UBIQUITY OF SCHEDULE-INDUCED POLYDIPSIA¹

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Spaced feeding of individual food pellets to food-deprived rats induced excessive drinking after pellet delivery if water was continuously available. When access to water was restricted to a portion of the inter-pellet interval, and competition from food-reinforced bar pressing was removed, excessive drinking occurred whenever drinking was possible. This finding extends the generality of accounts of excessive behavior that implicate induction by apparently unrelated scheduling characteristics of the environment.

Spaced feeding of small portions of food to a food-deprived rat often produces polydipsia if water is freely available (Falk, 1972). The excessive drinking is usually confined to the periods that follow food delivery, a phenomenon that has led to two explanations for the polydipsia. One was proposed by Stein (1964), who implicated the stimuli associated with food ingestion. Another was suggested by Falk (1969), who agreed that post-prandial factors were implicated but noted too that the drinking might also be elicited by the low probability of reinforcement during the post-reinforcement period, when, as a consequence, there is little competition between drinking and food-related behavior. Clearly, neither of these accounts is adequate if it can be demonstrated that the excessive drinking can occur at times other than immediately after each pellet delivery.

Flory and O'Boyle (1972) prevented drinking by rats during 15-sec portions of a fixed-interval 1-min (FI 1-min) food reinforcement schedule under which one pellet was delivered for each bar press that followed the previous pellet delivery by at least 1 min. They found that the amount of drinking was only slightly affected by this procedure, even when drinking was not possible for the 15 sec that followed food delivery.

The present study extended this finding and confirmed that schedule-induced polydipsia by rats is a post-prandial phenomenon only when post-prandial drinking is possible. The first experiment examined the effect of restricting drinking to the final 30 sec and then to the final 10 sec of the 1-min intervals that separated pellet deliveries. In the second experiment, pellets were delivered every 1 min or every 3.5 min, and water was available for one brief period per interval in any part of the interval.

EXPERIMENT I

METHOD

Subjects

Two male albino rats were used, aged about 160 days at the beginning of this study. Both had experienced 25 daily 30-min sessions in experimental chambers similar to the ones used in the present study, during which one 45-mg Noyes food pellet was delivered after every fortieth depression of a response bar (FR 40 schedule of food reinforcement). Their weights had been maintained at close to 300 g for more than 60 days by restricting food rations, a regimen that continued through the experiment. Water was freely available in home cages throughout the experiment.

Apparatus

The two experimental chambers were modifications of standard Grason-Stadler two-bar rat chambers (Model E3125B). The right-hand bar of each had been removed. In the door (which was also to the right of the food-dis-

¹The retractable drinking tubes used in this experiment were designed by Dr. R. J. Gibbins and Mr. C. Milan of the Addiction Research Foundation. Their use is gratefully acknowledged, as is the experimental assistance of Marilyn Schwieder. Reprints may be obtained from the author, Addiction Research Foundation, 33 Russell Street, Toronto, Canada M5S 2S1.

penser outlet), was mounted a retractable drinking tube, below which was a tray for collecting spillage. The tubes had a metal, 2-mm diameter orifice, but were otherwise largely of glass construction, calibrated so as to allow amounts consumed to be measured to the nearest 1.0 ml. The tube was motor driven and required 2.2 sec to move from one limit of its excursion to the other. Liquid in the tube was accessible to a rat in the chamber for about half of the excursion. Thus, if the tube began in its retracted position, and two electrical signals 10 sec apart extended and retracted the tube, respectively, liquid in the tube was available for approximately 10 sec, the period of availability beginning 1.1 sec after the first signal and ending 1.1 sec after the second signal. The liquid in the tube and the floor of the chamber were part of a drinkometer circuit that enabled recording of licks. Scheduling, recording, and data analysis were conducted on-line by a Hewlett-Packard 2100 computer located in an adjoining room.

Procedure

To adapt behavior to an interval schedule of reinforcement, each rat was placed in its respective chamber for 15 daily sessions of approximately 2-hr duration, during which water was continuously available and food pellets were delivered on a FI 1-min schedule for bar pressing.

