Effects of sucrose concentrations upon schedule-induced polydipsia using free and response-contingent dry-food reinforcement schedules

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Food-deprived female albino rats were tested under free (FFI) and lick-contingent (FR) reinforcement schedules in which water was freely available both in the test chamber and the home cage. Five groups of four Ss each received different formulas of Noyes 45-mg dry food pellets during the experimental sessions. Group 1 received standard formula pellets containing 7.5% glucose. Group 2 received "no-glucose" formula pellets. Groups 3, 4, and 5 received "no-glucose" pellets with 4.0%, 16.0%, and 32.0% sucrose added, respectively, by weight. An inverse relationship between sucrose concentration of the pellets and water intake levels was obtained for the FFI 60-sec schedule, and Ss receiving sucrose pellets drank less water throughout all experimental phases than either the no-sugar group or the 7.5% glucose group of Ss. The differential effects of glucose and sucrose upon water intakes and the differences between FR and FFI drinking performances were discussed.

The development of schedule-induced polydipsia (Falk, 1961) is influenced by the size, type, and spacing of meals (Falk, 1967) as well as by their sugar content (Falk, 1967; Segal, Oden, & Deadwyler, 1965; Burks, Hitzing, & Schaeffer, 1967; Christian & Schaeffer, 1973a). Recently, Christian & Schaeffer (1973b) reported an ordered relationship between the sugar content of dry food pellets (i.e., 7.5% glucose, 4.0% sucrose, 16.0% sucrose, and 32.0% sucrose) and the amount of collateral drinking in animals exposed to a food reinforcement schedule. Specifically, using albino rats as Ss and a FFI 60-sec reinforcement schedule in which a food pellet was dispensed each 60 sec independently of the S's behavior, they found that increased sucrose concentration in the food pellets produced a decrease in water intakes.

The present experiment was undertaken to investigate further the relationship between pellet composition and collateral water intakes. The first two phases of the experiment were conducted not only as a direct replication of Christian & Schaeffer's (1973b) experiment but for the purpose of establishing a behavioral baseline for comparing water intakes associated with response-independent and lick-contingent reinforcement schedules. Fixed-ratio schedules for licks have been used previously in schedule-induced polydipsia research and reportedly generate polydipsia as well as licking performances similar to those of other operants on FR schedules (e.g., barpress) (Segal & Deadwyler, 1964; Ten Eyck & Schaeffer, 1969).

During the FFI and FR schedules, one group of Ss received a sugarless pellet (Christian & Schaeffer, 1973a) while Groups 2, 3, 4, and 5 received the sugarless formula with 7.5% glucose, 4.0% sucrose, 16.0% sucrose, and 32.0% sucrose added, respectively, by weight.

METHOD

Subjects

Ss were 20 female Sprague-Dawley albino rats, about 200 days old at the beginning of the experiment. Ss had water freely available in the home cage and in the test chambers throughout the entire experiment.

Apparatus

Five standard LVE Model 1316 test chambers, modified only by the removal of the right lever to allow for the insertion of the drink spout, were used. The tip of the drinking spout, slightly recessed behind a plastic collar used to position the drinking spout in standard position, was located 7 cm to the right of the food magazine and 3.5 cm from the floor of the chamber.

Recording of responses and delivery of Noyes 45-mg pellets were sensed and programmed automatically by standard relay circuitry. Each lick and each food pellet delivery were recorded on cumulative recorders and on an Esterline-Angus digital operations recorder. Water intake during the experimental sessions was recorded by weighing the water bottles before and after the experimental sessions.

Procedure

The 20 Ss were assigned randomly to five pellet formula groups, with four Ss in each group. Each group received a different type of Noyes 45-mg food pellet throughout the experimental sessions. Group 1 received standard formula Noyes pellets that contained 7.5% glucose; Group 2 received Noyes pellets that contained no glucose; Groups 3, 4, and 5 received standard Noyes pellets that contained no glucose but with 4.0%, 16.0%, and 32.0% sucrose added, respectively, by weight.

The experiment consisted of eight phases: (1) preexperimental, (2) baseline, (3) FFI 60-sec condition, (4) individualized FR condition, (5) FR 150, (6) FR 90, (7) FFI 60-sec condition reinstated, and (8) baseline reinstated. Ss remained in the test chamber 1 h and 40 min each session during each experimental phase. During the preexperimental phase, all Ss were given pelleted Purina Lab Chow ad lib in the home cage until free-feeding weights and home cage water intakes stabilized. Ss were then reduced to and maintained throughout the remainder of the experiment at 85% of their free-feeding weights by supplementing food pellets obtained in the test chamber with pelleted Purina Lab Chow given in the home cage about 15 min following each daily test session.

