VARYING THE TEMPORAL PLACEMENT OF A DRINKING OPPORTUNITY IN A FIXED-INTERVAL SCHEDULE

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Three rats, lever pressing for food delivered on a fixed-interval 128-s schedule, were presented with a 16-s opportunity to drink from a retractable water source. The temporal placement of the water probe within the reinforcement cycle was varied sequentially, in steps of 16 s. Although the lever-pressing pattern was modulated by the intercalated water probe, water consumption during the probe itself was a decreasing function of time from the following reinforcer. These results were interpreted as evidence against the notion that schedule-induced drinking is a "ubiquitous" phenomenon and are congruent with results from other "intruded stimulus" experiments.

Key words: polydipsia, intruded stimulus paradigm, fixed-interval schedule, discrete water probes, drinking, lever press, rats

One effect of schedules of reinforcement is their propensity to induce other forms of behavior. A common form of induced behavior is drinking in rats. Falk (1961b) found that rats, lever pressing for food under a variable-interval (VI) 60-s schedule, drank an average of 29 mL per hour of water that was available continuously within the experimental chamber. Relative to the rats' normal intake of about 1 mL per hour in their home cages, such consumption was excessive and led Falk to coin the term *psychogenic polydipsia* or simply, *polydipsia*. Subsequent experiments continued to use this term rather flexibly, apparently as a shorthand to designate almost any amount of drinking. For instance, in some experiments the volume of water consumed has been as little as 5 or 8 mL per hour, but nevertheless the phenomenon has still been called polydipsia (e.g., Gilbert, 1974, Condition 4; Stein, 1964). As Wetherington (1982, p. 344) has noted, there is no clear standard to categorize drink-

ing as truly excessive in this type of experiment. In addition to a lack of a standard to judge genuine polydipsia, several methods have been used that measure actual amounts of consumption only indirectly. For instance, Christian, Riester, and Schaeffer (1973), Moran and Rudolph (1980), and Segal (1969) reported rate of licking a drinkometer as their main datum. Flory and O'Boyle (1972), Heyman and Bouzas (1980), and Ponicki and Thompson (1972) reported rate of pressing a manipulandum (a lever or a button), which on operation delivered drops of water. Although these other dependent variables have shown orderly variation in drinking experiments, it seems clear that the actual character of the phenomenon as excessive drinking has lost some of its original interest (cf. Falk, 1969). In view of the ambiguity conveyed by the term polydipsia, the term *schedule-induced drinking* seems to be preferable (e.g., Staddon, 1977). An advantage of the latter term is its recognition of the fact that drinking is a continuous variable that can assume different values (including excessive drinking as a limiting case), depending on the parameters of the experiment (e.g., Falk, 1966).

Experiments in which water consumption returns to normal after the schedule is discontinued (e.g., Falk, 1961a, 1961b) show that a schedule of food reinforcement is a necessary condition for increased drinking. Schedule-induced drinking occurs under a variety of conditions. For instance, it is produced by ratio and interval schedules, as well as by composite schedules such as multiple and concurrent schedules. Schedule-induced drinking occurs

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under both response-dependent and response-independent reinforcement (see Christian, Schaeffer, & King, 1977, for a review of schedules used in studies of schedule-induced drinking).

Several theories have been advanced to explain schedule-induced drinking. Most of them have taken the specific temporal location of the drinking bout during the food cycle as crucial evidence to support their views. For example, Falk (1961a, 1961b), Lotter, Woods, and Vasselli (1973), Staddon (1977), Stein (1964), and Stricker and Adair (1966) found that water consumption was most likely just after food delivery. Many different explanations have used this fact as a basis. Three of these are most prominent. One suggested that the phenomenon was simply postprandial drinking, as an unconditioned response to eating (e.g., Booth, 1972a, 1972b), and that as reinforcement frequency increases so does water consumption (e.g., Lotter et al., 1973). A second explanation suggested that postfood drinking was behavior adjunctive to the reinforcement schedule and was similar to a displacement activity (Falk, 1969, 1972). A third explanation for drinking after food delivery suggested that the rat's inclination to drink is related to its motivation to eat. This in turn is modulated by factors such as the deprivation level and the frequency, amount, and type of food (e.g., Staddon, 1977).

