*SCHEDULE-INDUCED POLYDIPSIA:
ARE RESPONSE-DEPENDENT SCHEDULES
A LIMITING CONDITION?¹*

CHARLES D. BURKS

FLORIDA STATE UNIVERSITY

The collateral water intake of albino rats was measured when the inter-pellet intervals in fixed-ratio and fixed-time schedules were equated. Fixed-ratio and fixed-time inter-pellet intervals were equated by dividing the average fixed-ratio session time of each subject by 150 (food pellets). The average inter-pellet interval obtained then defined the subsequent fixed-time schedule for each individual subject. Shifts to fixed-time schedules followed the completion of each fixed-ratio 20, 40, and 80 schedule. This procedure permitted an assessment of the extent to which excessive collateral drinking was associated with inter-pellet interval length or adventitious food reinforcement. For both the fixed-ratio and fixed-time schedules, drinking progressively increased as a function of increasing the duration of the inter-pellet interval and was a post-pellet event under the control of variables other than adventitious food reinforcement.

Some investigators have interpreted schedule-induced polydipsia as due to the accidental reinforcement of drinking (Clark, 1962; Segal, 1965); others have suggested that some basic alteration in the motivational state of the animal induced by the temporally spaced character of pellet delivery (Falk, 1966) or by "thirst" (Stein, 1964) can explain the excessive collateral water drinking on dry food reinforcement schedules.

Two consistent findings have appeared in the literature. First, the rate of fluid consumption has been shown to be directly related to the combined effects of the average inter-reinforcement interval and the portion magnitude of each reinforcement (Falk, 1969). Second, interval schedules (fixed interval and variable interval) have been shown to produce consistently higher levels of fluid intake than have continuous reinforcement (CRF) and

fixed-ratio (FR) schedules (Falk, 1961, 1966; Schaeffer, Diehl, and Salzberg, 1966).

Falk (1966) found that rats that drank excessively during magazine training in which food pellets were dispensed every 1.33 min reduced their water intake when they were placed on a CRF bar-press schedule. Polydipsia reoccurred when the subjects were subsequently tested on a variable-interval (VI) 1 min bar-press schedule. Falk (1961) and Schaeffer *et al.* (1966) found that rats responding on FR bar-press schedules increased their water intake when they were shifted to a variable-time (VT) or a fixed-time (FT) schedule in which pellets were dispensed independently of the subject's behavior.

In both the Falk (1961, 1966) and Schaeffer *et al.* (1966) studies, the inter-pellet intervals (IPIs) used in the VT, VI, and FT schedules were apparently selected by the experimenter without reference to the IPI length associated with the CRF or FR schedule with which the VT, VI, and FT fluid intake values were to be compared. Consequently, the increased fluid consumption in the VT, VI, and FT as compared with the CRF and FR schedules could be potentially associated with the increase in IPI length or might be associated with the accidental reinforcement of drinking. If the length of the IPI is a major determinant of the amount of fluid consumed, then the amount of fluid consumed should remain con-

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stant or show a slight increase due to the increased opportunity to drink when the animals are shifted from FR to FT schedules and the IPI is held constant. On the other hand, if excessive fluid intake is under the control of adventitious reinforcement, licking in the FT case should assume a sequential relationship to reinforcement delivery characteristic of adventitiously maintained behaviors (Skinner, 1948).

In the experiment described below, rats were first tested on selected FR schedules in which they were permitted to establish their own IPIs. They were then switched to FT schedules in which the IPIs were of the same average duration as the IPIs established on the previous FR schedules.

METHOD

Subjects

Four 90-day-old female Sprague-Dawley albino rats (DB 55, DB 56, DB 57, and DB 58) were maintained at 80% of their free-feeding body weight and individually housed in the animal colony room in which 24-hr illumination, 22 degrees C temperature, and 55 to 60% humidity were constantly maintained. Water was freely available at all times, and subjects were given sufficient post-session Purina lab chow to maintain them at the 80% body weight level.

Apparatus

Four standard Lehigh Valley Electronics Model 1316 pellet dispensing rat test chambers, modified by the installation of a drinking aperture in place of the right bar, were used. Glass water bottles to which metal drinking spouts had been attached were affixed to the exterior of the interior chamber 2.75 in. (6.98 cm) to the right of the food magazine and 1 in. (2.54 cm) above the grid floor of the chamber and were held in a standard position for each experimental session by means of plastic positioning devices.

All experimental conditions were scheduled with appropriate relay switching circuitry. Tongue-tube contacts were sensed by standard Lehigh Valley Electronics Model 1520 drinkometer circuits, passed through pulse formers, and recorded on electromechanical counters and an Esterline-Angus recorder. Standard 45-mg Noyes lab rat food pellets were used

and 150 pellets were presented per experimental session.