Subsequently, in the experiment proper, the rats were studied for 23 or 24 daily sessions, each comprising 120 pellet deliveries. At first,

Noyes 45-mg food pellets were available according to the FI 1-min schedule. Water was accessible throughout the first three sessions, then only for the final 30 sec of each interval for six sessions. (Initiation of tube extension and retraction was timed from the beginning of the interval and occurred independently of the rats' behavior.) Next, water was available throughout each session for four sessions, and then only during the final 10 sec of each interval. During this last procedure, the behavior of the two rats differed markedly. Rat 24 was then exposed to a fixed-time schedule of food delivery, under which one pellet was delivered every minute (FT 1-min) independently of the rat's behavior. This was done in preparation for removal of the bar, the pressing of which seemed to be preventing an increase in licking during the final 10 sec of each interval. Subsequently, sessions with bar present and bar absent alternated. Finally, water was made continuously available. Rat 25 experienced a similar set of procedures that differed in detail. Further particulars of the order of procedures for the two rats are given in Table 1.

Finally, on two successive days, not shown in Table 1, each rat was put into its respective chamber with 120 pellets already piled in the dispenser, and the rat remained there for 2 hr with water continuously available.

RESULTS

Polydipsia occurred whether water was available throughout the session or restricted

Table 1
Summary of Procedures During Experiment I

<i>Schedule of Pellet Delivery*</i>	<i>Bar Position</i>	<i>Part of Interval for Which Water Was Available</i>	<i>Sessions for Which Procedure Was Implemented</i>	
			<i>Rat 24</i>	<i>Rat 25</i>
FI 1-min	In	Throughout	1-3	1-3
FI 1-min	In	Last 30 sec	4-9	4-9
FI 1-min	In	Throughout	10-13	10-13
FI 1-min	In	Last 10 sec	14-16	14-18
FT 1-min	In	Last 10 sec	17	
FT 1-min	Out	Last 10 sec	18-19	
FT 1-min	In	Last 10 sec	20	
FT 1-min	Out	Last 10 sec	21	19-20
FT 1-min	In	Throughout	22-23	21-22
FT 1-min	In	Last 10 sec		23
FT 1-min	In	Throughout		24

*See text for descriptions of the two schedules used.

to the final 30 sec or 10 sec of each interval. Figures 1 and 2 show that when water was always available, both rats licked much more during the first half than during the second half of each interval (Sessions 1, 2, 3, 10, and 11). When water availability was restricted to the final half of the interval (Sessions 4 to 9), the amount of licking by both rats during that half increased until it approached the amount for the whole interval when water was available throughout. The excessive nature of the total amounts becomes clear if it is noted that, throughout the study, Rat 24 made close to 200 licks per ml consumed and Rat 25 made close to 250 licks per ml consumed. Thus, during Sessions 1, 2, and 3, Rat 24 drank approximately 10 ml per 2-hr session (about 2000 licks), and Rat 25 drank approximately 24 ml (about 6000 licks). When 120 pellets were presented all together at the end of the

experiment, neither rat drank more than 4 ml in 2 hr. Rat 24 emitted fewer licks than Rat 25 but many more bar presses. During Sessions 1 to 3, Rat 24 emitted an average of 3263 bar presses per session, whereas the average for Rat 25 was only 692.

Water licking by Rat 25 increased also during the final 10 sec of the interval when water availability was restricted to that portion. (Figure 2, Sessions 14 to 18). Accompanying this increase was a decline in bar-pressing rates, as shown in the bottom panel of Figure 2, and a decline in reinforcement rate. Licking occurred in approximately the same amount when the bar was removed, for Sessions 19 and 20. Figure 2 shows that bar-pressing rates were restored when water was available throughout the interval (Sessions 21, 22, and 24).

