WITHIN-SESSION MEAL-SIZE EFFECTS ON INDUCED DRINKING

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As a control for the effects of session duration and hunger on the relation between food magnitude and induced drinking, four food-deprived rats were exposed to a variable-time 50-s schedule of food delivery in which the size of each food delivery varied randomly within sessions. Food-related behavior and schedule-induced drinking per opportunity were examined as functions of meal size and postfood time. All rats showed an inverted-U-shaped relation between drinking per opportunity and meal size. This relation was caused by variation in the percentage of intervals that contained drinking and by variation in the number of drinking bouts per interval, rather than by bout duration or by the amount of drinking within those intervals that actually contained drinking. Head-in-feeder time increased linearly with meal size. Schedule-induced drinking was entrained by food delivery in 3 of 4 subjects; the entrainment was due to regulation of the starting time of each drinking bout rather than to regulation of bout duration.

Key words: schedule-induced drinking, adjunctive behavior, interim activities, reinforcer magnitude, variable-time schedule, rats

When rats have access to water during periodic schedules of food delivery, they usually drink much more than when, over the same period, they are given the same amount of food en masse (Falk, 1961). The critical properties of the schedules that are responsible for this "schedule-induced" drinking have not been completely identified.

Two widely held hypotheses regarding the critical properties of the inducing schedule are (a) the motivation hypothesis, which assumes that the motivation to drink is positively related to the motivation to eat (Falk, 1969; Hawkins, Schrot, Githens, & Everett, 1972; Staddon, 1977; but see Reid & Dale, 1983; Reid & Staddon, in press); and (b) the S- hypothesis, which assumes that the schedule must have a period of relatively low probability of food delivery into which the subject allocates drinking rather than food-related activities (Staddon, 1977). Explicitly signaled periods of low food probability are not necessary for the obser-

vation of schedule induction. It appears to be sufficient that the schedule have a low, albeit constant, probability of food delivery (Shurtleff, Delamater, & Riley, 1983; but see Yoburn, Cohen, & Campagnoni, 1981).

The research reported here addresses some of the evidence supporting the motivation hypothesis. In particular, we address the relation between food amounts and schedule-induced drinking. Many researchers have investigated the effects of food amounts on drinking, but the data are confusing. Various measures of drinking have been used, and the data appear far from consistent. For example, Couch (1974), Flory (1971), Jacquet (1972), Rosellini and Burdette (1980), and Yoburn and Flory (1977) manipulated meal size across sessions and found that increases in meal size resulted in increases in drinking. However, Allison and Mack (1982) (in two different experiments), Falk (1967), Freed and Hymowitz (1972), Lotter, Woods, and Vasselli (1973), and Urbain, Poling, and Thompson (1979) also manipulated meal size across sessions and found that increases in meal size resulted in decreases in drinking. Reid and Staddon (1982) and Reid and Dale (1983) varied meal size within sessions and also found that any increase in meal size reduced drinking. Finally, Keehn and Colotla (1970, 1971) concluded that drinking was not related to meal size.

Hymowitz and Freed (1972) proposed that

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session duration may be an important factor when working with session totals because drinking decreases slowly over the session. Reid and Staddon (1982) demonstrated that, indeed, because rats satiate more rapidly when given larger meals, the relation between meal size and drinking in short sessions (using averaged session totals) is positive, whereas long sessions yield a negative relation. The inconsistency between the various studies above could be due simply to the effects of session duration and satiation.

The differential effects of session duration could possibly be eliminated by manipulating meal size across sessions and examining the session dynamics of the meal-size/drinking relation. However, it would be very difficult to equalize across differing meal sizes all factors that might contribute to drinking levels (e.g., hunger level across the session or the time available for drinking to occur) because eating could occupy different proportions of the interfood interval. It is, perhaps, better to manipulate meal size within sessions and measure the dynamics over the session separately for each meal size. In an earlier study, Gilbert (1975) delivered one or five pellets within sessions unpredictably on a fixed-time schedule and found that drinking occurred in a smaller proportion of intervals beginning with five pellets than of intervals beginning with one pellet. He recorded only session totals, so descriptions of the within-session dynamics are unavailable. Reid and Dale (1983) and Reid and Staddon (1982) also manipulated meal size within sessions, although only two meal sizes were delivered in these experiments. They were able to show dynamic changes: Drinking always decreased when meal size was increased within the session. The reductions occurred both within and across fixed intervals. In addition, by manipulating meal size across sessions, they also found that larger meals resulted in more drinking during short- than during long-duration sessions. Hence, they proposed that the relation between meal size and drinking is likely to be an inverted U because of satiation factors. Independent support of this prediction is provided only indirectly by the data of Osborne (1978). He observed an inverted-U relation between general activity and meal size with rats, even though he manipulated meal size across sessions.