Procedure

Baseline. A baseline procedure was employed in which 150 pellets were placed in a food cup in the home cage and 7 hr allowed for pellet ingestion. During the 7-hr period, total water intake was recorded. Baseline sessions continued until water intake stabilized. During the baseline sessions, water was always freely available in the home cages during the 17-hr period in which pellets were not present.

Experimental. After the baseline sessions, subjects were shaped to bar-press and then were tested alternately on selected FR and FT food reinforcement schedules, obtaining 150 pellets per experimental session. On the FR 20, 40, and 80 schedules, testing continued until session time, licks, and the amount of water ingested on the last three days of a given experimental schedule fell within the range established during the previous six days of the schedule in effect. The average number of sessions to stability in the FR conditions was 25 (range 17 to 35).

After attaining stability on a given FR requirement, each subject was shifted to an FT schedule that corresponded to its own mean IPI established on the preceding FR schedule. For example, DB 58 required 20 min on the average to complete the FR 20 requirement to a criterion of 150 pellets; therefore, on the average, one pellet per 8 sec was obtained. Hence, the corresponding FT schedule for DB 58 was one in which one pellet was dispensed every 8 sec until all pellets were obtained. In the FT case, pellets were dispensed independently of the subject's behavior. Similar shifts to FT schedules also followed the FR 40 and FR 80 schedules.

The FT stability criterion was identical to that of the FR case with one exception. In the FT cases, the number of licks that occurred in each of the five temporally equal segments of the IPI was recorded in addition to the total number of licks per session. Consequently, a stability requirement was placed on the percentage of total licks occurring in each of the five temporally equal segments of the IPI. The average number of sessions to stability in the FT conditions was 22 (range 19 to 25). After meeting the stability requirements in the FT

Fig. 1. Mean ml of water ingested by each subject during the last three days of the baseline (BL) and each fixed-ratio and fixed-time condition presented as a function of inter-pellet interval (IPI) length.

condition, subjects were advanced to the next FR schedule (e.g., FR 40).

The home cage water intake was recorded daily during the FR and FT experimental conditions.

RESULTS

Figure 1 presents mean water consumption during the last three days of the baseline (7 hr—pellets; 17 hr—no pellets) condition; the FR, FT, and their corresponding home cage conditions. The range of IPI values obtained in the FR 20, 40, and 80 condition and the IPI subsequently used in the following FT condition are presented on the x-axis. The session data points represent from left to right the FR 20, 40, and 80 and their corresponding FT water intake values. Excessive water intake in the experimental conditions was defined as more than twice the amount of water con-

sumed during the baseline condition when the 150 pellets were freely available. As a minimum requirement, a 100% increase in water intake sufficiently reflects the effectiveness of the experimental manipulations.

When the FR and FT session intake values are compared with those of the 7-hr baseline condition in which 150 pellets were freely available, Fig. 1 shows that none of the subjects drank excessively in the first FR condition (FR 20), three drank excessively under the FR 40 condition, and all drank excessively under the FR 80 condition. Three of the subjects drank excessively in the first FT condition; the same three drank excessively under the second FT condition, and all four subjects drank excessively under the last FT condition. For the individual subjects the mean IPI associated with the first occurrence of excessive drinking was as short as 12 sec, 15 sec, and 20 sec (DB 57, DB 55, and DB 56 respectively)

Fig. 2. Mean ml of water ingested by all subjects during the last three days of each fixed-ratio and fixed-time condition. Fixed-ratio and fixed-time values are presented as a function of inter-pellet interval (IPI) length without identifying each individual subject.

and was as long as 30 sec (DB 58). In all cases the IPI associated with the development of excessive drinking was 30 sec or less.

Following the FR 20 condition, the water consumed in the home cages between the ex-

perimental sessions (FR and FT) never exceeded 10 ml per day with the exception of DB 58 when it was tested on the FR 40 and FT 14-sec schedules. Consequently, the water consumed in the home cages between experimental sessions will not be further considered.

In general, each successive schedule shift from FR to FT schedules and subsequent shifts from FT to FR schedules resulted in a progressive increase in water intake. The amount of water ingested under both FR and FT conditions by all subjects is shown in Fig. 2 without identification of each individual. As may be seen, water intake progressively increased as a function of IPI length, with the FT intake values shown in Fig. 2 generally exceeding the FR intake values.

