THE REINFORCEMENT VALUE OF SCHEDULE-INDUCED DRINKING¹

IRA L. COHEN

RUTGERS UNIVERSITY

The effect of food reinforcement schedules on the reinforcement value of drinking water was evaluated. Food-deprived rats were exposed to concurrent, identical variable-time schedules of food presentation, the food thus being delivered independently of the rats' behavior. When the relative amount of time spent in a schedule component stabilized, an opportunity to drink water was introduced into one schedule component. The value of the variable-time schedules was varied from 60 to 90 to 270 sec. The relative amount of time spent in the schedule component associated with drinking water was a decreasing function of food frequency for two animals and remained constant for the third. Drinking rates were direct functions of food frequency, and the amount of water drunk per pellet was an inverse function of food frequency. The reinforcement value of drinking water, according to the Matching Law, was a direct function of the frequency of food presentation. It was concluded that food reinforcement schedules indirectly influence rates of drinking by altering the reinforcement value of drinking water and that certain properties of schedule-induced drinking can be accounted for in terms of the reinforcement value of drinking water, the rate of drinking, and the frequency of food presentation.

Falk (1966a) showed that a food-reinforcement schedule enhances the reinforcement value of drinking water by demonstrating that fixed-ratio (FR) schedules of water reinforcement will maintain lever pressing in food-deprived rats if the rats are concurrently exposed to an intermittent food schedule. However, the precise relation between the rate of food presentation and the reinforcement value of drinking is not clear. For example, when one considers the relation between the amount of water drunk per pellet and the interfood interval, it appears that the reinforcement value of drinking water is a bitonic function of reinforcer frequency (Falk, 1966b). Indeed, as Falk (1966a) demonstrated, only intermittent food schedules sustain water-reinforced FR behavior. However, if one considers the relation between the rate of drinking and food frequency, a different result is obtained

(cf. Figure 1). In this instance, it would appear that the reinforcement value of drinking is an increasing function of food frequency.

It would appear to be worthwhile to have a generally accepted measure of the reinforcement value of some response-reinforcer relation expressed in terms other than rate or amount.

In the present experiment, the reinforcement value of drinking water was assessed with a concurrent reinforcement schedule (Catania, 1966; Herrnstein, 1961, 1970). With this procedure, animals are trained to choose between two or more concurrently available reinforcement schedules by emitting an operant that is designated as the changeover response. Each reinforcement schedule is identified by a discriminative stimulus, S^D . For example, consider two concurrently available variable-interval schedules, VI 1-min (Schedule 1) and VI 2-min (Schedule 2), the first associated with a red light and the second with a blue light. If Schedule 1 is in effect and a changeover response is emitted, the red light is extinguished and the blue light is illuminated, indicating that reinforcers are now available according to the VI 2-min schedule.

It has been reported that if the relative number of Schedule 1 responses (the number emitted in Schedule 1 divided by the total

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Fig 1. The rate of water drunk (ml per hour) as a function of the frequency of food presentation. Derived from Figures 1 and 2 in Falk (1966b).

number of responses) or the relative amount of time spent in Schedule 1 (the amount of time spent in Schedule 1 divided by the total session time) is plotted as a function of the relative rate of reinforcement obtained from Schedule 1 (the obtained rate of Schedule 1 reinforcers divided by the total obtained reinforcer rate), a linear function with a slope of 1.0 and an intercept of 0.0 best describes the data (Baum and Rachlin, 1969; Herrnstein, 1961). Similar results have been obtained with respect to the relative duration of reinforcement (Catania, 1963), relative immediacy of reinforcement (Chung and Herrnstein, 1967), and simultaneous manipulation of the relative rate and duration of reinforcement (Ten Eyck, 1970). Thus, it would appear that the concurrent schedule procedure can serve as a sensitive and reliable indicator of the reinforcement value of certain response-reinforcer relations (Baum and Rachlin, 1969).

Mathematically, the relation between relative time and relative reinforcement rate, otherwise known as the Matching Law (Herrnstein, 1970), is expressed as follows:

$$\frac{T_1}{T_1 + T_2} = \frac{R_1}{R_1 + R_2}$$

where T_1 and T_2 refer to the absolute amount of time an animal spends in Schedules 1 and 2, respectively, and R_1 and R_2 refer to the *obtained* rates of reinforcement from Schedules 1 and 2, respectively (Baum and Rachlin, 1969).

