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# POLYDIPSIA INDUCED IN THE RAT BY A SECOND-ORDER SCHEDULE[1]

JOAN Z. ROSENBLITH

HARVARD MEDICAL SCHOOL

Drinking was studied in rats pressing a bar on a second-order schedule in which every third completion of a 1-min fixed interval was followed by food presentation. A brief flash of light signaled the completion of each fixed-interval component. The rats drank not only after the food presentations but also after presentations of the light flash alone. A high rate of steady drinking followed intervals terminated by a food presentation. Drinking that followed intervals terminated by a light flash alone was of comparable rate, but characteristically interrupted by bar pressing. When 250-mg food pellets were used instead of 45-mg pellets, both drinking and bar-pressing rates increased substantially.

Characteristic patterns of excessive water drinking are associated with various schedules of food presentation in the rat. For example, rats bar pressing on a variable-interval (VI) schedule for 45-mg Noyes pellets (Falk, 1961*a*) develop a polydipsia totaling three to four times their normal 24-hr water intake within a 3 to 5-hr experimental session. While interval schedules favor the phenomenon, ratio schedules (Falk, 1961*b*) and schedules that differentially reinforce low rates of response (Segal and Holloway, 1963; Segal and Deadwyler, 1965; Segal and Oden, 1965) also engender convincing levels of polydipsia. Furthermore, pellets presented with no specified response dependency involved can also produce the phenomenon (Falk, 1961*a;* Reynierse, 1966).

As Falk (1969) pointed out in his comprehensive review, the determinants of this behavior appear to be complex. Regardless of the schedule employed, however, polydipsia can be elicited from suitably deprived rats by the manipulation of only two variables (Falk, 1966*b*, 1969). Briefly, if a suitable food is chosen, variation of the interreinforcement time and the amount of food presented produce a characteristic drinking behavior. Once developed, the polydipsia is quite stable, but easily manipulated.

In the present experiments, a second-order schedule was employed in which every completion of a 1-min fixed-interval schedule was followed by brief presentation of a stimulus and every third completion of the fixed interval was also followed by presentaion of food. The pattern of drinking that occurred after the presentation of food also came to occur after the presentation of the visual stimulus alone. This result emphasizes the importance of schedule factors in determining polydipsia and allows analyses of the phenomenon not directly related to the usual sequence of drinking following eating.

## METHOD

### *Subjects*

Three previously untrained male albino Charles River Farms rats, initially weighing approximately 250 g, were maintained at 70% of their original weight by limited feedings immediately after the experimental sessions. Session length varied with the particular phase of the experiment, but averaged 2.5 hr. Sessions were conducted daily, Monday through Friday. Maintenance feedings were given on weekends to maintain appropriate body weights. Water was always available in the home cage, and a daily record of water consumption in the cage was maintained both before and during the experimental regime.

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*Apparatus*

A chamber measuring 7.8 by 8.8 by 7.8 in. (20 by 22.5 by 20 cm) contained a response key (Lehigh Valley Electronics rat lever, LVE 1352) mounted on the right side of one wall 1.5 in. (3.75 cm) above a grid floor. An insulated metal drinking spout attached to a calibrated reservoir was mounted 0.25 in. (6 mm) behind a 0.5 in. (1.25-cm) hole in the middle of the same wall to prevent continuous sucking at the spout. An electronic circuit drinkometer recorded every lick on the spout. Each food delivery was accompanied by a click and preceded by a 2-sec flash of an overhead light. The food magazine was attached to a standard Gerbrands pellet dispenser equipped to dispense either 45-mg Noyes pellets or 250-mg SKF pellets (Riddle, Rednick, Catania, and Tucker, 1966). The magazine was mounted on the same wall 1 in. (2.5 cm) to the left of the drinking spout. The apparatus was equipped with two 6-w magazine lights and a 6-w overhead light. The experimental chamber was enclosed in a sound-attenuated box equipped with a white-noise generator. Scheduling and recording were automatic.

*Phase 1*

Two subjects (R1, R3) were trained on a 1-min fixed-interval schedule (FI 1-min) with 45-mg Noyes pellets and were studied under this schedule for about 10 days until the response pattern appeared to be stable. Each session terminated after 120 reinforcements.

