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CONTROL OF SCHEDULE-INDUCED POLYDIPSIA: TYPE, SIZE, AND SPACING OF MEALS[1]

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Rats were given daily 1-min variable-interval sessions for several types of food delivered in various amounts per reinforcement and the concurrent, schedule-induced polydipsia was measured. Dry, solid food was neither a necessary nor sufficient condition for the development of polydipsia. Small portions of liquid Standard Monkey Diet produced polydipsia, but 45-mg dextrose or sucrose pellets did not. Within the range studied, smaller portions of both solid and liquid foods produced more drinking than larger portions per reinforcement. Two-min variable-interval sessions produced a greater polydipsic response than 1-min variable-interval, even though the number of 45-mg Noyes pellets allowed per session was held constant. Polydipsia was greatly attenuated on these schedules when the number of pellets remained constant, but were delivered two at a time. Within the ranges studied, the concurrent polydipsic response was increased by decreasing the rate of food acquisition, either by using smaller portions of food per reinforcement or by increasing the interreinforcement time.

Rats required to press a bar for most of their daily food ration on various schedules of reinforcement develop a marked, concurrent polydipsia (Falk, 1961*a*; 1961*b*; 1964; 1966*a*; 1966*b*; 1966*c*). Extended bursts of drinking followed the consumption of each food pellet throughout the course of each daily session. Much of this research has utilized a 1-min variable-interval schedule of food reinforcement (VI 1-min). In this schedule an operant response such as bar-pressing with a paw, or pushing a plastic key with the nose, is reinforced by the intermittent delivery of a food pellet at variable times, the average time being 1 min. For example, during 3.17 to 3.50-hr daily sessions on VI 1-min for 45-mg Noyes pellets, rats drank close to one-half of their body weight in water. This polydipsia was about three or four times their normal 24-hr water intake.

Such polydipsia is not the effect of the food-deprivation regimen itself in which animals were maintained at 80% of their free-feeding weights by limiting food intake; rats held at that weight decreased their intake of water (Falk, 1964). Noyes Lab rat pellets *per se* do not produce polydipsia; only when the inter-pellet time is increased to about 45 sec does polydipsia begin to be evident (Falk, 1966*b*). With longer inter-pellet times the effect is greater. Polydipsia is not attributable to the adventitious reinforcement of drinking by food delivery since it is a post-pellet phenomenon (Falk, 1961*a*). It can occur on fixed-ratio (FR) schedules (Falk, 1961*b*) and its development is unimpeded when food cannot follow drinking by less than 15 sec (Falk, 1964). Considering the above range of initiating conditions, the major variable remaining to account for the polydipsia is some threshold degree of intermittence in the food delivery schedule. Indeed, the food schedule itself need not involve contingent behavior of the animal (Falk, 1961*b*) for polydipsia to result. Therefore, extensive experimental analyses of the relations between the scheduled bar-pressing behavior and the adjunctive drinking responses are perhaps less requisite at this time than studies of the factors which exert first-order control over the drinking. While a schedule such as noncontingent 1-min variable-interval food delivery is sufficient to evoke polydipsia, making pellet delivery contingent upon an operant such as a bar-press serves as a useful, ancillary channel of information on the food-oriented behavior.

In previous research, while the schedule of reinforcement has been varied, the food sub-

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stance has been limited to 45-mg Noyes Lab rat food pellets. An exception to this is Stein (1964). He concluded that schedule-induced polydipsia "depends on the eating of dry or thirst-provoking food" since substituting 0.15 ml portions of milk in place of 45-mg Noyes pellets eliminated polydipsia. In Exp. 1, the notion that the schedule-induced polydipsia depends upon the consumption of dry pellets was tested by comparing the drinking response to three types of food pellets and three types of liquid food. With the liquid foods, the size of the portion per reinforcement was varied. The food schedule was held constant at VI 1-min across all amount and type comparisons. The choice of types of pellets and fluids delivered during the sessions was governed by the following considerations. Liquid Standard Monkey Diet and Metrecal were chosen to compare with Noyes Lab rat food pellets since they are all nutritionally well-balanced. Sucrose and dextrose pellets were compared to the Noyes pellets as other types of dry pellets which would be acceptable to rats, although they are radically different in composition. A 30% sucrose solution was used to compare a high-carbohydrate, fluid diet with the sucrose and glucose pellets and also to compare it with the Metrecal, which has about the same per cent water content (approximately 75%).