If the stimuli maintaining schedule-induced drinking derive their value from the food schedule, adding an opportunity to drink water in one of the two schedule components should increase the reinforcing value of that schedule. Thus, if the obtained food frequency in Schedules 1 and 2 were approximately

equal, but Schedule 1 also provided the opportunity to drink, an animal should spend more time in Schedule 1 than in Schedule 2. In terms of the Matching Law, this relation can be expressed as:

$$\frac{T_1}{T_1 + T_2} = \frac{R_1 + W_1}{R_1 + R_2 + W_1}$$

where W_1 stands for the reinforcement value (expressed in dimensions compatible with R_1 , e.g., food pellets per hour) attributable to the water available in Schedule 1. Because R_1 and R_2 are assumed to be equal, the relation simplifies to:

$$\frac{T_1}{T_1 + T_2} = \frac{R + W_1}{2R + W_1}$$

On the other hand,

$$\frac{T_2}{T_1 + T_2} = \frac{R}{2R + W_1}$$

so the difference in the proportion of time spent in Schedules 1 and 2 may be expressed as

$$\frac{W_1}{2R + W_1}$$

Given this relation, it is apparent that if the amount or rate of drinking produced by changes in food frequency can be related to the reinforcement value of drinking water, manipulations of R_1 and R_2 in the concurrent procedure should result in corresponding changes in the value of W_1 . The purpose of the present experiment was to evaluate the direction of these changes. In other terms, is the reinforcement value of drinking water greatest at short interreinforcement intervals (as is rate of drinking) or at relatively long interreinforcement intervals (as is amount of water drunk per pellet)?

METHOD

Subjects

Three naive male hooded rats (Long Evans strain), initially weighing between 420 and 550 g, were housed individually and maintained at 80% of their free-feeding body weights by postsession supplements of Purina Lab Chow. Water was freely available in the home cage.

Apparatus

The test chamber was a standard Grason-Stadler two-lever operant chamber mounted

in a sound-attenuating enclosure (model E3125A-300). Reinforcers consisted of 45-mg Noyes pellets. White noise was delivered from a Grason-Stadler noise generator (model 901 B) to a speaker mounted on the lower-left side of the instrument panel. Standard electro-mechanical scheduling and recording equipment was located in an adjacent room. Licks were monitored by a drinkometer circuit. Lever presses and licks were recorded on counters and a cumulative recorder. The right lever was immobilized throughout the experiment. A houselight was always on. On the lower-right side of the instrument panel was a hole large enough to enable a rat to reach with its snout a metal tube attached to a calibrated water bottle. The water bottle could be retracted beyond the reach of the animal by means of a motor-operated cam located outside the sound-attenuating enclosure.

Procedure

Pretraining. After each rat had been reduced to 80% of its free-feeding weight, it was magazine trained for one session and received 100, 45-mg Noyes pellets delivered at irregular intervals. In the second session, the lever-press operant was shaped on the left lever by successive approximations. The session was terminated when each rat received 100 pellets on an FR 1 schedule.

Concurrent schedule. In the third session, a concurrent schedule was introduced in which food pellets were allocated according to two independent variable-time (VT) schedules. Each schedule consisted of 13 intervals starting at zero with a progression constant equal to one-sixth of the mean interfood interval. The intervals were spaced according to a random sequence. Each schedule was associated with a different stimulus condition (illumination *versus* nonillumination of three panel lights).

In the presence of a discriminative stimulus, reinforcers were delivered independently of the rat's behavior. Each response on the left or changeover lever changed the discriminative stimulus and schedule then in effect to the alternate condition. A changeover delay of 3 sec followed every response on the changeover lever. This delay ensured that a changeover response would not be followed by food delivery until 3 sec had elapsed. The changeover-delay procedure ensures that each schedule will maximally control behavior in the pres-

ence of each discriminative stimulus, rather than controlling rapid changeover rates that distort the matching function (Herrnstein, 1961).

Each tape timer ran continuously and did not stop when the rat changed over to the alternate reinforcement schedule. If a food pellet was scheduled to be delivered by a schedule not in effect, the tape timer governing pellet delivery was stopped and the pellet was stored. When the animal changed over to that schedule, the food pellet was delivered when the changeover delay was completed and the tape timer was operated. The stimulus initiating each session was arranged according to an ABBA sequence.

Phase 1. In this phase, the mean interfood interval for both schedules was 60 sec. The relative amount of time spent in one schedule component was averaged across two successive sessions in which the stimulus initiating each session (*i.e.*, illumination or nonillumination of the panel lights) differed. When this baseline value did not vary systematically across five successive calculations, an opportunity to drink water was introduced into the less-preferred component (if one existed). Changeovers now had the effect of presenting and removing a water bottle. When the results appeared stable according to the above criterion, the stimuli identifying each reinforcement schedule were reversed and a new stability criterion was sought.