During the baseline phase, all food was removed from the home cage. Magazine training was accomplished by placing 100 pellets of the appropriate Noyes formula in the food magazine before each S was placed in the test chamber on each day of the baseline sessions. The empty feeder was operated on a free-/fixed-interval (FFI 60-sec) schedule, in which the mechanism operated every 60 sec independently of S's behavior.

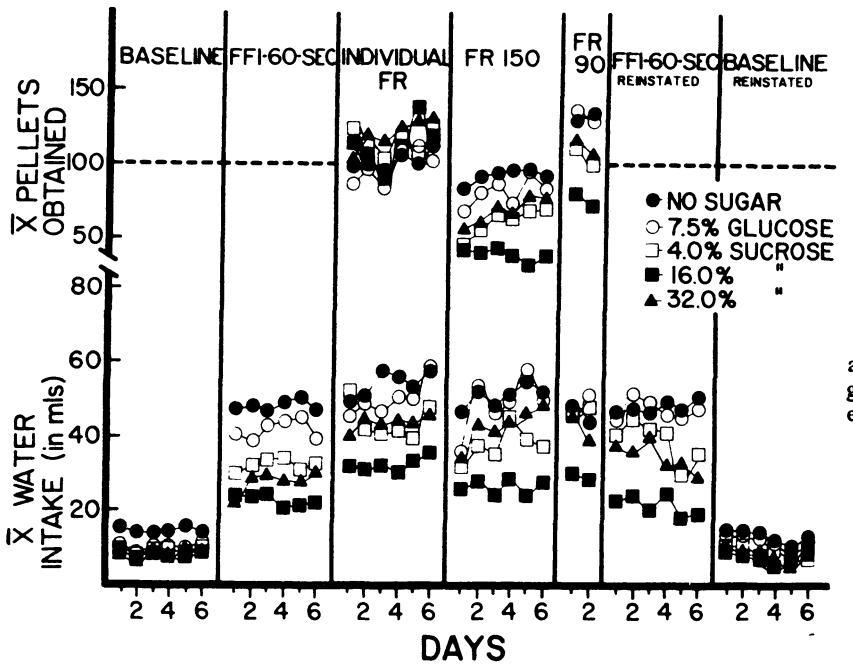

Fig. 1. Mean water intake (in milliliters) and mean pellets obtained for five formula groups throughout all phases of the experiment.

Baseline sessions were continued until water intakes in the test chamber stabilized and Ss regularly ate all 100 pellets in the magazine.

In the first experimental phase, the loaded feeder mechanism dispensed 100 of the appropriate Noyes pellets for each S in each group on a FFI 60-sec reinforcement schedule. This phase continued until water intakes in the experimental chamber stabilized. Ss were then switched to a lick-contingent FR schedule of reinforcement. An individualized FR requirement (FR-Ind) was determined for each S polydipsic on the FFI 60-sec schedule, based on twice its average intake (in milliliters) on that schedule (derived by multiplying 200 licks per milliliter as an approximate lick rate for our Ss by the average number of milliliters consumed by each S during the FFI 60-sec schedule, and dividing this product by 100). The average FFI 60-sec intakes for each group were used in determining the lick ratios for each group's nonpolydipsic Ss. Upon the completion of its FR, each S received one pellet of the appropriate Noyes formula for its group. This phase was continued for 6 days.

During the next experimental phase, Noyes 45-mg pellets of the appropriate formula for each group were delivered upon each S's completion of a FR 150 contingency for licks. This phase was continued for 6 days. In order to investigate the possibility that the FR 150 presented a "strained ratio" for the Ss, a 2-day probe condition was introduced, during which all Ss were switched to a FR 90 schedule during which Noyes 45-mg pellets of the appropriate formula were delivered upon each S's completion of the FR 90 contingency for licks.

The seventh phase of the experiment consisted of a reinstatement of the FFI 60-sec condition until water intakes in the test chamber stabilized at their previous FFI 60-sec levels. In the eighth, and final, phase of the experiment, baseline conditions were reinstated until the water intakes in the test chamber stabilized at their previous baseline levels.