In Exp. 2, both the number of Noyes 45-mg pellets delivered at each reinforcement and the average time between reinforcements was varied in order to estimate the interaction of these two variables and to extend information on the "amount of food per reinforcement" factor to the Noyes pellet diet.

EXPERIMENT I

Subjects

Two female, littermate, albino rats of the Hisaw strain were used. Both weighed 263 g and were four months old at the start of the experiment. They were caged individually in a temperature-controlled, constantly-illuminated room. An additional group of five female animals, similarly caged, was used for a control procedure described below.

Procedure

Apparatus. A picnic ice chest contained a Gerbrands rat lever, dc house lights, and a Gerbrands dipper feeder. Water was continuously available in each home cage and in the experimental space, where a calibrated reservoir was clipped to the end of the ice chest opposite the lever. The spout of this reservoir was located just beyond the confines of the box but was accessible for licking through a small slot cut in a ⅛-in. Micarta panel. Each lick was detected by an electronic drinkometer. Automatic apparatus for the control and recording of the experiment was located in an adjoining room.

Schedule and diets. The animals were food-deprived and held to 80% of their free-feeding weight for the duration of the experiment. They were trained to bar-press, given two sessions in which each press produced a portion of food, and then placed on a VI 1-min schedule for 353-mg portions of liquid Standard Monkey Diet.[2] The values of the intervals composing the VI 1-min schedule were 100, 5, 56, 50, 68, 12, 109, 80, 20, 120, 40, 90, and 30 sec. Sessions were 3.33 hr. It soon became apparent that sessions could be allowed only every second day in order to maintain body weight at 80%. After 10 sessions at 80%, the amount of diet was reduced to 62 mg per reinforcement for one rat. Again many sessions had to be omitted due to increases in body weight. However, 30 sessions were given at 80% body weight with 62-mg portions on the chance that polydipsia might develop. Finally, the portions were reduced to 22 mg, and 30 consecutive sessions were completed for both animals. Post-session Purina chow supplements of 2 to 3 g were necessary to maintain body weight.

Four sessions were programmed at each of two volumes of reinforcement (0.08 and 0.02 ml) of liquid Metrecal and of 30% sucrose solution. After each four-session determination, baseline polydipsia was recovered by

[2]As supplied in powder form by Nutritional Biochemical Corp., Cleveland, Ohio, this diet contains: Alphacel, 6.5%, Salt Mixture U.S.P. XIV, 6.5%, Sucrose, 51.0%, Special Vitamin Free Casein, 34.0%, Vitamin Diet Fortification Mixture, 2.0%. These values vary slightly from those given by Ellison and Riddle (1961). To 90 g of this mixture 10 g of Wesson Oil and 50 ml of tap water were added. When well shaken and placed in the dipper feeder tray, which was canted so as to pool most of the fluid at the end where the dipper moved up and down, little separation took place during the session. In future use of this diet, however, one would do well to mix in the emulsifying agent sodium carboxymethylcellulose (Clark, 1965).

using 22-mg liquid Standard Monkey Diet portions for several sessions.

Next, the experiment was transferred to another box which was similar in all important respects to the one described except 45-mg Noyes Lab rat pellets, rather than a liquid diet, were delivered on the VI 1-min schedule. After the polydipsic baseline had stabilized four sessions were given using 45-mg dextrose pellets, baseline was recovered with 45-mg Noyes Lab rat pellets again, and then four sessions with 45-mg sucrose pellets were given.

Owing to the extreme dilution and/or the nutritionally unbalanced nature of the sucrose and Metrecal liquid diets and the sucrose and dextrose pellets, it was deemed advisable to use only four consecutive-session determinations interspersed by a return to either the liquid Standard Monkey Diet or Noyes pellet diet. Post-session supplements of Purina Chow assured that attenuation of the polydipsia was not due to a deteriorating nutritional state. This is also supported by the fact that drinking values for the first session were representative of the values for all four sessions in each case.