Therefore, the present study was designed

to manipulate meal size over a substantial range within sessions, to ensure that equal time was available for drinking after each meal size and that within-session data were fully recorded. We were particularly interested in identifying those behavioral factors that are responsible for the meal-size/drinking relation. Of most interest was the effect of food delivery on subsequent drinking. Thus, the temporal stimuli signaling upcoming food delivery were maintained constant for all meal sizes by delivering the various meal sizes in random sequence according to a variable-time schedule in which the various component intervals were presented in random order. This procedure produced a rectangular frequency distribution of interval duration and a linearly increasing relation between postmeal time and the conditional probability of food delivery at any second given that this postfood second occurred without previous food delivery (Millenson, 1963). We also wanted to see whether this schedule would entrain drinking to postmeal periods and to isolate the factors responsible for the temporal distributions of drinking.

METHOD

Subjects

Four experimentally naive, female Charles River hooded rats approximately 120 days old at the beginning of the experiment were housed individually in one room with continuous light. Their free-feeding weights were determined before training by averaging each subject's weight over 3 consecutive days. Their weights were reduced to 80% of the free-feeding values over a period of 11 days. Body weights were maintained at this 80% level by delivery of Purina Rat Chow several hours after daily sessions. Water was freely available in the home cages.

Apparatus

The octagonal apparatus described by Reid and Staddon (1982) was used with access provided to the feeding area, the center, and the area containing the retractable drinking tube; all other areas were blocked off. The distance between the feeder opening and the tip of the drinking tube was 66 cm. The tip of the metal drinking tube was recessed 0.3 cm behind the clear Plexiglas wall to eliminate extraneous

contacts, and all except the tip was electrically insulated. The contact-lickometer circuitry required less than $0.7 \mu\text{A}$ for operation and could be activated only by contact with the rat's tongue. The apparatus was located in a large sound-attenuating chamber, and white noise (86 db SPL) was present during all sessions. Noyes 45-mg pellets, Formula M, were dispensed in all sessions.

A photocell in the food hopper detected the presence of subject's head in the hopper. A microcomputer recorded every discrete event (licks, head in hopper, head out of hopper) and their times of occurrence with 1/60 s resolution. Subjects were usually monitored informally via closed-circuit television.

Procedure

Sessions were conducted 7 days per week in two phases.

Phase 1. Massed-food baseline: 181 food pellets were available en masse at the beginning of each of 10 30-min sessions.

Phase 2. All subjects were exposed to a variable-time (VT) schedule of food delivery, in which pellet delivery was independent of behavior, with a mean interval duration of 50 s and a range of 1 to 100 s. All interval durations presented in each session were drawn from a rectangular distribution and presented in random order. This distribution also produces a linearly increasing function that relates postfood time with the conditional probability of food delivery at any second, given that this postfood second has occurred without previous food delivery (Millenson, 1963).

The size of each food presentation (each meal) was varied randomly within each session with a range of one to nine 45-mg pellets, with the restriction that each of the nine meal sizes occurred exactly four times in each session, producing 36 intervals. Delivery of the 182nd pellet terminated each session, withdrew the drinking tube, and terminated data recording.

To maintain a constant session duration and a constant food intake per session, but to ensure that subjects did not learn the order of presentation of the interfood intervals or the meal sizes, the 36 interval durations were determined before the experiment began, each was randomly assigned to a meal size, and three sequences of interval presentation were determined. The three sequences of interval presentation with their corresponding meal sizes

are presented in Table 1. The actual sequence used for each daily session for each subject also varied randomly.

In summary, a randomly selected number of pellets (ranging from one to nine) was delivered after a randomly selected interval duration, independent of the subject's behavior. Each session consisted of 36 intervals, 182 pellet deliveries, and lasted exactly 30 min. Pellet deliveries within individual meals occurred at ¼-s intervals, and the pellet dispenser was cleaned regularly to ensure that pellets were always dispensed correctly. All subjects were exposed to this phase for 36 sessions.