Mean bar presses and licks for the last three days of each experimental condition are summarized in Fig. 3. As may be seen by comparing Fig. 1 and Fig. 3, licking in general varied with water intake. However, licking and water intake are not interchangeable in each case. There were some instances in which the number of licks under two different experimental conditions was roughly equivalent but the

Fig. 3. Mean licks (L) and bar presses (BP) emitted during the last three days of each fixed-ratio and fixed-time schedule presented as a function of inter-pellet interval (IPI) length.

amount of fluid consumed under the two conditions was quite different. For example, the mean number of licks emitted by DB 55 under the FT 37-sec and FT 72-sec conditions was 14,176 and 14,901 respectively. The average fluid consumed, however, was 68 ml under the FT 37-sec condition and 85 ml under the FT 72-sec condition. Further, a marked increase in licking at times did not necessarily produce a marked concomitant increase in water intake. For example, the mean number of licks emitted by DB 57 increased by more than 4000 under the FT 30-sec condition when compared with the previous FT 12-sec condition. However, this increase in licking only produced a 6 ml increase in fluid intake in the FT 30-sec case.

Representative Esterline-Angus records, which show the sequential order of pellet delivery, licking, and bar pressing on FR and FT schedules, are presented in Fig. 4. When bar pressing and licking both occurred in a given FR or FT inter-pellet interval, the sequential relation between licking and bar pressing on the FR and FT schedules was similar in that no repetitive alternations between these two behaviors occurred within the IPIs (*e.g.*, DB 57, FR 40; DB 58, FT 14-sec).

When FR and FT records are compared, some differences in the IPI behaviors are evident. In the FR cases, pellet delivery and licking were followed by uninterrupted bar-pres-

sing behavior that terminated with pellet delivery (see DB 57, FR 40). In the FT cases, bar pressing was markedly attenuated (DB 58, FT 14-sec) or totally disappeared (DB 57, FT 30-sec). Because of the schedule requirement, bar pressing necessarily occurred in close proximity to pellet delivery in the FR cases, but drinking was always at least as far removed from pellet delivery as the time required to complete the FR. In FT cases with IPIs of less than 30 sec, when either licking or bar pressing occurred in any given IPI, they frequently terminated in close proximity to pellet delivery (DB 58, FT 14-sec). Close temporal contiguity between licking and pellet delivery would obviously enhance the probability that licking would join bar pressing as an adventitiously maintained response in the FT case.

In order to present more succinctly the temporal pattern of drinking with respect to pellet delivery, the percentage of licks occurring within each segment of the five-segment IPI was computed. Table 1 shows that in the FT cases more than 50% of the licking occurred in the first three segments of the IPI, with the per cent of total licking occurring in the first three segments increasing as a function of increasing IPI length. An exception to the above generalization was DB 58 which had less than 50% of its FT licking occurring in the first three segments of the IPI until the final free case tested. However, the licking of

Fig. 4. Representative records of the sequential order (left to right) of inter-pellet interval (IPI) pellet delivery, licking, and bar pressing under fixed-ratio (FR) and fixed-time (FT) schedules.

DB 58 was commensurate with the finding that the per cent of licking occurring in the early IPI segments increased as IPI length increased.

Table 1

Mean per cent of licks in the initial three segments of the five successive and temporally equal segments of the inter-pellet intervals (IPIs).

Subjects	Schedules	Lick Per cent
DB 55	FT 15-sec	53
	FT 37-sec	66
	FT 72-sec	99
DB 56	FT 9-sec	58
	FT 20-sec	58
	FT 52-sec	99
DB 57	FT 12-sec	68
	FT 30-sec	72
	FT 55-sec	80
DB 58	FT 8-sec	41
	FT 14-sec	46
	FT 30-sec	56

The cumulative distributions of mean IPI bar presses and licks for each subject on the last three days of each FT case are presented in Fig. 5. The data points within each in-

dividual schedule represent the cumulative mean licks and bar presses at each of the five successive and temporally equal segments of the IPI.

Examination of the lick distributions makes it clear that the subjects did not lick throughout the entire IPI once IPIs had exceeded 30 to 40 sec. In the description of Table 1, it was pointed out that more than 50% of the subjects' licking occurred in the first three segments of the five-segment IPI independently of its length. Figure 5 shows that although licking was concentrated in the temporal portion of the IPI immediately following pellet delivery, there was some licking throughout the entire IPI when IPIs were less than 30 to 40 sec. When IPIs exceeded 30 to 40 sec, licking was not distributed throughout the entire IPI but rather was concentrated within the first 30 to 40 sec. This was a consistent finding for all subjects (DB 55, 56, and 57) that established IPIs greater than 30 sec.

Bar-press curves for DB 56 and DB 58 indicate that bar pressing was maintained by adventitious reinforcement in some FT cases when IPIs were 30 sec or less.

Fig. 5. Cumulative mean distributions of licks (L) and bar presses (BP) for DB 55, DB 56, DB 57, and DB 58 plotted across five successive and temporally equal segments of the fixed-time (FT) schedules tested.