*Phase 2*

The two subjects studied in Phase 1 and an additional subject (R6) that had been trained only to press the bar were studied on a second-order schedule for 30 sessions in which the third completion of an FI 1-min schedule was followed by a 2-sec flash of light, a click, and a 45-mg food pellet: FR 3 (FI 1-min). The end of the other components was accompanied only by a 2-sec flash of light and a click. Again, sessions ended after 120 FI 1-min components so that only 40 food presentations occurred per session.

*Phase 3*

The experimental apparatus was modified to deliver 250-mg SKF pellets. In addition, the number of FI 1-min components was reduced to 90 so that with the FR 3 (FI 1-min) schedule employed, only 30 reinforcements occurred per session. No additional feedings after the session were required to maintain the animals at the appropriate weight. Approximately 60 sessions were administered to each animal.

## RESULTS

Average water consumption in the home cage before experimentation was between 15 and 20 ml per day for each of the three subjects. No attempt to determine a spillage factor was made. Therefore, these figures are maximum. During Phase 1, both subjects consumed approximately 60 cc of water per session (or about three times as much as their previous daily water consumption in the home cages). Discrete bursts of licking followed closely after delivery of each pellet. Home cage water consumption fell to almost zero.

Under the second-order schedule, drinking occurred initially only after the third FI 1-min component; that is, after the delivery of food (Fig. 1, top frame). After several weeks, however, a distinct tendency to drink after the first two FI 1-min components became evident. This pattern was particularly well developed in Subject R3 (Fig. 1, middle frame). The general distribution of licking was divisible into two patterns. After each flash of light, even when unpaired with food presentation, drinking tended to occur. A second type of drinking during the first two intervals occurred as an alternation between responses on the lever and the drinking spout.

In Phase 3, during which 250-mg SKF pellets were substituted for the 45-mg Noyes pellets, changes occurred immediately, on Day 1 of the experiment, in both bar-pressing and licking behaviors. The number of bar presses per three-interval component increased (Fig. 2) and showed more clearly the scalloping characteristic of fixed-interval schedules. In all subjects the amount of water consumed per interval increased substantially (Fig. 3). Note, however, that the drinking behavior of R3 was eventually accentuated so that more water was consumed in the two intervals after which no food was presented than in the interval following a food delivery (Fig. 1, bottom frame; Fig. 3); the records of the other two subjects came to resemble the performance of

R3 (Fig. 4). All three subjects drank not only immediately after food delivery but also after the flash of light signaling the end of the first two FI 1-min intervals. Again, two types of drinking behavior were present. The first was characterized by a very high rate and occurred