Phase 2. In this phase, the mean interfood interval for both schedules was 90 sec. The procedure was identical to Phase 1.

Phase 3. In this phase, the mean interfood interval for both schedules was 270 sec. The procedure was identical to Phase 1 except for Rat I-7. The stimuli identifying each reinforcement schedule were not reversed for this animal.

Sessions were terminated after 60 pellets had been collected.

RESULTS

Under baseline conditions, in which water was absent, two of the three rats exhibited a preference for the schedule associated with relative darkness. The other rat, I-13, spent approximately equal amounts of time in each schedule. Table 1 presents the relative amount of time spent in a schedule component as-

Table 1

The relative amount of time spent in a schedule component and the obtained relative frequency of reinforcement in that component for Phases 1, 2, and 3. LT = the component associated with light as an S^p. $\overline{LT}$ = the component associated with relative darkness as an S^p.

Rat	Baseline VI Schedule (seconds)						Water VI Schedule (seconds)					
	60		90		270		60		90		270	
	LT	$\overline{LT}$	LT	$\overline{LT}$	LT	$\overline{LT}$	LT	$\overline{LT}$	LT	$\overline{LT}$	LT	$\overline{LT}$
I-7												
Rel. Time	0.45	0.55	0.44	0.56	0.46	0.54	0.61	0.60	0.60	0.60	0.56	—
Rel. Reinf.	0.49	0.51	0.49	0.51	0.49	0.51	0.55	0.55	0.51	0.51	0.50	—
I-9												
Rel. Time	0.49	0.51	0.47	0.53	0.40	0.60	0.65	0.68	0.67	0.73	0.47	0.64
Rel. Reinf.	0.51	0.49	0.48	0.52	0.50	0.50	0.52	0.54	0.56	0.57	0.50	0.52
I-13												
Rel. Time	0.51	0.49	0.47	0.53	0.50	0.50	0.61	0.66	0.61	0.63	0.64	0.59
Rel. Reinf.	0.50	0.50	0.50	0.50	0.51	0.49	0.54	0.55	0.51	0.53	0.52	0.52

Fig. 2. The cumulative records of Rat I-9 showing the pattern of schedule-induced drinking under Phases 1, 2, and 3. Note that drinking occurred both after food was consumed and after the animal changed over to the water component. The upper tracing indicates the pattern of drinking. Each step upward indicates one lick. Downward deflections of the pen indicate deliveries of food. The pen was reset each time the animal changed over to another schedule component except for the 60-sec schedule condition. The lower tracing indicates the number and duration of changeovers. Upward deflection of the pen indicates time spent in the water component.

sociated with illumination or nonillumination of the panel lights and the obtained relative frequency of food presentation in that schedule averaged across the 10 sessions used to evaluate stability according to the criterion described above.

When the opportunity to drink water was added to one component schedule, each animal rapidly developed schedule-induced drinking. The amount of water consumed per session gradually increased across sessions until a stable value was attained. The pattern of schedule-induced drinking is shown in a typical cumulative record in Figure 2. As can be

seen, drinking appeared both after a pellet was delivered and after an animal changed over to the water-associated schedule. There were also many instances in which changeovers, rather than drinking, occurred after a pellet was eaten in the water-associated schedule.

Figure 3 displays the rate of water consumption (expressed in terms of the amount of water drunk per hour per session) and the amount of water drunk per 60 pellets as a function of the three different reinforcement schedules. The rate of water consumption increased ($F = 83.86$; $df = 2,81$; $p < 0.001$) and the amount of water drunk per 60 pellets decreased ($F = 189.47$; $df = 2,81$; $p < 0.001$) as the frequency of food presentation increased.

The relation between the mean relative amount of time spent in a schedule as a function of the scheduled frequency of food presentation is shown in Figure 4. The difference between the relative amount of time spent in the water-associated schedule and baseline conditions was significant ($F = 806.94$; $df = 1,2$; $p < 0.001$). For the water condition, as the scheduled frequency of food presentation decreased from 60 to 40 pellets per hour, the mean relative time spent in the water-associated schedule remained the same. A further decrease from 40 to 13.3 pellets per hour resulted in a decrease in the relative amount of time spent in the water-associated schedule (t -test, $p < 0.001$) for Rats I-7 and I-9. The mean relative time spent in the water-associated schedule remained constant for Rat I-13.

The effect of reversing the stimuli identifying the water- and nonwater-associated schedules on the relative amount of time spent in the water-associated schedule is shown in Figure 5. Each rat readily learned to track the stimulus identifying the water-associated schedule.