RESULTS

Drinking during the intermittent food schedule (Phase 2) was elevated over that in massed-food baseline sessions (MFB) (Phase 1) in all rats. The average number of licks during the last five sessions in both conditions (massed-food baseline in parentheses) for the four rats were: RHF-6: (1,034), 2,110; RHF-8: (978), 1,138; RHF-A: (1,098), 1,493; RHF-C: (992), 1,649.

In Phase 2 time spent drinking and with head-in-feeder became very stable after about 12 sessions and showed no systematic increases or decreases in the subsequent 24 sessions, after which the phase was terminated. Therefore, in Phase 2 all data analysis was carried out on the last 15 sessions for each subject.

Because drinking was measured as discrete licks and head-in-feeder (HIF) was a continuous measure, the raw data from each session were converted to second-by-second bins, each of which could contain only one of three mutually exclusive and exhaustive activities: drinking, HIF, or other unmeasured behavior. Any occurrence of a lick or HIF within any 1-s bin was considered a second of that activity, independent of the number of times it actually occurred within that 1-s bin. On those rare occasions in which licking and HIF occurred within the same second (rare because the drinking tube and the food hopper were 66 cm apart), the last activity within the bin was recorded as the only activity occupying the bin. Because sessions were always of equal duration, they always had precisely the same number of 1-s bins.

In order to assess the amount of drinking for each of the nine meal sizes on the VT

Table 1

Columns represent the order and durations of intervals between meals and the number of pellets in each meal over a complete session. Three random orders of intervals and meal sizes were developed before the experiment began. The order of presentation of the three random orders was randomized with the restriction that each was presented equally often.

Interval number	Random order 1		Random order 2		Random order 3	
	Pellets delivered	Interval duration (s)	Pellets delivered	Interval duration (s)	Pellets delivered	Interval duration (s)
No data collected until second meal delivered						
Begin session	1	37	1	3	1	23
1	9	21	6	33	2	15
2	5	87	9	53	5	47
3	3	53	1	15	4	21
4	9	74	7	74	7	69
5	7	14	3	85	3	14
6	5	96	1	48	4	74
7	2	3	6	50	6	3
8	5	15	3	54	9	37
9	1	47	4	15	3	98
10	7	50	2	48	1	50
11	1	6	5	58	9	58
12	4	92	4	98	8	7
13	8	48	8	50	2	96
14	4	78	3	1	6	14
15	5	7	7	14	1	48
16	8	32	9	87	5	6
17	1	98	3	32	7	86
18	4	1	1	69	8	86
19	3	69	8	48	2	15
20	8	50	7	17	3	78
21	9	15	2	37	4	17
22	2	14	5	78	1	48
23	9	48	9	6	7	40
24	6	86	5	86	9	87
25	1	86	2	40	6	48
26	3	58	4	84	3	31
27	7	23	6	86	5	85
28	4	40	8	14	4	53
29	2	84	4	31	7	33
30	6	17	5	21	1	54
31	8	85	9	7	6	32
32	2	31	8	23	5	1
33	6	4	6	96	8	50
34	3	3	1	47	2	92
35	6	54	7	92	8	84
36	7	100	2	100	9	100
End of session	1		1		1	
Total	182	1,800	182	1,800	182	1,800

schedule, it was necessary to determine the amount of drinking per opportunity to drink; that is, the number of 1-s bins containing drinking divided by the number of occasions that each of those postmeal bins occurred. Because each meal size occurred four times in each session and the data are from the last 15 sessions, the analysis includes 60 postfood intervals for each meal size.

Because postfood interval duration also var-

ied randomly across meal sizes, it was necessary to assess drinking per opportunity across only that portion of the interval that actually occurred after every meal size in all sessions. The longest postfood interval that, in the combined three sequences, occurred at least once after each of the nine meal sizes, was 86 s in duration. Longer intervals often occurred, but they did not follow all nine meal sizes due to the randomization of the relation between in-

Fig. 1. Time spent drinking per opportunity to drink for each of the nine meal sizes. The ordinate measure was calculated as the number of 1-s bins containing drinking divided by the number of occasions that the corresponding postmeal bins occurred, with these proportions summed over the first 86 bins after food delivery. The top four panels contain the data for individual subjects and the bottom panel contains their mean for each meal size.

interval duration and meal size. Therefore, all analysis was restricted to the first 86 s after the last pellet delivery of each meal.