Diet-difference control. In order to control for differences in water intake, which the various rations might command in a situation not involving an intermittent schedule of delivery, the control group of five rats was reduced to 80% body weight and given the various rations used in the order shown in Fig. 3. Daily, each animal was weighed and an amount of diet was presented in a food cup attached to the living cage. This amount approximately equaled the total earned during a variable-interval session where concurrent drinking was maximized for the particular diet. The total water consumed for 3.5 hr after presentation of the diet was recorded and then sufficient Purina chow supplement to maintain the 80% body weight was given. Dietary rations were presented for either four or seven (Noyes pellets, liquid Standard Monkey Diet) consecutive daily sessions.

Results

Figures 1 and 2 show the mean session water intakes and their standard errors for the various dietary conditions. Both 45-mg lab rat pellets and 22-mg portions of liquid Standard Monkey Diet induced marked concurrent polydipsia when they were contingent upon a VI 1-min schedule. All other types and amounts of food were much less effective and can hardly be considered as inducing a strong polydipsia. For each liquid diet, the larger the portion delivered per reinforcement, the smaller the concurrent water intake. For all diets water intake in the home cage between sessions was negligible; it was usually 0 to 1 ml and never more than 3 ml.

The mean water intake of the diet-difference control animals is shown in Fig. 3. In general, considering the scale of the effects illustrated in Fig. 1 and 2, the amount of water drunk under the control condition was rather small for all diets. The absolute differences among pellet-associated water intakes are trivial, while water intake under the liquid Standard Monkey Diet condition is somewhat lower (it differs from the preceding Noyes-pellet condition at the 0.02 level). The other two fluid diets produced almost no water intake.

Table 1

Mean total responses per session ± S.E. VI 1-min for liquid and solid foods. Calories per reinforcement also shown (Cal/Rf). Stn. SKF = liquid Standard Monkey Diet.

Diet	*Cal/Rf*	*Rat 1 Mean Session Responses*	*Rat 2 Mean Session Responses*
Stn. SKF, 22 mg	0.060	3783 ± 268	7260 ± 195
Stn. SKF, 62 mg	0.168		5644 ± 345
Stn. SKF, 353 mg	0.957	662 ± 44	1301 ± 99
Metrecal, 0.08 ml	0.076	1378 ± 65	3396 ± 118
Metrecal, 0.02 ml	0.019	853 ± 50	1657 ± 215
30% Sucrose, 0.08 ml	0.098	2008 ± 193	1270 ± 108
30% Sucrose, 0.02 ml	0.025	3354 ± 239	3193 ± 215
Noyes Pellet, 45 mg	0.171	1175 ± 41	1123 ± 57
Dextrose Pellet, 45 mg	0.164	1947 ± 238	623 ± 20
Sucrose Pellet, 45 mg	0.173	1060 ± 58	619 ± 249

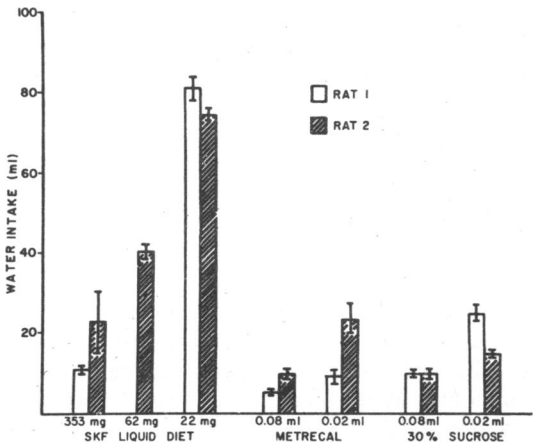

Fig. 1. Mean water intake (ml) ± S.E. during 3.33-hr VI 1-min sessions for various types and portions of liquid food, SKF liquid diet = liquid Standard Monkey Diet.

Table 1 shows the mean total responses per session for the various diets. The fluid-diet responses should not be compared with the pellet-diet responses, strictly speaking, for these data were gathered in different boxes. While responding at rather different average rates for two of the three fluid diets, the ordering of the response rates was similar for the two animals with respect to: (a) the effect of portion on rate within each type of fluid and (b) liquid Standard Monkey Diet (22 mg) yielding the highest rates.