Initially, licking by Rat 24 did not increase when water availability was restricted to the

Fig. 1. Total licks and bar presses made by Rat 24 during each session of Experiment I. Filled bars or bar portions show total licks during the final 30 sec of the scheduled 60-sec interval (Sessions 1 to 11). During Sessions 4 to 9, water was available only during the final 30 sec of the interval. Hatched bars or bar portions show total licks during the final 10 sec of the scheduled interval (Sessions 12 to 23). Throughout Sessions 14 to 21, water was available only during the final 10 sec of the interval. The bar was removed for Sessions 18, 19, and 21. Otherwise it was available throughout each session.

Fig. 2. Total licks and bar presses by Rat 25 during each session of Experiment I, shown in the manner of Figure 1. Note the slight procedural differences between the two animals (see Table 1 for a summary) and the differences in vertical scale between Figures 1 and 2.

final 10 sec of each interval (Figure 1, Sessions 14 to 17). When the bar was removed, for Sessions 18 and 19, licking during that part of the interval increased dramatically, and then declined when the bar was reintroduced for Session 20.

EXPERIMENT II

The results of Experiment I extend the finding of Flory and O'Boyle (1972) that schedule-induced polydipsia is not necessarily a postprandial phenomenon. Excessive drinking occurred when water availability was restricted to the final 30 sec or to the final 10 sec of each scheduled interval, although, in the latter case, Rat 24 did not drink excessively until the opportunity to emit a strongly competing behavior was removed.

In Experiment II, the procedure of Experiment I was generalized by making water available for brief periods in different parts of the

interval, with the location varying from interval to interval. This provided a means of discovering the locus of maximum induced drinking, and a more elegant assessment of the ubiquity of schedule-induced polydipsia, *i.e.*, the phenomenon's capability of appearing anywhere in the interval.

METHOD

The animals and apparatus used in Experiment I were used also in Experiment II, which followed Experiment I after an interval of four days. The rats' weights were still maintained at close to 300 g and water continued to be freely available in home cages.

Procedure

Sessions were conducted on alternate days. Each session comprised 300 response-independent presentations of one 45-mg Noyes pellet at equally spaced intervals. Water was available for the whole or for one portion of each

Table 2
Summary of Procedures Used in Experiment II

Condition	No. of Sessions		Inter-pellet Interval	Water Availability
	Rat 24	Rat 25		
1	2	2	60 sec	10 sec per interval
2	2	3	210 sec	35 sec per interval
3	2	3	210 sec	10 sec per interval
4	3	3	210 sec	Throughout
5	2	2	60 sec	Throughout
6	2	2	60 sec	10 sec per interval

interval. Six successive conditions were employed, as described in Table 2, each for two or three sessions. In Conditions 1 and 2, each period of water availability was for one of the ordinal sixths of the interval. The sixth selected for any one interval was determined by the output of a software random-number generator. Condition 3 resembled Condition 2, but differed in that the water was available only for the middle 10 sec of the sixth of the interval scheduled. For example, if the third sixth of the 210-sec interval was scheduled, presentation of the drinking tube began 82.5 sec after the beginning of the interval and withdrawal began 10 sec later. Condition 6 was a repeat of Condition 1. In Conditions 1, 2, 3, and 6 tube presentations occurred at each position in the interval with approximately equal frequency.

RESULTS

When the inter-pellet interval was 60 sec, the maximum rate of licking by both rats occurred at a point in the interval other than the beginning, whether water was available continuously or restricted to 10-sec portions of the interval. This is clear from the graphs in the upper panels of Figures 3 and 4, which show data from the final session under each of Conditions 5 and 6. (Data from Condition 1 resembled those from Condition 6 in essential points.) The rats differed in the locus of maximum licking rates. For Rat 24, these occurred in the third or fourth sixth of the interval, whereas Rat 25 licked most during the second sixth. The rats differed too in the effect of restricting drinking upon the total consumption of water, which is presented in the histograms at the right of each graph. Restriction reduced total consumption by Rat 24, as might be expected, whereas for Rat 25, restriction had the surprising effect of producing higher

consumption than did free availability. Further analysis showed that, although Rat 25 continued to eat pellets throughout the 3.5-hr session, licking declined after the first 90 min to the extent that no licking occurred during the final 60 min. This decline occurred only in Condition 5, when water was continuously available, and not during Conditions 1 and 6, when water availability was restricted to one-sixth of each interval.