Figure 1 shows the time spent drinking per opportunity to drink during intervals that followed each of the nine meal sizes. Time spent drinking per opportunity (a value between 0 and 1) was calculated for each 1-s postfood bin and summed over the first 86 bins. Thus, if drinking occurred throughout all intervals following a given meal size, the corresponding ordinate value in Figure 1 would be 86. The top four panels contain the data for individual subjects and the bottom panel contains the mean across animals for each meal size. In all cases, more drinking occurred after two-pellet meals than after one-pellet meals, and for Subject RHF-A, drinking reached its highest level after three-pellet meals. After this sharp increase, drinking decreased slowly and irregularly with further increases in meal size, reaching its lowest level after eight- or nine-pellet meals. All subjects showed this increasing-then-decreasing relation between drinking and meal size.

Figure 2 depicts the same analysis for head-

Fig. 2. Time spent with head-in-feeder per opportunity for each of the nine meal sizes. The top four panels contain the data for individual subjects and the bottom panel contains their mean for each meal size. Computational details are the same as for Figure 1.

in-feeder (HIF per opportunity) as a function of meal size. As the top four panels show, HIF increased quite regularly in all rats with increases in meal size.

The drinking/meal-size relation in Figure 1 could result from variation in any of four factors: (a) the percentage of postfood intervals that contained drinking; (b) the amount of drinking within those intervals; (c) the drinking-bout duration after each meal size; or (d) the number of drinking bouts per interval. Therefore, in order to isolate the factors responsible for the increasing-then-decreasing function between drinking and meal size (Figure 1), we examined each of these possibilities.

Figure 3 shows the percentage of the postfood intervals that contained at least 1 s of drinking (the dark lines) and the amount of drinking per opportunity within these intervals (the light lines). The dark lines show that the percentage of the postfood intervals that contained drinking generally decreased as meal size increased. In all cases, as meal size increased, drinking occurred in fewer intervals. The shape and slope of these curves closely resemble the decreasing portion of the drinking/meal-size relation in Figure 1. However, the functions in Figure 3 decrease uniformly and do not show the sudden increase shown

Fig. 3. Percentage of postfood intervals that contained at least 1 s of drinking for each meal size. The dark lines show the percentage of the postfood intervals containing drinking across the nine meal sizes. The light lines show seconds of drinking per opportunity averaged across only those intervals that contained drinking.

by the drinking functions as meal size was increased from one to two pellets.

The light lines of Figure 3 show the number of seconds of drinking per opportunity averaged across only those intervals that actually contained drinking. The amount of drinking within these intervals did not vary systematically across meal sizes. Thus, given that an interval contained some drinking, the amount of drinking did not appear to be influenced by meal size.

The two other behavioral factors that could be responsible for the observed drinking/meal-size relation in Figure 1 are variation in drinking-bout duration and the number of bouts per interval. We defined a drinking bout as a period of uninterrupted drinking, beginning with the first 1-s bin containing drinking following a bin that did not contain drinking and ending with the last consecutive drinking bin which was followed by a bin without drinking. Thus, the criterion for the termination of a bout was 1 s without drinking. This criterion permits the occurrence of multiple drinking bouts within the variable-duration intervals.

Figure 4 shows the mean drinking-bout durations (dark lines) and the mean number of bouts per interval (light lines) for each of the nine meal sizes for all subjects as well as means

Fig. 4. Mean drinking bout durations (dark lines) and the mean number of bouts per interval (light lines) for each of the nine meal sizes for all subjects, and the means across subjects for each meal size.

across subjects. The mean drinking-bout durations did not change systematically across meal sizes; the largest deviation occurred in the two-pellet interval with Rat RHF-C. However, for each rat the mean number of drinking bouts per interval (light lines) systematically decreased with increases in meal size. This decrease resembles both the decreasing limb of the original drinking/meal-size relations from Figure 1 and the decreasing function from Figure 3 representing the percentage of intervals that actually contained drinking.

So far, we have described only data averaged across intervals. Now, we turn to the dynamics of drinking and head-in-feeder within the postfood intervals for each meal size. The left panel of Figure 5 shows the temporal distributions of drinking (per opportunity) across the postmeal interval for the nine meal sizes as well as their average across meal sizes for Subject RHF-6. The right panel shows the same analysis for the HIF measure.