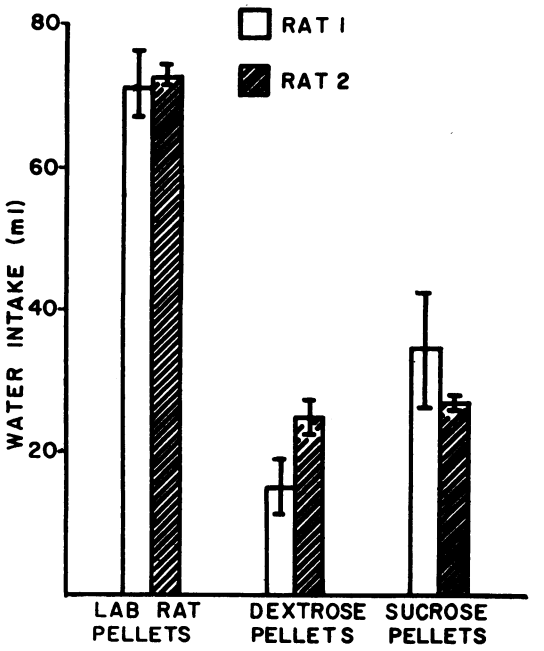

Fig. 2. Mean water intake (ml) ± S.E. during 3.33-hr VI 1-min sessions for three types of 45-mg, solid food pellets.

EXPERIMENT II

Subjects

Three female, four-month-old Irish rats, I-51, I-52, and I-53, weighing 180, 182, and 195 g respectively at the start of the experiment, were used. Caging conditions were as in Exp. I.

Procedure

The animals were run at 80% free-feeding body weight on VI 1-min for 45-mg Noyes Lab rat pellets. Daily 3.5-hr sessions were continued for six weeks, and then four sessions were run for VI 1-min in which two pellets, rather than one, were delivered at reinforcement. This is designated as VI 1-min (90 mg). These sessions were not given consecutively; rather, baseline session water intake on VI 1-min (45 mg) was recovered for a few sessions before instituting the next VI 1-min, double-pellet (90 mg) probe. Throughout all these probes and the other changes to be described, the number of pellets allowed per session was limited for each animal to the mean number earned under the VI 1-min (45 mg) condition. Before the following changes were introduced, this mean pellet number was readjusted slightly for two animals. Each animal's pellet number is shown near the top of Table 2. Since previous research has shown that the drinking response is closely associated with the consumption of each food pellet, it is important to control the number of pellets delivered when comparing the efficacy of various schedules in producing polydipsia.

After the VI 1-min (90 mg) determinations, eight consecutive sessions at VI 2-min (45 mg) and then five consecutive sessions at VI 2-min (90 mg) were given. Only the data from the last four of these five sessions were utilized.

Results

Table 2 shows first that the initial levels of water intake established by VI 1-min (45 mg) differed for the three animals. I-52's intake under this condition, while about twice the normal, 24-hr, free-feeding water intake, remained one of the smallest polydipsic responses to VI 1-min (45 mg) observed in the