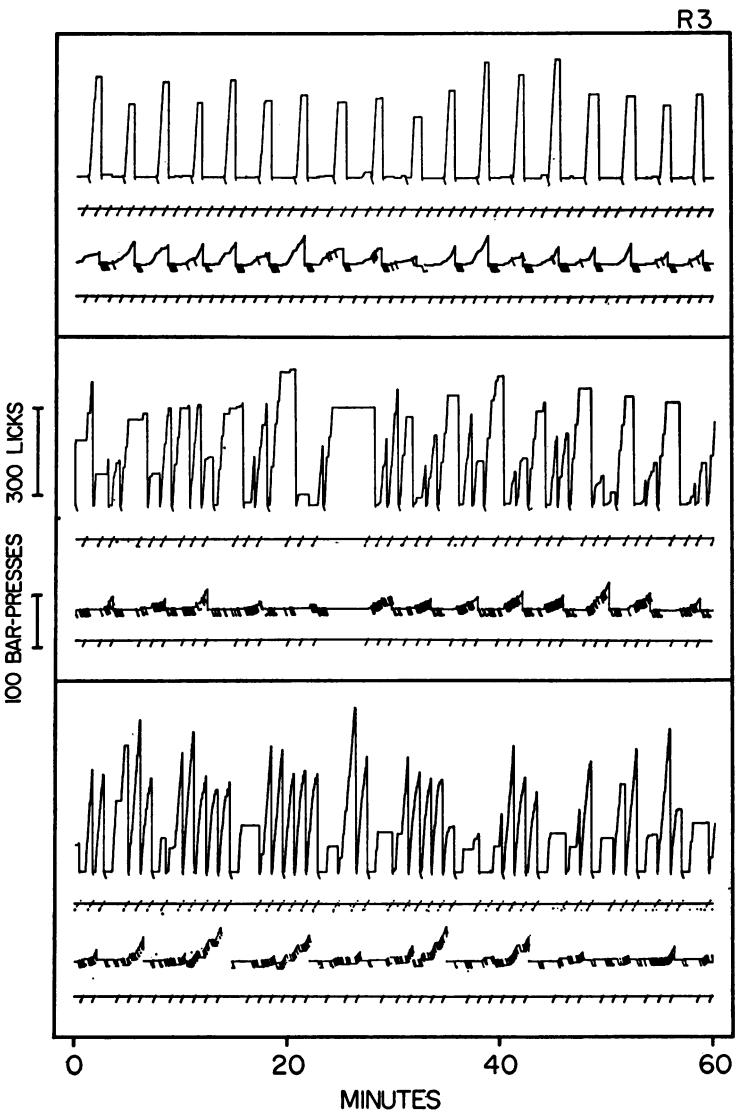


Fig. 1. Top: early performance (Day 3) of Rat R3 under the FR 3 (FI 1-min) schedule with 45-mg Noyes pellets. Middle: stabilized performance (Day 31) of Rat R3 under the FR 3 (FI 1-min) schedule with 45-mg Noyes pellets. Bottom: performance (Day 25) of Rat R3 under the FR 3 (FI 1-min) schedule with 250-mg SKF pellets. Ordinate: cumulative number of bar presses and cumulative licks on the drinking spout; abscissa: time. The food presentation or light flash terminating each FI 1-min interval is marked by a diagonal stroke on the event pens. The pen recording cumulative licks resets after each FI 1-min interval. The pen recording cumulative bar presses also indicates licks at the drinking spout by diagonal strokes; each diagonal stroke corresponds to approximately 12 licks. The cumulative bar-press pen resets after each reinforcement, *i.e.*, after each FR 3 (FI 1-min) component. Note in the middle frame how the rat begins to drink not only after food presentations but also after presentation of the visual stimulus alone. In the bottom frame, when 250-mg pellets were substituted for 45-mg Noyes pellets, notice both the increase in licking after visual stimuli alone and the increase in bar pressing. The bottom trace, showing bar pressing, with licks superimposed as diagonal strokes, gives a clear picture of interrelations between bar pressing and licking during intervals that terminate with a light flash and click alone. The rat alternates between licking and pressing the bar in contrast to those intervals following a food delivery during which he licks exclusively.

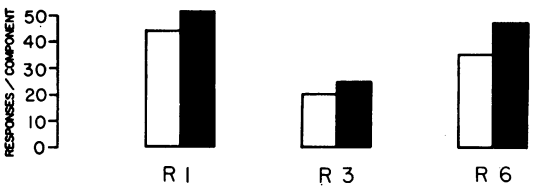


Fig. 2. A comparison of bar-pressing behavior between 250-mg SKF pellets (black bars) and 45-mg Noyes pellets (white bars) used in an FR 3 (FI 1-min) schedule (Rats R1, R3, R6). Note the increase in number of bar presses per three fixed-interval component with the 250-mg SKF pellets.

just after a food delivery. The second type was frequently interrupted by bar pressing and occurred after a light flash alone.

The number of licks necessary to consume 1 ml of water did not change between phases for each animal, suggesting that the manner of licking was similar regardless of the experimental phase. In all experimental phases, the home cage water consumption dropped to near zero. The experimental water consumption for Phases 2 and 3 ranged from an average of 24 to 40 ml per session, depending on the animal. This is a significant decrease from the 60 ml average reported in Phase 1 and is due in part to the reduction in number of food pellets delivered from 120 in Phase 1 to 40 in Phase 2 and finally to 30 in Phase 3. Another determinant of water intake is the quality of the food pellet itself, since more water was actually consumed during Phase 3 than during Phase 2, even though the number of food presentations was smaller.