Of the 4 subjects, Rat RHF-6 showed the most pronounced temporal entrainment of drinking by food presentation. Drinking was always postfood, and the onset of drinking occurred later with increasing meal sizes. A comparison of the left and right panels indicates

Fig. 5. The left panels show the temporal distributions of drinking across the postmeal interval for each of the nine meal sizes, and the distribution averaged across meal sizes, for Rat RHF-6. The right panels show the same analysis for the measure of head-in-feeder.

that the increasing delay with larger meal sizes was simply related to the HIF distributions: it took longer to eat more food. In addition, the height of the drinking distributions generally decreased and the width increased with larger meal sizes. The height appears to have increased slightly from one- to four-pellet meals, but decreased rapidly with further increases in meal size. This informal observation of nonmonotonicity is correlated with the increasing and decreasing function of Figure 1 describing drinks per opportunity over meal size for Rat RHF-6.

Figures 6 through 8 show the drinking and HIF distributions for the 3 remaining rats, RHF-8, RHF-A, and RHF-C. The temporal distributions of drinking for RHF-8 (Figure 6) did not show postfood entrainment of drinking. Drinking was nearly as entrained with RHF-A (Figure 7) as it had been with RHF-6, and there is only a slight indication of this entrainment of drinking with RHF-C in Figure 8.

Head-in-feeder distributions were always at maximum magnitude just after food delivery, as might be expected because the sound of food delivery was a perfect predictor of food availability. HIF duration always decreased essentially monotonically after this peak, although RHF-8 showed much more variability in its pattern of food-related behavior than did the other subjects.

DISCUSSION

One of the most widely held hypotheses regarding the causes of schedule-induced drinking is the motivation hypothesis, which assumes that the motivation to drink is positively related to the motivation to eat (Reid & Staddon, in press; Staddon, 1977). That is, larger meal sizes should result in more drinking. This relation has been widely tested by varying meal size across sessions and measuring average amounts of induced drinking over each session, but the results have been inconsistent.

Fig. 6. The left panels show the temporal distributions of drinking across the postmeal interval for each of the nine meal sizes, and the distribution averaged across meal sizes, for Rat RHF-8. The right panels show the same analysis for the measure of head-in-feeder.

Meal-size variation across constant-duration sessions allows animals to eat more with larger meal sizes, reducing hunger levels within sessions. If the motivation to drink is positively related to hunger level, drinking would be facilitated more with larger than with smaller meal sizes only at the beginning of the session (Reid & Staddon, 1982).

We manipulated meal size within sessions to control for any effects of session duration or hunger. The relation between drinking and meal size was an increasing, and then decreasing, function. Thus, it did not support the assumption of a positive relation between the two motivational systems. A similar nonmonotonic relation was also observed by Osborne (1978), who manipulated meal size across sessions and measured general activity rather than drinking. The drinking/meal-size relations in the present study were independent of session duration, because meal size was varied within sessions. However, the relation could, perhaps, differ if the average food rate were varied.

There are relatively few dimensions of the subject's behavior that could account for the observed increasing-then-decreasing relation in Figure 1. These dimensions include (a) the percentage of intervals that contained drinking, (b) the amount drunk within those intervals, (c) the number of drinking bouts per interval, and (d) the duration of each drinking bout. These surely are not independent of one another, because variation in amount drunk per interval could be due to variation in amount drunk per drinking bout.

Figure 3 showed that the percentage of intervals containing drinking (dark lines) decreased systematically with increases in meal size. This decreasing relation closely resembled the decreasing limb of the drinking/meal-size relation in Figure 1. Of course, the amount of drinking within these intervals (light lines) could also be a determinant of the relation, but the amount of drinking (per opportunity per interval that actually contained drinking) did not vary systematically with meal size. How-

Fig. 7. The left panels show the temporal distributions of drinking across the postmeal interval for each of the nine meal sizes, and the distribution averaged across meal sizes, for Rat RHF-A. The right panels show the same analysis for the measure of head-in-feeder.

ever, it is quite possible that the amount of drinking in these intervals (light lines) is responsible for the increasing limb because for each subject there was an increase from the one-pellet meal to the two-pellet meal. This possibility is further substantiated by the observation of further increases in both functions with three-pellet meals for RHF-A.

Other factors may contribute to the drinking functions in Figure 1. For example, drinking occurs in bouts, whose duration or number per interval could vary in some systematic way with meal size. In Figure 4 we saw that no systematic variation of the duration of drinking bouts occurred with increasing meal size. However, for each rat, the mean number of drinking bouts per interval decreased systematically with increases in meal size. This decrease resembles both the decreasing limb of the original drinking functions from Figure 1 and the decreasing function from Figure 3 representing the percentage of intervals that actually contained drinking.