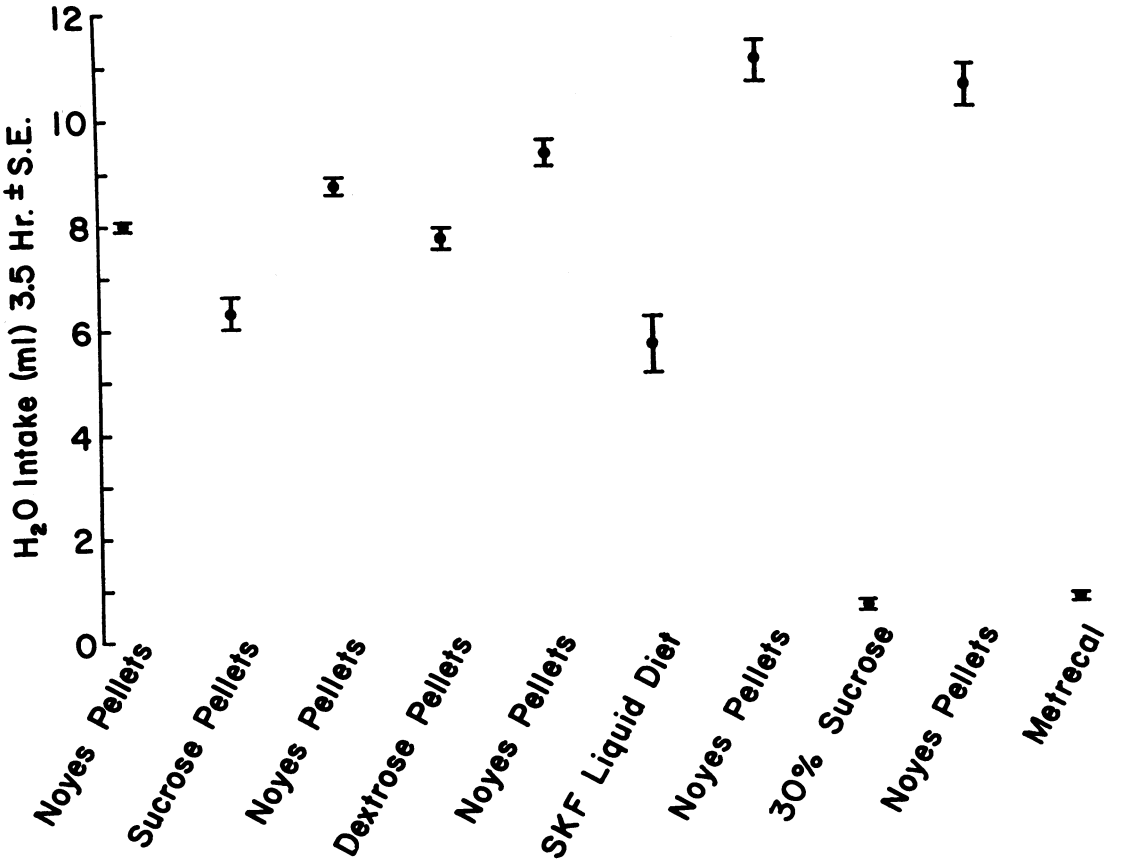

Fig. 3. Mean water intake (ml) ± S.E. during 3.5-hr diet-difference control sessions in home cage. SKF liquid diet = liquid Standard Monkey Diet.

course of many such experiments. While the VI 1-min (45 mg) levels differed among animals, the standard error for each animal was small and all schedule changes affected animals similarly.

The VI 1-min (90 mg) session probes drastically reduced drinking, while VI 2-min (45 mg) brought intake up to well above the VI 1-min (45 mg) level for all animals. Finally, VI 2-min (90 mg) again illustrated the attenuating effect that increasing the amount of food per reinforcement had on drinking.

Figure 4 illustrates the effects described above. The number of pellets delivered per session was constant so that the differences among the records are not a function of varia-

Table 2

Mean session water intake (ml) ± S.E. induced by each of four schedules for three animals. 90 mg = delivery of two 45-mg pellets; pellet limit = average of number of pellets earned on the VI 1-min (45-mg) schedule during 3.5-hr sessions.

	Pellet Limit		
Schedule	*Rat I-51* *200* *45-mg pellets*	*Rat I-52* *170 to 175* *45-mg pellets*	*Rat I-53* *195 to 203* *45-mg pellets*
VI 1-min (45 mg)	132.2 ± 4.1	34.5 ± 4.5	59.6 ± 7.5
VI 1-min (90 mg)	24.5 ± 0.6	17.0 ± 0.4	34.0 ± 0.3
VI 2-min (45 mg)	191.6 ± 3.8	50.6 ± 2.5	75.0 ± 3.0
VI 2-min (90 mg)	167.0 ± 16.3	35.3 ± 1.3	64.0 ± 1.1

tions in food intake. The records show post-reinforcement bursts of water drinking; variable-interval bar pressing is not shown. Pellet delivery reset the recorder and also deflected the pen momentarily, making a short, vertical hatch mark. Each lick at the water spout stepped the recorder cumulatively. For VI 1-min (45 mg), almost every pellet delivery (and consumption) was quickly followed by a burst of drinking. These bursts were considerably larger on VI 2-min (45 and 90 mg). For VI 1-min (90 mg), drinking bursts all but ceased about halfway through the session, but they tended to be larger when they did occur. The attenuation of drinking in the second half of this session cannot be attributed to food satiation ("pellets per session" was held constant) or to the 90-mg portion *per se* (note