Extending the inter-pellet interval to 210 sec produced essentially similar data in the case

Fig. 3. Licking rates by part of interval and total licks by Rat 24 during the final session of each of the various conditions of Experiment II. The upper and lower panels refer to sessions in which pellets were spaced by 60 sec and 210 sec respectively. Filled circles indicate licking rates in each sixth of the interval during sessions in which water was continuously available. Open circles show data from sessions in which water was available only for one-sixth of each interval. Triangles refer to a session in which water was available only during the middle 10 sec of one sixth of the 210-sec inter-pellet intervals. The corresponding bars indicate total licks during the respective sessions. See text for further details.

Fig. 4. Data from Rat 25 during Experiment II. Details are as for Figure 3. Note the vertical scale differences between Figures 3 and 4.

of Rat 24, as is apparent from the lower panel of Figure 3. Confining opportunity to lick to the middle 10 sec of each sixth of the interval removed the relatively larger difference between rates during the first and subsequent sixths of the interval, indicating that the large differences had probably arisen because of the competition between licking and eating that occurred during the few seconds after pellet delivery. Rat 24 remained polydipsic when pellets were spaced by 210 sec. When water was continuously available, total consumption during the 17.5-hr session was over 100 ml, well in excess of the approximately 35 ml that this rat drank under similar food deprivation conditions but when the same amount of food was presented at one time.

Rat 25, on the other hand, ceased to exhibit polydipsia when the inter-pellet interval was increased to 210 sec. Total consumption of continuously available water during the 17.5-hr session was less than 15 ml, even though all pellets were eaten. This amount was close to one half of the usual daily water intake by this rat when food deprived. Licking, when it occurred, happened mostly near the beginning of the interval, as is indicated by the bottom panel of Figure 4. It also tended to occur near the beginning of the session, whether or not water availability was restricted to a portion of each interval.

GENERAL DISCUSSION

Data from Rat 24 during Experiment II extend the findings of Experiment I, confirming that schedule-induced polydipsia is not necessarily a post-prandial phenomenon. This is especially clear in the results from Conditions 2 and 3, when water availability was restricted to 35-sec or 10-sec portions of the 210-sec inter-pellet interval. Except immediately after pellet delivery, drinking occurred at approximately the same rate whenever in the interval water was made available. The exception probably reflects post-pellet competition between eating and licking.

The Experiment II data from Rat 25 are difficult to interpret because of the failure of the intermittent feeding schedule to sustain polydipsia when either the session duration or the inter-pellet interval was extended to 210 sec. They suggest, however, that drinking is more likely to be confined to the post-prandial period when polydipsia does not occur. Falk (1966) also reported failure to achieve polydipsia with intervals that exceed 180 sec. The difference between Rats 24 and 25 may have been related to their bar-press rates in Experiment I. Rat 24, which continued to exhibit polydipsia when the inter-pellet interval was extended, had bar pressed for food during Experiment I at approximately twice Rat 25's rate.

One objection to the present evidence for the ubiquity of schedule-induced polydipsia is that the excessive drinking could have been maintained by the contingency between licking and pellet delivery when licking occurred at the end of the inter-pellet interval. This was unlikely in the part of Experiment I in which water availability was confined to the final 30 sec of the scheduled interval (Sessions 4 to 9) because substantial amounts of bar pressing always intervened between licking and food presentation. It could have been a factor in the development of excessive drinking during the subsequent procedure of that experiment in which water was available only during the final 10 sec of the interval, especially in the case of Rat 24, which licked excessively only when the bar was removed. The effect of such reinforcement could have persisted into Experiment II, and been maintained by an occasional contingency between licking and pellet delivery. However, if lick-

ing during Experiment II had been maintained by food reinforcement, rather than by the intermittent feeding schedule, rates of licking probably would have been higher for tube presentations that occurred late in the interval, perhaps in the manner of the results of a study by Farmer and Schoenfeld (1966). These experimenters observed pecking by pigeons during a stimulus that was intruded at different points of a fixed-interval schedule. Pecking during the stimulus increased as a function of the temporal distance of the intrusion from the beginning of the interval.