Thus, two behavioral factors varied with meal size in a manner similar to the decreasing limb of the drinking/meal-size relations in Figure 1. As both factors are more molecular measures than the molar averages representing the original functions, we can conclude that either, or both, contribute to the form of the drinking/meal-size relation. Drinking (per opportunity) was reduced after large meals because of reductions in both the percentage of intervals containing drinking *and* in the number of drinking bouts. These two factors are probably related to one another, but it is not possible to identify their relationship from the manipulations in this study. Nor can we determine which factor is more important for the determination of the original drinking/meal-size relations.

The increasing limb of the drinking/meal-size relation appears to result from variation in drinking within those intervals that actually contained some drinking. However, our evidence is rather weak: (a) both functions in-

Fig. 8. The left panels show the temporal distributions of drinking across the postmeal interval for each of the nine meal sizes, and the distribution averaged across meal sizes, for Rat RHF-C. The right panels show the same analysis for the measure of head-in-feeder.

creased together at small meal sizes before dropping off, (b) both functions increased to three pellets per meal only in Rat RHF-A, and (c) none of the other behavioral measures increased after small meals for all subjects. It is not clear why the latter function would affect the original drinking/meal-size relation only after small meals, especially because there was substantial unsystematic variation after large meals.

There are many published studies investigating the S- hypothesis, that is, that schedules must have a period of low, or relatively low, probability of food delivery to induce behavior. In most schedules, the induced activity is entrained in such a way that it occupies periods of consistently low probability of food delivery, although schedules with a very low, albeit constant, probability of food delivery can also induce activities (see Shurtleff et al., 1983, for a review). It is not clear to what extent schedule induction depends upon temporal entrainment by the schedule. For example, food

delivery might entrain the temporal distribution of drinking, or other activities, but not induce it to excessive levels (Porter & Kenshalo, 1974; Reid, Piñones, & Alatorre, 1985; Rosenblith, 1970). Or, a particular schedule might be able to induce drinking to excessive levels, yet be unable to entrain the temporal distribution of drinking (Millenson, Allen, & Pinker, 1977; Plonsky, Driscoll, Warren, & Rosellini, 1984).

Of particular interest are those studies that have explicitly controlled the probability of food delivery over time, such as random-time (RT) schedules in which the probability of food delivery is constant over postfood time (Millenson, 1963). Shurtleff et al. (1983) placed rats on various RT schedules in which the average interval duration was varied from 10 s to 480 s. Polydipsia developed and was maintained on the RT just as on fixed-time (FT) or on variable-time (VT) schedules. Drinking was also entrained by food delivery. This schedule entrainment is particularly in-

Fig. 9. Drinking bout durations as a function of their starting times within the interval for all subjects for one-, five-, and nine-pellet meals. Each point represents a single bout. Data are from the last 15 sessions with four occurrences of each meal size in each one. Thus, each graph shows bouts from 60 intervals for each meal size. More than one bout of drinking could occur in any interval.

teresting because the probability of food delivery at any instant was constant. Thus, no period of the postfood interval had a lower probability than any other period. These data contrast with those Keehn and Burton (1978) who used a random-interval schedule. They found that, although drinking was excessive, it was both postfood and alternated with bar pressing, that is, was not tightly entrained. Millenson et al. (1977) used geometrically random variable-interval (VI) schedules and also found that drinking was not entrained by the random VI. In addition, drinking was not excessive in most of their rats.

We randomized the order of presentations within a set of interval durations between meals, rather than sampling a probability gate every second or so as is more usual. The latter technique produces a constant conditional probability of food delivery at every postfood second, given that the second has occurred without food delivery. Our schedule, however, produced randomly presented intervals sampled from a rectangular distribution of interval

durations. A rectangular distribution created a linearly increasing conditional probability of food delivery with postfood time. Therefore, the sampling technique used in our schedule approximated this linearly increasing conditional probability of food delivery with postfood time, with any deviation from linearity being due to relatively small sample size. (Our samples did include departures from rectangularity of the distribution, with relatively small numbers of intervals in the ranges of 21 s to 30 s and 51 s to 80 s. However, the animals' behavior showed no effects peculiar to those values.) We found that drinking was entrained by our schedule of food delivery in 3 of the 4 rats (cf. Figures 5 through 8), but the form of the drinking distributions varied considerably.

Thus, it is of considerable interest to identify how time differentially influenced the drinking patterns for the 4 subjects. For example, was postfood time an effective stimulus for some rats but not for others, or was it simply a matter of degree? One way of answering this

question is to examine the variations in drinking-bout durations as a function of the time of onset of the bout within the postfood interval.