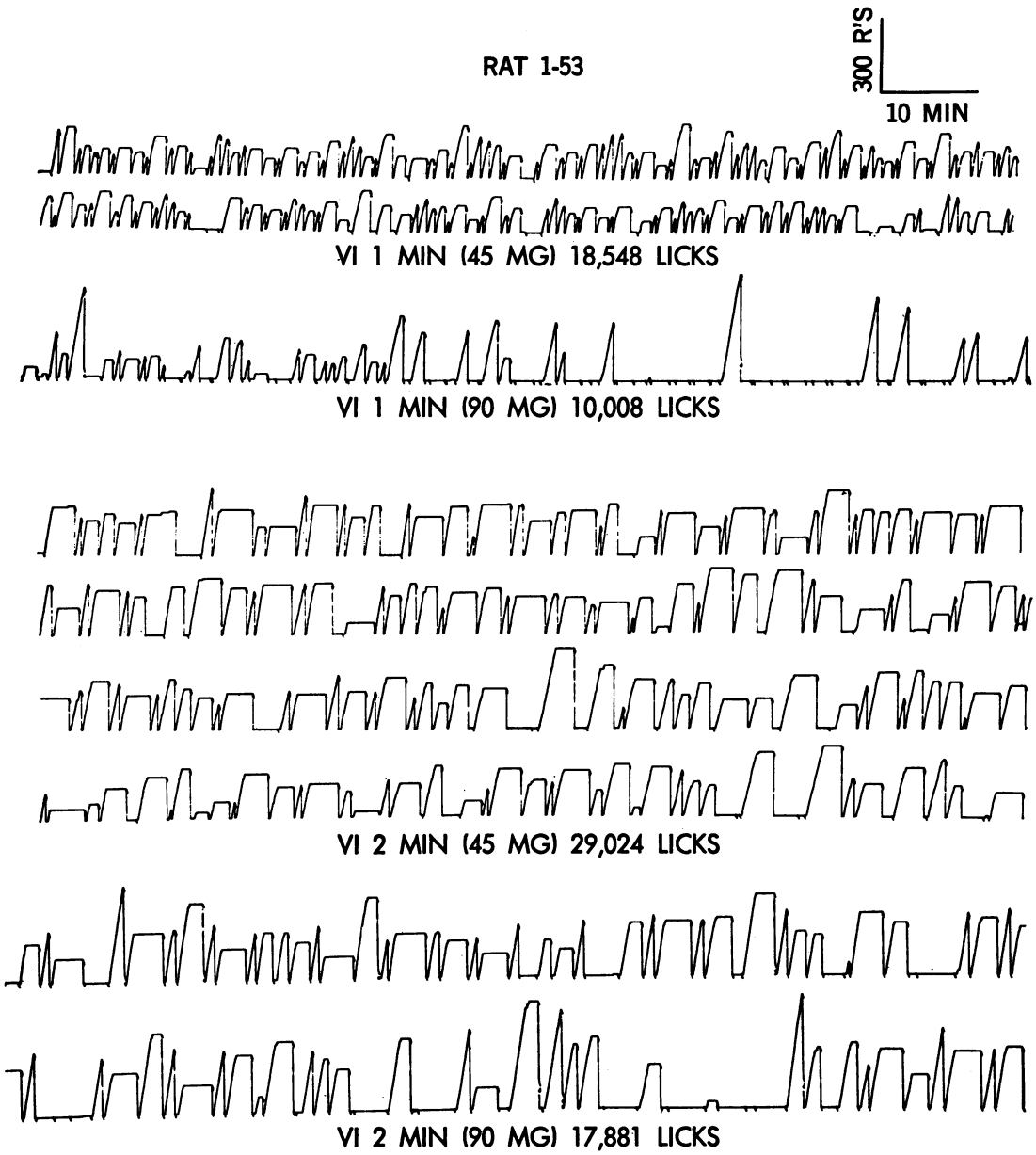

Fig. 4. Representative drinking records of complete sessions from Rat I-53. Number of 45-mg pellets per session limited to 195-203. Each lick steps the recorder cumulatively. Pellet delivery resets the pen to the bottom and also deflects it momentarily, making a short, vertical hatch mark.