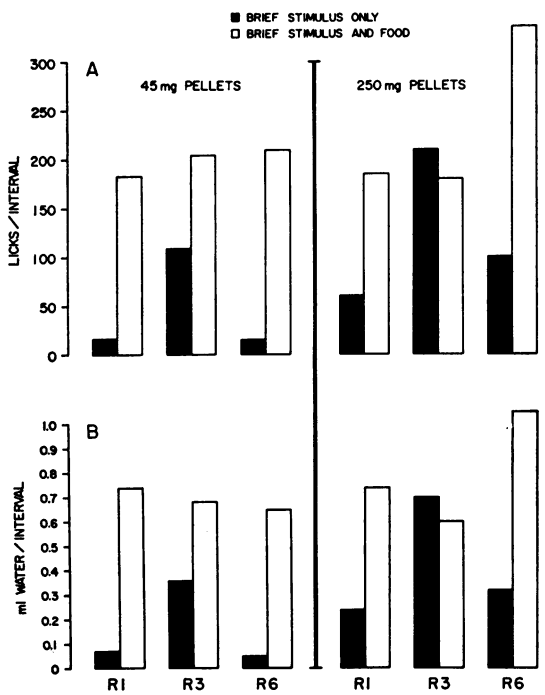


Fig. 3. A comparison of drinking behavior between 250-mg SKF pellets and 45-mg Noyes pellets used in an FR 3 (FI 1-min) schedule (Rats R1, R3, R6). Licks per interval in Part A reveal an increase in licking behavior during intervals following a light flash and click alone with use of SKF 250-mg pellets. R6 also showed a large increase in licks after delivery of a food presentation. Part B is a measure of ml of water consumed per interval, and again water consumption rises in intervals following a light flash and click alone with the SKF 250-mg pellets. As expected, R6 also consumes more water in intervals following a food presentation.

## DISCUSSION

The advantage of employing a second-order schedule is the dissociation of "psychogenic" polydipsia from the drinking that occurs naturally after a meal. "Doling out the food ration over a period of hours in a reinforcement schedule is tantamount to increasing the number of meals and therefore the number of drinking periods" (Stein, 1964). The use of the more complex second-order schedule does permit a more detailed analysis of polydipsia than just the natural predilection for drinking after eating.

Polydipsia with a second-order schedule is clearly dependent on more than the simple association of eating with drinking. Since drinking occurs after presentation of a light flash and a click alone, it has been removed from its usual position as a response to eating. This clearly rules out interpretations of drinking as a requirement to "eliminate the postprandial oral effect of each pellet" (Stricker and Adair, 1966). Likewise, the dissociation of eating and drinking contradicts dry-mouth interpretations (Stein, 1964; Teitelbaum, 1966).

There is little question that the factors determining and maintaining polydipsia are crucial and complex. Properly scheduled, polydipsia is a powerful behavior capable of sustaining a fixed-ratio schedule in its own right (Falk, 1969). Falk (1969) likens polydipsia to "displacement activity" where the behavior is misplaced and occurs out of its proper context. He points out, however, that displacement activities are usually described as being