Figure 9 shows how the bout durations of drinking varied as a function of their starting times within the interval for all subjects for one-, five-, and nine-pellet meals. Each point represents a single bout. Because the data are from the last 15 sessions with four occurrences of each meal size in each one, each graph contains bouts from 60 intervals for each meal size. Each interval could have more than one bout of drinking. With the exception of RHF-8, bout duration generally decreased as its starting time in the interval increased. This decrease was not simply a function of less time available to continue drinking, because (a) only 3.8% of all bouts were interrupted by pellet deliveries, (b) there was no increase in competition from HIF as the session progressed (cf. averaged HIF distributions in Figures 5 through 8), and (c) the duration of drinking bouts was unaffected by increases in meal size (see Figure 4).

The graphs for Rats RHF-6 and RHF-C clearly show the entrained pattern of drinking: There were more bouts early in the interval than late, and bout duration was much longer if it began early in the interval. This observation is true also for RHF-A, but to a lesser degree: Most bouts after one-pellet meals were very short, yet it is apparent that there were many more bouts in the first half of the interval than during the latter half. After nine-pellet meals, bout duration did not appear greatly influenced by its starting time, except for Rat RHF-6.

Bout duration for RHF-8 appeared to be independent of its starting time with all meal sizes; this was the only rat to show this independence. This animal also drank less and had fewer bouts than any of the other subjects.

The entrainment of drinking to the early portions of each interval could be due to at least two factors: Drinking could follow food delivery because of its relation to eating or to reinforcement, or because it is allocated to periods of lowest food probability. Rats could be sensitive to food probability in at least two ways: They could be sensitive to the conditional probability of food delivery at any postfood second, given that the interval has progressed to this postfood second without food (Lashley & Rosellini, 1980), or they could be

sensitive to the average duration of the interfood interval (Shurtleff et al., 1983).

If rats allocate food-related behavior and schedule-induced activities according to the probability of food delivery at each second in the interval, then (in this study in which the probability of food delivery increased with postfood time) drinking should have occupied the earliest portions of the interval and food-related activities should have increased over the interval in anticipation of food delivery. Therefore, of particular interest are the averages of the HIF distributions for each of the subjects shown at the bottoms of Figures 5 through 8. Because the averages of the first half of the interval were means of different temporal distributions offset from one another, they are of no importance. However, the average HIF distributions reached their lowest level over the second half of the interval—they did not increase as the interval progressed in anticipation of upcoming food. Hence, in this study we found no evidence that behavioral allocation over the interval was caused by the conditional probability of food delivery. If the drinking distributions were due, at least in part, to sensitivity to food probability, it seems that the average interfood interval (an average S— period) had the same important role as it has with truly random schedules with a constant (rather than linearly increasing) probability of food delivery at any postfood second (Shurtleff et al., 1983).

REFERENCES

- Allison, J., & Mack, R. (1982). Polydipsia and auto-shaping: Drinking and leverpressing as substitutes for eating. *Animal Learning & Behavior*, *10*, 465–475.
- Couch, J. V. (1974). Reinforcement magnitude and schedule-induced polydipsia: A reexamination. *Psychological Record*, *24*, 559–562.
- Falk, J. L. (1961). Production of polydipsia in normal rats by an intermittent food schedule. *Science*, *133*, 195–196.
- Falk, J. L. (1967). Control of schedule-induced polydipsia: Type, size, and spacing of meals. *Journal of the Experimental Analysis of Behavior*, *10*, 199–206.
- Falk, J. L. (1969). Conditions producing psychogenic polydipsia in animals. *Annals of the New York Academy of Sciences*, *157*, 569–593.
- Flory, R. K. (1971). The control of schedule-induced polydipsia: Frequency and magnitude of reinforcement. *Learning and Motivation*, *2*, 215–227.
- Freed, E. X., & Hymowitz, N. (1972). Effects of schedule, percent body weight, and magnitude of reinforcer on acquisition of schedule-induced polydipsia. *Psychological Reports*, *31*, 95–101.