Clark (1962) found that drinking frequently occurred just before reinforcement under VI schedules. Segal (1965) showed that the duration of the postfood drinking bout can increase to the point at which drinking coincides with the delivery of the following reinforcer. Using a fixed-interval (FI) 4-min schedule, Segal (1969) observed that the drinking pattern gradually developed into a regular scallop for at least 1 rat (see also Schaeffer & Salzberg, 1967, for a similar result). Thus, these findings suggest that even if drinking emerges initially as a postfood bout, continued exposure to the experimental conditions can result in its "superstitious" conditioning, given the proximity of the subsequent reinforcement. Deadwyler and Segal (1965) showed that water consumption occurred throughout the interreinforcement interval when a schedule of differential reinforcement of low rates (DRL) was in effect. Thus, drinking was taken to be a

time-mediating behavior for spaced responding.

The evidence mentioned above was obtained in situations in which water had been available during the entire interfood interval. However, drinking also occurs when the availability of water is restricted to portions of the food cycle. For example, Flory and O'Boyle (1972) exposed rats to an FI 60-s schedule for pressing one lever while a second lever, concurrently available, produced 0.1 mL of water per response. After a period of unrestricted availability of the water-producing lever, the lever was withdrawn from the chamber during successive 15-s periods of the fixed interval. Regardless of the placement of the lever-removal period, drinking occurred at the same level as when the lever was available continuously (about 37 mL in a 100-min session). This finding was taken to mean that postprandial effects were not as predominant as originally suspected (cf. Lotter et al., 1973). Instead of removing the availability of water during discrete periods, Gilbert (1974) exposed 2 rats to discrete periods of water availability of 10 or 35 s, interpolated between consecutive reinforcers delivered by a fixed-time (FT) 60-s or 210-s schedule. The period of water availability was placed randomly in any of six subintervals between reinforcers. Rate of licking a tube during the last of two or three sessions was the main published dependent variable. Gilbert (1974, Conditions 1, 2, and 3) found that both rats licked the water tube through the entire interfood interval (the estimated rate of licking—an average of 250 licks per milliliter—resulted in a consumption of about 100 mL in a 17.5-hr session), and thus concluded that drinking was ubiquitous (i.e., occurred at all locations of the water probe). A related experiment was conducted by Daniel and King (1975) using an FT 65-s schedule and water probes 20 s long intruded at the beginning, middle, or end of the interfood interval. Their dependent variable was the volume of water consumed. In contrast to Gilbert's random intrusions of the water probe, in Daniel and King's experiment the temporal position of the water probe remained fixed for each of three groups of rats. Drinking occurred approximately at the same level for the three locations of the water probe (43 mL in sessions of 108 min). This outcome is similar to Gilbert's, thus

supporting the notion of the ubiquitousness of schedule-induced drinking. Such evidence was taken to support none of the theories of schedule-induced drinking.

The results from the experiments performed by Gilbert (1974) and by Daniel and King (1975) are intriguing because if it were not for the fact that water presentation was the specific event intruded between successive reinforcers, their results would appear to contradict other findings. Specifically, Farmer and Schoenfeld (1966a, 1966b) presented data on the intrusion of a neutral stimulus (a keylight change) during responding controlled by an FI schedule. Using pigeons, Farmer and Schoenfeld showed that varying the temporal placement of this stimulus altered the temporal pattern of responding under the FI in very specific ways. The changes in the response pattern before, during, and after the stimulus were all attributed either to the discriminative functions of the stimulus or to its role as a conditioned reinforcer. These findings have been replicated in different situations (e.g., Avila & Bruner, 1989; Bruner, 1981; Dews, 1962, 1966; Evra, 1974; Martin, 1971). One prominent and consistent finding of these studies is that responding during the stimulus itself increases as the stimulus is moved forward during the interval, temporally closer to the food at the end of the interreinforcer interval.

The intruded stimulus experiment is an "irreducibly primitive paradigm" to study the temporal relations between stimuli and behavior (Farmer & Schoenfeld, 1966a, p. 15; Skinner, 1938, p. 14ff). The procedures used by Gilbert (1974) and by Daniel and King (1975) can be viewed as intruded stimulus experiments in which the water-access period is the stimulus intruded into an unspecified pattern of behavior controlled by the schedule of response-independent reinforcement. Therefore, the temporal relation between the reinforcer and the opportunity to drink and the relation of the latter to the response pattern emerge as potentially important variables for the study of schedule-induced drinking. In the present experiment, a water-access probe was sequentially intruded into FI-controlled responding instead of the typical stimulus change. The experiment was also conducted to assess the generality of the intruded stimulus procedure in a situation in which rats pressed a

lever instead of the more common situation of pigeons pecking a response key.