DISCUSSION

The results are consistent with previous observations that increases in food frequency command increases in rate of drinking and decreases in the amount of water consumed per pellet. The bitonic function frequently reported for the amount of water consumed per pellet was not obtained in the present study. This could be attributed to the possibility that the overall frequency of food presentation covered only the increasing side of

Fig. 3. The rate of water consumption (ml per hour per session) (closed circles) and the amount of water drunk per 60 pellets (open circles) as a function of the scheduled frequency of food presentation for all three animals.

Fig. 4. The mean relative amount of time spent in a schedule component as a function of the scheduled frequency of food presentation for all three animals. Open circles indicate baseline measures and closed circles indicate relative time spent in the water component.

the function. Undoubtedly, further decreases in food frequency would have led to a decline in the amount of water consumed per pellet.

Similarly, the results are also consistent with the hypothesis that decreases in food frequency are associated with a decrease in the reinforcement value of drinking water. In

Fig. 5. The relative amount of time spent in the water component 10 sessions before and 10 sessions after reversal of the stimuli identifying the water and nonwater components is shown for all three animals under Phases 1, 2, and 3.

Figure 6, the mean reinforcement value of drinking water (expressed in pellets per hour) is plotted as a function of the scheduled frequency of food presentation. The former value was calculated from the following equation derived from the Matching Law discussed above:

$$W_1 = \frac{PR_1 + PR_2 - R_1}{1 - P}$$

where P equals $T_1/(T_1 + T_2)$.

As shown in Figure 6, as the scheduled frequency of food presentation increased, the reinforcement value of drinking water, in general, increased. (It should be noted that this equation was derived directly from the Matching relation. The shifts in the reinforcement value of water after stimulus reversal could in part be attributed to the bias (displayed in two

animals) for the schedule associated with relative darkness). Inasmuch as rate of drinking bears the same relation to reinforcer frequency, it would appear that rate of drinking is a better reflector of the reinforcement value of drinking water than the amount of water drunk per pellet. How, then, can one account for the bitonic function? Figure 1 suggests that under some conditions, a monotonic, negatively accelerated, increasing function for drinking rate implies a bitonic function for the amount of water consumed per pellet. Thus, the shape of the function relating schedule-induced drinking to food frequency

depends upon the manner in which the data are plotted.

The most interesting fact about the function relating the amount of water consumed per pellet to the interfood interval is, however, not its bitonicity but the fact that this method of plotting reveals the polydipsic nature of schedule-induced drinking. Clearly, the most impressive feature of the data is the enormous amount of water an animal can be induced to drink in a short period of time. A parsimonious account of this polydipsia cannot, however, be divorced from the relation between rate of drinking, the reinforcement value of drinking, and the frequency of food presentation.

Hawkins, Schrot, Githens, and Everett (1972) suggested that schedule-induced polydipsia is determined by two factors: the thirst-inducing properties of food and the direct reinforcement of drinking by food. However, it is not clear to this author how this explanation could account for the exaggerated levels of drinking and the relative insensitivity of polydipsia to delay of reinforcement contingencies (Falk, 1971). If schedule-induced drinking were, to some extent, directly reinforced by food presentation, one would expect to see some drinking before the presentation of food (Stein, 1964).

The present results suggest another possibility.

First, food-reinforcement schedules indirectly increase rates of drinking by altering the reinforcement value of drinking water. The greater the frequency of food presentation, the greater the reinforcement value of drinking water and the greater the rate of drinking.

Second, the amount of water drunk per pellet is determined by the reinforcement value of water and the time available for drinking. Thus, according to Figures 1 and 6, rates of drinking and the reinforcement value of drinking water (*cf.* Staddon and Simmelhag, 1971) appear to reach an asymptote at the higher frequencies of food presentation. Hence, the amount of water drunk per pellet is solely determined by the length of the interfood interval. At the lower frequencies of food presentation, the reinforcement value of drinking water is low (*cf.* Figure 6) and, hence, the amount of water drunk per pellet is low.

Finally, the motivational properties of a food-reinforcement schedule may be best under-

Fig. 6. The reinforcement value of drinking water, expressed in terms of food pellets per hour, as a function of the scheduled frequency of food presentation for all three animals. LT = the water component associated with light as an S^P . $\overline{LT}$ = the water component associated with darkness as an S^P .

stood with respect to the relative reinforcement value of drinking water, *i.e.*, $W/(W + R)$. If the reinforcement value of drinking water eventually reaches an asymptote as R increases (as some functions in Figure 6 suggest), it is not surprising that FR 1 schedules of food presentation have little or no motivational properties (where the relative reinforcement value of water is low), whereas intermittent schedules of food presentation can motivate water-reinforced FR behavior (where the relative reinforcement value of water is higher).

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