- Gilbert, R. M. (1975). Meal-size effects on schedule-induced ethanol and water consumption. *Bulletin of the Psychonomic Society*, **6**, 575-577.
- Hawkins, T. D., Schrot, J. F., Githens, S. H., & Everett, P. B. (1972). An analysis of water and alcohol ingestion. In R. M. Gilbert & J. D. Keehn (Eds.), *Schedule effects: Drugs, drinking, and aggression*, (pp. 95-128). University of Toronto Press.
- Hymowitz, N., & Freed, E. X. (1972). Inconstancy of drinking bursts during schedule-induced polydipsia. *Psychonomic Science*, **28**, 283-284.
- Jacquet, Y. F. (1972). Schedule-induced licking during multiple schedules. *Journal of the Experimental Analysis of Behavior*, **17**, 413-423.
- Keehn, J. D., & Burton, M. (1978). Schedule-induced drinking: Entrainment by fixed- and random-interval schedule-controlled feeding. *Tower International Technomedical Journal of Life Sciences*, **8**, 93-97.
- Keehn, J. D., & Colotla, V. A. (1970). Prediction and control of schedule-induced drink durations. *Psychonomic Science*, **21**, 147-148.
- Keehn, J. D., & Colotla, V. A. (1971). Stimulus and subject control of schedule-induced drinking. *Journal of the Experimental Analysis of Behavior*, **16**, 257-262.
- Lashley, R. L., & Rosellini, R. A. (1980). Modulation of schedule-induced polydipsia by Pavlovian conditioned states. *Physiology & Behavior*, **24**, 411-414.
- Lotter, E. C., Woods, S. C., & Vasselli, J. R. (1973). Schedule-induced polydipsia: An artifact. *Journal of Comparative and Physiological Psychology*, **83**, 478-484.
- Millenson, J. R. (1963). Random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, **6**, 437-443.
- Millenson, J. R., Allen, R. B., & Pinker, S. (1977). Adjunctive drinking during variable and random-interval food reinforcement schedules. *Animal Learning & Behavior*, **5**, 285-290.
- Osborne, S. R. (1978). A quantitative analysis of the effects of amount of reinforcement on two response classes. *Journal of Experimental Psychology: Animal Behavior Processes*, **4**, 297-317.
- Plonsky, M., Driscoll, C. D., Warren, D. A., & Rosellini, R. A. (1984). Do random time schedules induce polydipsia in the rat? *Animal Learning & Behavior*, **12**, 355-362.
- Porter, J. H., & Kenshalo, D. R. (1974). Schedule-induced drinking following omission of reinforcement in the rhesus monkey. *Physiology & Behavior*, **12**, 1075-1077.
- Reid, A. K., & Dale, R. H. I. (1983). Dynamic effects of food magnitude on interim-terminal interaction. *Journal of the Experimental Analysis of Behavior*, **39**, 135-148.
- Reid, A. K., Piñones, P., & Alatorre, J. (1985). Schedule induction and the temporal distributions of adjunctive behavior on periodic water schedules. *Animal Learning & Behavior*, **13**, 321-326.
- Reid, A. K., & Staddon, J. E. R. (1982). Schedule-induced drinking: Elicitation, anticipation, or behavioral interaction? *Journal of the Experimental Analysis of Behavior*, **38**, 1-18.
- Reid, A. K., & Staddon, J. E. R. (in press). Mechanisms of schedule entrainment. In S. J. Cooper & C. T. Dourish (Eds.), *Neurobiology of behavioural stereotypy*. Oxford: Oxford University Press.
- Rosellini, R. A., & Burdette, D. R. (1980). Meal size and intermeal interval both regulate schedule-induced water intake in rats. *Animal Learning & Behavior*, **8**, 647-652.
- Rosenblith, J. Z. (1970). Polydipsia induced in the rat by a second-order schedule. *Journal of the Experimental Analysis of Behavior*, **14**, 139-144.
- Shurtleff, D., Delamater, A. R., & Riley, A. L. (1983). A reevaluation of the CS- hypothesis for schedule-induced polydipsia under intermittent schedules of pellet delivery. *Animal Learning & Behavior*, **11**, 247-254.
- Staddon, J. E. R. (1977). Schedule-induced behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*, (pp. 125-152). Englewood Cliffs, NJ: Prentice-Hall.
- Urbain, C., Poling, A., & Thompson, T. (1979). Differing effects of intermittent food delivery on interim behavior in guinea pigs and rats. *Physiology & Behavior*, **22**, 621-625.
- Yoburn, B. C., Cohen, P. S., & Campagnoni, F. R. (1981). The role of intermittent food in the induction of attack in pigeons. *Journal of the Experimental Analysis of Behavior*, **36**, 101-117.
- Yoburn, B. C., & Flory, R. K. (1977). Schedule-induced polydipsia and reinforcement magnitude. *Physiology & Behavior*, **18**, 787-791.

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