METHOD

Subjects

Three female Wistar rats, 3 months old and experimentally naive, served as subjects. The rats were kept at 80% of their ad libitum body weights. This deprivation level was used because it is known to be conducive to the development of drinking (Falk, 1969). The rats were housed individually, with free access to water.

Apparatus

A standard experimental chamber (BRS/LVE Model RTC-020) was used. The chamber had one lever (sensitive to 0.10 N) and a metal tube that could be retracted and inserted. The metal tube was connected through a rubber hose to a bottle of water graduated in 5-mL steps and affixed outside the chamber. The water-dispensing method was the same used to provide water in the rat's home cage. When extended, the water tube protruded 1 cm into the chamber, at about a 30° angle and 8 cm from the floor. For food reinforcement, 25-mg pellets manufactured in this laboratory were used. These pellets were made by remolding powdered Purina® Nutri-Cubes. The pellet-dispensing mechanism was a standard BRS/LVE Model PDC-PPC.

The experimental chamber was placed inside a sound-attenuating cubicle (BRS/LVE Model SEC-002) that provided air circulation and masking noise. The cubicle was placed in a room adjacent to the control equipment. The experiment was controlled automatically by means of a Radio Shack TRS-80 computer coupled to an LVE Corp. interface.

Procedure

The lever-pressing response was shaped by reinforcing successive approximations. Immediately afterwards the response was maintained by an FI 128-s schedule that remained in effect throughout the experiment. In an attempt to facilitate the development of drinking during this phase, in addition to using the FI 120-s schedule, during the first 40 sessions water remained continuously available (i.e.,

the tube protruded inside the chamber throughout the session). Access to water then was shortened to a 16-s probe that occurred once during each interreinforcer interval. The temporal placement of the probe period was varied in consecutive 10-session blocks. During the first block, the water probe occurred just before reinforcement delivery, that is, from Seconds 113 to 128. During the second block of 10 sessions, the water probe occurred from Seconds 97 to 112. During successive blocks, the probe was moved backwards within the FI in 16-s steps. This order was chosen because it is typical of previous intruded stimulus experiments. After the eight temporal placements had been explored, two redeterminations were obtained, one at 49 to 64 s and another at 113 to 128 s. Data on lever pressing were collected during successive 8-s subintervals of the reinforcement cycle. Sessions were conducted 7 days per week at approximately the same time each day. Each session began with the onset of the houselight and lasted until 50 food reinforcers had been collected.

RESULTS

Lever Pressing

Figure 1 shows, for each subject, the mean number of responses within each 8-s bin of the interfood interval. The top row of panels shows the mean of the last 5 days under the condition in which water remained available throughout the entire FI. The rows of panels below show the effects of intruding the 16-s water probe into different locations within the food cycle. The effects of the independent variable tended to increase from a first to a second 5-day block after the transition between successive conditions. In the condition in which water remained available throughout the FI, each rat developed a scalloped pattern of lever pressing that served as a baseline to evaluate the effects of shortening the water-access period and varying its temporal placement.

The effects of shortening the water-access period to 16 s and then intruding the probe into different locations within the food cycle were generally similar for Rats A1 and A3. Rat A2 differed in that the scalloped pattern remained more or less undisturbed by either shortening the access to water or moving it during the FI. Some generalities can be de-

scribed for the lever pressing of A1 and A3. After a food presentation, responding occurred at a low rate (a postreinforcement pause) and then increased until it was interrupted by the water probe. The acceleration toward the water probe diminished gradually as the opportunity to drink was moved backwards during the FI. Lever pressing that overlapped with the probe itself generally was lower than during the preceding 8 to 16 s and during the interval that followed, and ended with food presentation. For the 3 rats, the interval between the water probe and the delivery of the following food was characterized by a progressive acceleration of responding. The two redeterminations show these effects to be replicable.