the continued bursts on VI 2-min, 90 mg). The critical factor here is most probably the amount of food per unit period of time. For example, comparing VI 1-min (45 mg) with VI 2-min (90 mg), pellet delivery density over time was equal and the drinking responses were comparable.

Again, under all conditions water intake in the home cage between sessions was slight, typically 0 or 1 ml and never more than 4 ml.

DISCUSSION

The type of food, the amount delivered per reinforcement, and the mean time between deliveries are all major variables regulating the degree of schedule-induced polydipsia. Stein (1964) concluded that schedule-induced polydipsia depends on the eating of dry food, since substituting 0.15 ml portions of milk (one part Borden's sweetened condensed milk, two parts tap water) in place of 45-mg Noyes pellets immediately eliminated almost all session water intake. In the light of the present study, one might consider whether it was the comparatively large portion given (0.15 ml) or the dilution (66% water) which blocked the drinking response. Likewise in Exp. I, it may have been the high aqueous content (about 75%) of the nutritionally balanced (Metrecal) and unbalanced (sucrose solution) diets which attenuated, but by no means eliminated, adjunctive drinking. Since these were the two diets which effectively eliminated water intake in the home cage control group, the intakes associated with VI 1-min were comparatively high, if not truly polydipsic. In any case, polydipsia did develop not only with the solid Noyes pellet but with the fairly aqueous Standard Monkey Diet (33% water). On the other hand, it failed to occur when dry, solid, sucrose and dextrose pellets were substituted.

While this study was not designed to investigate the relation between Calories per reinforcement and the drinking response, inspection of the Caloric values in Table 1, together with Fig. 1 and 2, reveals that across types of diet similar Caloric content of the reinforcer fails to predict the drinking response. For example, liquid Standard Monkey Diet-22 mg and Metrecal-0.08 ml are close calorically, but at the extremes in adjunctive drinking. When type of diet was held constant and Calories per reinforcement altered by changing amount, the small meal sizes, whether liquid (Exp. 1) or solid (Exp. 2), induced more drinking than the larger portions. This relationship held whether or not the intakes reached frankly polydipsic levels.

Table 2 shows that the VI 2-min schedule produced more drinking than the comparable VI 1-min schedule for both 45-mg and 90-mg values of meal size. This confirms for these two mean variable-interval values the effect found when fixed-interval length was systematically varied: within this general temporal range the degree of polydipsia was an increasing function of inter-pellet time (Falk, 1966*b*). The table also shows that by simultaneously manipulating interreinforcement time and meal size, the order of the polydipsic effect can be simply predicted for each animal.

Inter-meal time and meal magnitude are simply two variables controlling the rate of food acquisition. They combine to determine lick burst length and probability. At the highest food acquisition rate used in Exp. 2 (VI 1-min, 90 mg), the drinking during the second half of the session was attenuated compared to the rather stable, characteristic states produced by the other acquisition rates (Fig. 4). Such split-half session instability is probably characteristic of acquisition rates which are transitional in producing frank polydipsia.

The results of both experiments indicate that, within the ranges studied, decreasing the rate of food acquisition increased the polydipsic response. This was accomplished by two means: (a) giving smaller portions per reinforcement and (b) increasing the interreinforcement interval. The type of diet was also an important factor controlling adjunctive drinking: dry pellets were neither necessary (*cf.* liquid Standard Monkey Diet-22 mg) nor sufficient (*cf.* sucrose and dextrose pellets; VI 1-min, 90-mg Noyes) conditions for producing polydipsia, nor was Caloric value per reinforcement, when compared across diets, a predictor of drinking.

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