DISCUSSION

Literature reviewed earlier in this paper indicated that the incidence of polydipsia was greater when subjects were shifted from CRF or FR to VT, VI, or FT schedules (Falk, 1961, 1966; Schaeffer *et al.*, 1966). However, in the VT, VI, and FT cases, IPIs were established at a length known to enhance the initiation of excessive drinking and that were independent of the previous CRF and FR inter-pellet intervals to which the VT, VI, and FT water-intake values were to be compared. Under such conditions, it was questionable as to whether the increase in drinking noted in the VT, VI, and FT as opposed to the CRF and FR cases was a function of increased IPI length (a variable known to effect the extent of polydipsia) or a result of drinking being instated and maintained by adventitious reinforcement once the bar-press response requirement was removed.

In this experiment, an attempt was made to equate time variables between FR and subsequent FT schedules to which the subjects were shifted by maintaining equivalent IPIs in both cases. The control of time intervals between successive food pellet deliveries permitted an assessment of the extent to which polydipsia was associated with the IPI length and/or adventitious reinforcement of drinking. When the average IPI was equivalent in both the FR and FT cases, drinking was found to increase progressively as a function of increasing IPI length. In most cases, drinking in the FT cases slightly exceeded that of the corresponding FR cases. This increase was probably due to the removal of the bar-press requirement which increased the opportunity to drink in the FT case.

Inter-pellet interval lick distributions obtained leave little doubt that excessive drinking is a post-pellet phenomenon under control of factors other than adventitious reinforcement. Previously, a reinforcement interpretation (Segal, 1965) of polydipsia was made on the assumption that post-pellet licking is only the first link in a behavioral chain terminating with food reinforcement. In the present study, when subjects were shifted from FR to FT schedules, bar pressing in almost every case was markedly attenuated while licking failed to decline. If licking was one of two IPI behaviors forming a behavioral chain main-

tained by food reinforcement, why did one member of the chain (bar pressing) drop out or become disrupted when response contingencies were removed, while the other behavior in the chain (licking) continued to occur at a high rate? In the present study, the probability that licking would emerge as an adventitiously maintained behavior was enhanced under the FT conditions in which IPIs were 30 sec or less. Under those conditions, bar pressing or licking often occurred alone in a given IPI. When this was the case, the behavior occurring often terminated in close temporal proximity to pellet delivery, hence maximizing the likelihood that the behavior would come under the control of food reinforcement. However, in the case of licking, this did not occur. As IPIs became increasingly longer (greater than 30 sec), licking remained a post-pellet event concentrated in the initial temporal portion of the IPI and failed to maintain the close proximal relationship to pellet delivery characteristic of adventitiously maintained behaviors (Skinner, 1948).

Under similar conditions of IPIs of 30 sec or less, bar pressing was often adventitiously maintained at a high rate and in a similar sequential position just before pellet delivery in the FT case as in the previous FR case.

It may be argued that "other" behaviors replace attenuated bar pressing in the free case and that a new behavioral chain is formed in which licking maintains its previous position as the first link of the chain with some new, unspecified behavior replacing bar pressing as the pre-pellet link. If, in fact, licking is still a part of an adventitiously maintained chain held intact in the FT case by the addition of a new behavior that replaces attenuated bar pressing, then the arrangement of experimental contingencies that reinforce behaviors other than licking and under which licking is punished by the postponment of reinforcement, should effectively eliminate licking as a component of the behavioral chain if it is a component under the control of food reinforcement.

In a recent investigation, Hitzing (1968) found that subjects in which polydipsia had been instated on bar-press or lick-contingent fixed-interval 60-sec schedules still continued to lick at rates markedly in excess of baseline when placed on a differential reinforcement of other behaviors schedule in which licking

postponed pellet delivery for as much as 60 sec. This finding supports Falk's (1966) conclusion that schedule-induced polydipsia has associated motivational properties capable of maintaining behavior in its own right. Falk's conclusion was based on the finding that polydipsia could be maintained on a VI 1-min food reinforcement schedule even when delivery of water was contingent upon concurrent bar-press responding up to FR 50. While the origin and identity of these motivational properties are still unclear, they apparently are associated with the spaced character of pellet delivery which seems to be a necessary or sufficient condition for schedule-induced polydipsia to be instated.

In light of previous findings and the data reported in this paper, it is obvious that schedule-induced polydipsia cannot be accounted for solely on the basis of a reinforcement interpretation. In the present experiment, characteristics of adventitiously maintained behaviors were not reflected in the extent and distribution of drinking responses, although sufficient opportunity was available for those characteristics to emerge, especially when subjects were tested on schedules having IPIs of 30 sec or less.

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