Water Consumption

Table 1 shows the amount of water consumed by each rat during each condition of the experiment. Figure 2 shows these results graphically as averages over the last five sessions of each condition. For the first condition, in which water remained available throughout the reinforcement cycle, the mean and the standard deviation were calculated for four blocks of 10 sessions (first four rows of the table).

When water remained continuously available in the chamber, the mean amount of water consumed by Rats A2 and A3 increased gradually to about 20 and 30 mL per session, respectively, towards the end of the condition. Rat A1 maintained a steady consumption of about 10 mL per session. When the period of access to water was reduced to 16 s and placed next to the following reinforcer, water consumption remained similar to the preceding condition for Rats A1 and A3, in spite of the fact that the time of access per cycle was shortened to 16 s. Rat A2 decreased its drinking from 20 mL to approximately 10 mL. Moving the probe to Seconds 97 to 112 increased drinking for all 3 rats. As the water probe was intruded at locations further away from the following food, water consumption decreased systematically for all subjects.

DISCUSSION

Lever Pressing

When the temporal placement of the opportunity to drink was varied sequentially, the

Fig. 1. Histograms showing the average number of responses within each 8-s subinterval of the FI 128-s schedule. The dotted bars overlapped on the solid ones represent two redeterminations (i.e., the first from Seconds 49 to 64 and the other from Seconds 113 to 128). The horizontal mark next to each abscissa shows the temporal placement of the water-access period. The columns show the results for each rat, and the rows show the successive conditions of the experiment. These means are based on the last five sessions of a condition.

Table 1

Mean water intake (and standard deviation in parentheses) for 10 consecutive sessions. Each pair of values is shown for each rat and experimental condition. The first four rows show water intake when water remained continuously available in the chamber.

Water access period (s)	Water intake (mL)		
	Subject		
	A1	A2	A3
0-128	7 (6)	15 (9)	11 (6)
	9 (6)	11 (10)	14 (13)
	10 (3)	21 (9)	23 (8)
	10 (3)	20 (8)	28 (7)
113-128	11 (8)	11 (8)	24 (7)
97-112	21 (7)	16 (7)	26 (5)
81-96	19 (5)	20 (7)	28 (8)
65-80	19 (6)	14 (5)	21 (5)
49-64	15 (5)	11 (5)	19 (9)
33-48	13 (6)	11 (5)	18 (7)
17-32	11 (5)	7 (4)	13 (4)
0-16	9 (4)	2 (2)	7 (4)
49-64	9 (3)	9 (3)	10 (6)
113-128	18 (4)	3 (4)	17 (4)

temporal distribution of the rats' lever pressing was similar to that reported in intruded stimulus experiments in which pigeons pecked keys and different color keylights served as intruded stimuli (e.g., Farmer & Schoenfeld, 1966a, 1966b). The scallop typical of FI responding developed in the present experiment when the access to water overlapped the entire inter-reinforcement interval. When the period of access to water was shortened to function as a discrete stimulus and was then interpolated between successive reinforcers, 2 of the 3 rats developed a double scallop pattern, similar to that reported in other intruded stimulus procedures (e.g., Farmer & Schoenfeld, 1966a, 1966b). As the water probe was moved towards the beginning of the FI, its presentation modulated less and less the single scallop obtained at the beginning of the experiment.

The phenomena described above are typical of other experiments involving intruded stimuli and show that the effects are similar in rats and pigeons. The results also show that, just as any other intruded stimulus, the water probe may have functioned as a conditioned reinforcer for responding that occurred before its presentation, as a negative stimulus for responding during its presence, and as a discriminative stimulus for responding between its removal and the following food. These stimulus functions were obtained from the first

Fig. 2. Mean volume of water consumed by each subject as a function of the temporal placement of the water-access period within the food cycle. The empty circle shows the data for Rat A1, the black circle indicates those for Rat A2, and the square indicates those for Rat A3. The unconnected symbols show redeterminations. The average is based on the last five sessions of a condition.

exposure to each condition and in all cases were determined by the temporal position of the probe.