Both experiments indicate that competing behavior may be an important determinant of what Falk (1972) has described as "adjunctive behavior". In Experiment I, bar pressing was found to prevent excessive drinking by Rat 24 during the final 10 sec of the interval. In Experiment II, the same rat's probability of drinking was lowest immediately after food delivery, when licking was probably suppressed by pellet ingestion. The Experiment I data from Rat 25 also indicate competition between bar pressing and licking. This rat emitted licking at a higher rate than bar pressing, although bar pressing always followed licking within each interval. When water availability was confined to the final 10 sec of the scheduled interval, bar-pressing rates during that portion declined to such an extent that reinforcement rate was reduced. For this rat, the adjunctive behavior was a toxic response in the sense used by Falk (1972), *i.e.*, it appeared to prevent adaptive behavior.

Earlier studies, including those of Falk (1969) and Keehn and Colotla (1971), have also shown suppression of schedule-induced drinking by competing behavior. In both of these studies, the normal post-reinforcement drinking induced by a time-based food-reinforcement schedule was inhibited by making food-reinforced behavior highly probable after spaced pellet presentations. Other evidence that adjunctive drinking can be in competition with food-reinforced behavior comes from earlier studies in which spaced food presentations were not dependent upon a particular operant. It might be predicted that more induced behavior would occur with no dependency because of the relative absence of competition from operant behavior. No direct comparison between the inducing properties of dependent and independent food delivery has

been reported. However, in at least two reports of behavior induced by independent, spaced pellet presentations to rats, the induced behavior was observed to occur throughout the interval. In one (Burks, Hitzing, and Schaeffer, 1967), water drinking was induced throughout the 40-sec intervals between sucrose pellet presentations. In another, Mendelson and Chillag (1970) indicated that, after several prolonged sessions, pellets spaced at 90-sec intervals induced so much air licking that often pellets were missed, a phenomenon that did not occur with water licking. During shorter sessions, water licking was largely confined to the first 20 to 30 sec of each interval, whereas air licking continued for 40 to 50 sec. The relatively rapid satiation of water licking may be a factor in confining induced drinking to the first part of the interval when water is available throughout.

The present results support a three-factor account of adjunctive behavior. (1) Spaced feeding of small portions of food within a certain range of mean intervals constitutes a "drive operation" of the kind defined by Catania (1968); *i.e.*, certain stimuli are made more effective as reinforcers. (2) Which stimuli become more effective depends on the actual environment of the animal. For the food-deprived rat, spaced feeding of small pellets at 1-min intervals makes water a reinforcer, if water is available. (3) The frequency of licking or other induced behavior depends upon the probability and patterning of the competing behavior, particularly the food-reinforced behavior if food is the reinforcer specified by the schedule that constitutes the drive operation. The frequent occurrence of adjunctive behavior only at the beginning of the interval may also depend upon local satiation factors that inhibit drinking after a certain amount has been consumed. When water is available throughout the interval, such satiation would effectively limit drinking to the first portion of the interval.

The ability of a reinforcement schedule for one behavior to induce another behavior at any time extends the utility of this mechanism as an account of "natural" behaviors that have no apparent cause. Excessive eating and excessive drinking of alcohol solutions are such behaviors. A simple account of alcohol polydipsia as a schedule-induced phenomenon requires that the drinking occurs soon after the un-

specified reinforcement. The present account accommodates the occurrence of such adjunctive drinking on any occasion when alcohol is available and there is no stronger competing behavior.

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