rate of polydipsic licking with about the same precision as it did polydipsic button pressing. Data reviewed from other studies show this to be the case. Figure 6 displays the rate of schedule-induced licking as a function of food pellet rate for two rhesus monkeys, Tonto and Jason (Allen & Kenshalo, 1976) and three rats, 2, 3, and 4 (Flory, 1971). Tonto and Jason obtained banana pellets on a series of fixed-interval (FI) schedules. The best fitting eating times, *E,* for both monkeys were approximately the same, 9.5 sec. The values for *T* were calculated from the obtained reinforcement rates rather than the scheduled ones, as shown in Figure 3, since in an FI schedule the reinforcer depends on a response. Given the long eating times and short FI intervals, Equa-
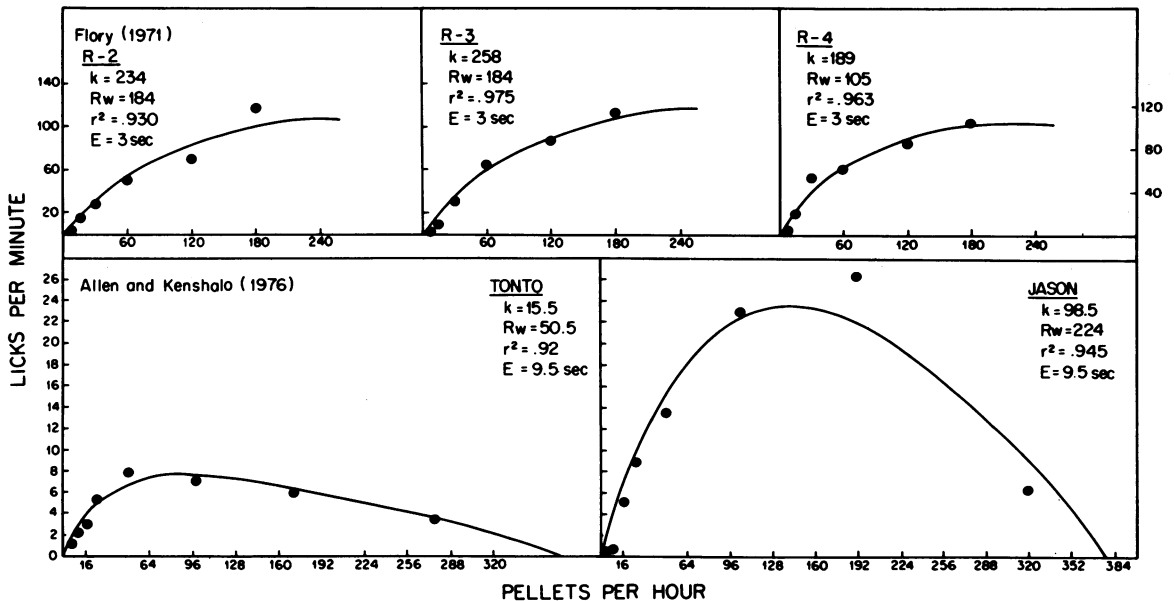
Fig. 6. Rate of polydipsic licking as a function of food pellet rate. Tonto and Jason are rhesus monkeys (Allen & Kenshalo, 1976). Subjects 2, 3, and 4 are rats (Flory, 1971). The equation is a simple modification of the equation that describes the rate of instrumental responding as a function of rate of primary reinforcement (see text and Figure 2).

tion 2 predicted bitonic functions. The amount of variance accounted for was .92 for Tonto and .95 for Jason. Data for Rats 2, 3, and 4 were derived from Figure 4 of Flory's paper (1971). The curves are not bitonic because Flory did not use FI intervals shorter than 20 sec. An increasing function does not delimit a value for eating time, E, so that we selected 3 sec on the basis of our results (Figure 3). The amount of variance accounted for ranged from .92 to .98.

Although Equation 2 generally accounted for over 95% of the variance in the bitonic data (Figures 3 and 6), there was a systematic deviation between the obtained and predicted values. For both rats and monkeys, the maximum obtained drinking rate was invariably (in 6 of 6 cases) greater than the maximum predicted drinking rate. This is because Equation 2 does not take into account the temporal pattern of induced drinking. The term $(T - E)/T$, see Equation 2, implies that eating will interfere with induced drinking independently of the length of the interfood interval, T. However, the data show that the probability of induced drinking declines as a function of time since eating (e.g., Staddon, 1977). Therefore, eating is more likely to constrain the rate of schedule-induced drinking in a short inter-

val than in a long interval, and consequently Equation 2 will underestimate the maximum. For example, the event recorder tracings showed that the rats rarely pressed the button for water in the last 15 sec of the 30-sec interpellet intervals (see Figure 3), whereas in the 8-sec and 3.6-sec intervals, the majority of button presses for water were in the second half of the intervals. Equation 2, therefore, does not provide a complete theory of the reinforcing strength of polydipsia.

The shape of the curves in Figure 3 and Figure 6 is also pertinent to Killeen's theory of behavioral arousal (1975). Killeen derived a mathematical model of behavior on intermittent schedules that quite successfully describes the temporal pattern of polydipsia. However, the model (Killeen, Hanson, & Osborne, 1978) implies a linear relationship between food reinforcement rate and schedule-induced drinking rate, whereas Figures 3 and 6 and other data (e.g., Cohen, 1975) consistently show a curvilinear relationship. Therefore, some modification of Killeen's otherwise powerful model would seem to be in order.

Although Equation 2 successfully described the rate of schedule-induced drinking in three different studies, it may not apply to the description of other types of induced behaviors.

For example, data from three experiments on schedule-induced attack were analyzed (reviewed by Staddon, 1977), and the obtained rates differed widely from those predicted by Equation 2. This discrepancy, however, may be due to a procedural constraint. In each study (Cherek et al., 1973; Cohen & Looney, 1973; Flory, 1969), an attack that occurred within 15 sec of the next scheduled food delivery delayed that delivery for another 15 sec. The subjects, pigeons, appeared to learn this contingency so that it is likely that the rate of attack was inhibited in a way that did not take place in the studies of schedule-induced drinking.

Summary. The data displayed in Figures 3, 4, and 6 are easily summarized if it is assumed that the reinforcing strength of polydipsia depends on the stimulus conditions provided by periodic food schedules. In the terminal link, periodic eating induced a drive that empowered polydipsia with reinforcing strength, whereas in the initial link the conditions for polydipsia were not met, and, therefore, responding at the two levers was controlled by food pellet rate alone. Importantly, once the reinforcing power of polydipsia was engendered, it maintained response rates according to a well-established quantitative version of the law of effect (de Villiers & Herrnstein, 1976).

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