Water Consumption

Using fixed-interval schedules of different lengths, Falk (1966) found that as the inter-food interval was lengthened from 2 to 180 s, water intake increased steadily from about 15 mL to almost 100 mL (180 45-mg pellets per session). Further increases in the length of the food cycle resulted in gradual decreases in water consumption, to about 20 mL in a 300-s interval. Under an FI 120-s schedule, water consumption was approximately 10 mL per hour. During the last 10 sessions of the first condition of the present study, in which water was available during the entire 128-s reinforcement cycle, the average consumption for the 3 rats was 10.87 mL per hour. Relative to Falk's findings, water consumption in the first phase of the present experiment was of about the same magnitude. When water availability was restricted to only 16 s per cycle and the probe was intruded just before reinforcement delivery, the average intake was 15.33 mL per session. The absolute levels of water consumption are not, however, of primary concern to the purpose of the study. Rather, the systematic variation in the magnitude of drinking as a function of temporal location is the main contribution of the present experiment to the area of schedule-induced drinking.

Although the removal of water availability in the Flory and O'Boyle (1972) study can be considered to be an intruded stimulus procedure, their data cannot be compared directly to the results from the present experiment because the intake during the periods of water availability was not reported separately. Water-reinforced lever pressing before and after the removal of the stimulus was pooled together and reported as total lever presses (and an estimate of total volume consumed) during the FI cycle. Although the main dependent variable in Gilbert's experiment (1974, Conditions 1, 2, and 3) was rate of licking, the data are comparable because the report included an estimate of the volume of water consumed by the rats during the presentation of a single water probe per cycle. Using periods of 10 or 35 s of water availability, randomly intruded into different temporal locations of FT 60-s or 210-s schedules, Gilbert found about equal levels of drinking during the water probes. The results from the experiment performed by Daniel and King (1975) are also comparable to the results obtained here because volume consumed was studied as a function of 20-s water probes intruded once at the beginning, the middle, and the end of an FT 60-s schedule, using a different group of rats for each placement of the probe. As in Gilbert's experiment, water consumption was ubiquitous.

In contrast to the results obtained by Gilbert (1974) and by Daniel and King (1975), in the present experiment water consumption was a generally decreasing function of lengthening the probe-to-food interval. Relative to the experiments by Gilbert and by Daniel and King, the most obvious procedural differences were the within-subject sequential presentations of the probe, the intrusion of the probe into an FI schedule, and the use of an FI 128-s schedule, which is longer than the more common 60-s interreinforcement interval used in this type of study. Although it is impossible to determine the contribution of the several procedural differences involved in the present experiment, the longer interreinforcement interval is a likely candidate to explain the results obtained. Segal (1969) found that post-reinforcement drinking shifted into a scalloped pattern when the interreinforcement interval was lengthened from 60 s to 240 s. Falk (1972) also observed that under long FI values (approximately 180 s), drinking tends to occur

more towards the end of the interval. It should be noted that Gilbert tested FT schedules of 60 s as well as 210 s. However, only the 60-s value was reliably conducive to ubiquitous drinking. The FT 210-s schedule resulted in drinking at all locations of the probe for only 1 of 2 rats, because the 2nd rat did not develop schedule-induced drinking (see Gilbert, 1974, p. 282).

Although the results from the present experiment seem to fit a "superstitious" account of drinking (e.g., Clark, 1962), the present outcome does not necessarily support or undermine any specific theory of schedule-induced drinking. Rather, each data point seems to be consistent with predictions made by most explanations of the phenomenon. For example, when the probe was presented just after food delivery, drinking did occur in agreement with postprandial (e.g., Booth, 1972a, 1972b; Stein, 1964) or adjunctive (e.g., Falk, 1969; Staddon, 1977) accounts of schedule-induced drinking. As shown in the present study, the delivery of food does indeed appear to evoke drinking. However, any increment above this level as a function of moving the probe forward in time seems to reflect the action of other conditioning variables.

The increasing trend for water consumption as the intruded stimulus moved forward into the interval is similar to results obtained in other experiments using this paradigm. For instance, Farmer and Schoenfeld (1966a, 1966b) and Dews (1966) described a similar increasing function for key pecking in pigeons during a visual stimulus interpolated within an FI. Bruner (1981) also found an increasing function for pigeons pecking a key during a stimulus intruded into an FT schedule using an autoshaping/automaintenance procedure. Avila and Bruner (1989) obtained similar results using a variable-delay-of-reinforcement procedure, in which pigeons pecked the key during the stimulus to produce food at the end of a cycle of fixed duration. The similar results of these different experiments involving intruded stimuli suggest that the intruded stimulus procedure can be extended to the study of schedule-induced drinking.

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