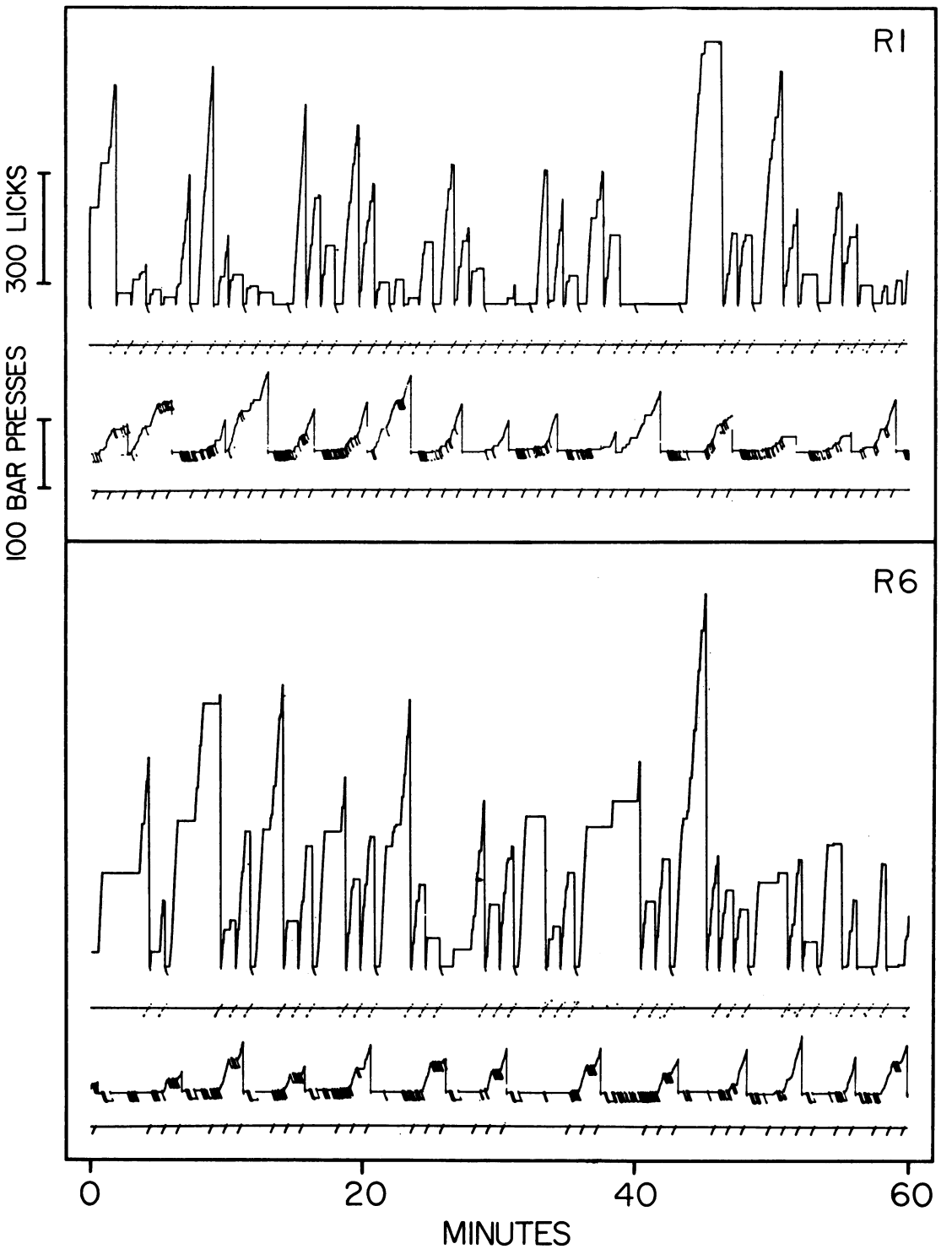


Fig. 4. Stabilized performances of Rats R1 and R6 under the FR 3 (FI 1-min) schedule with 250-mg SKF pellets. Recording is the same as in Fig. 1. Inspection of the bottom trace facilitates the appreciation of two types of drinking. The rats drink with no interruption after a food delivery, while alternating between bar pressing and licking after presentation of the light flash and click alone.

"incomplete, of low intensity, or poorly oriented", which is not typical of schedule-induced polydipsia. Reference to Fig. 1 and 4 reveals two types of licking: a high-rate drinking occurring after delivery of a pellet and a drinking frequently interrupted for bar pressing after intervals terminated by a light flash and a click alone. The second type of licking behavior could be interpreted as a "displacement" type of drinking, while the high-rate drinking following a pellet could be interpreted as the rat's habitual response to a meal.

The second-order schedule, however, allows further analyses of polydipsia involving the two distinct types of drinking. For instance, drinking in the second-order schedule could occur similarly to a classically conditioned response. The food pellet would constitute an unconditioned stimulus (UCS) for drinking, while the light flash and click were temporally positioned to become conditioned stimuli. Polydipsia occurring in nonreinforced intervals could then be explained by a classical paradigm. Such an explanation could also attribute the usual failure of liquid reinforcers to produce polydipsia to their poor quality as a UCS for drinking. Indeed, the increase in drinking shown when the rats in this study were given larger pellets in Phase 3 could also be a result of the large pellet being a more effective UCS than the small one.

Further experiments are needed to analyze polydipsia under the second-order schedule. Fortunately, the good experimental control over polydipsia produced by the second-order schedule makes such analyses possible.

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