RESULTS AND DISCUSSION

Mean water intakes obtained in the test chamber in all phases of the experiment are presented in Fig. 1. Home cage water intakes are not reported, since these intakes were of the same low magnitude as has consistently been reported in all previous SIP research (cf. Falk, 1961, 1967). Relative to the mean baseline intakes, the FFI 60-sec schedule produced a dramatic increase in the mean water drunk by all groups of Ss. Relative to baseline, elevated intake levels were maintained throughout all three FR conditions. When Ss were returned to the FFI 60-sec condition, mean water intake levels obtained in the original FFI 60-sec condition were recovered. Similarly, when Ss were returned to the baseline condition, mean intake levels obtained in the original baseline were recovered.

Examination of the mean fluid intakes obtained in the FFI 60-sec schedule revealed the same inverse relationship between sucrose content of the pellet and mean fluid intake previously reported by Christian & Schaeffer (1973b). The group that received the sugarless pellet drank more than the group that received the standard Noyes pellet containing 7.5% glucose on the FFI 60-sec schedule, and both of these groups drank more than any of the groups that received pellets containing sucrose. Application of the Kruskal-Wallis one-way analysis of variance by ranks (Siegel, 1956) to the total amount drunk by polydipsic Ss in each group (defined by water intakes in the FFI condition being at least twice as great as in the original baseline condition) indicated a significant difference between formula groups ($H = 11.93$, $df = 4$, $p < .02$).

Application of the Kruskal-Wallis one-way analysis of variance by ranks to the mean intakes of polydipsic Ss on each of the FR conditions indicated a significant difference between formula groups on the FR 150 condition ($H = 13.46$, $df = 4$, $p < .01$), but a statistically nonsignificant difference between groups on the Fr-Ind condition ($H = 5.16$, $df = 4$, $p > .05$) and the FR 90 condition ($H = 3.44$, $df = 4$, $p > .05$). Analysis of the

mean intakes of polydipsic Ss on the reinstated FFI 60-sec condition (Phase 7) indicated a significant difference between formula groups ($H = 15.84$, $df = 4$, $p < .01$). In addition, application of the McNemar test (Siegel, 1956) for the significance of changes between mean intakes of polydipsic Ss on the original and mean intakes on the reinstated FFI 60-sec schedules indicated that mean intakes did not differ between these conditions ($\chi^2 = 1.14$, $df = 1$, $p > .05$).

The statistically significant inverse relationship between sucrose concentration of the food pellets and the water intake levels of polydipsic Ss on both original and reinstated FFI 60-sec conditions was not found for water intakes generated by the FR-Ind, FR 150, and FR 90 schedules. Although the introduction of the response contingency affected the magnitude of the water intakes of the polydipsic Ss in the 4.0%, 16.0%, and 32.0% sucrose groups, the Ss in the no-sugar and 7.5% glucose groups drank more fluid, throughout all three FR conditions, than did the sucrose groups.

Figure 1 also presents the mean number of pellets obtained by each group of Ss during all experimental phases. During the baseline and FFI 60-sec conditions, all Ss in each group received 100 pellets of the appropriate Noyes formula. During the FR-Ind condition, no significant relationship between the pellet formula delivered and the number of pellets earned by the Ss was found. However, there was an obvious relationship between the FR requirement imposed on the Ss and the number of pellets earned, i.e., Ss with low individual ratios (typically the nonpolydipsic Ss from the FFI 60-sec condition) earned more pellets than did Ss with high FRs. During the FR 150 schedule, an ordered relationship was evident between the sucrose composition of the pellets and the number of pellets earned. Ss receiving sugarless pellets, on the average, earned more pellets than Ss receiving pellets with either sucrose or glucose added. The significance and generality of this relationship is questionable, however, since this relationship was not found on the FR 90 schedule.

Examination of the relationship between mean licks and mean milliliters of fluid consumed for each S on the last 2 days of each experimental phase revealed a consistently high positive correlation (rho) between the two. Correlations between mean licks and mean milliliters ingested of .91 for the baseline condition, .80 for the FFI 60-sec condition, .77 for the FR-Ind, .92 for the FR 150, and .57 for the FR 90 were obtained.

These findings suggest that rats display two kinds of lick behaviors under response-independent as opposed to lick-contingent dry food reinforcement schedules. Namely, in the former, Ss appear to lick-to-drink, since the number of licks are highly correlated with amount consumed (.80), whereas in the latter, they show a lick-to-eat pattern in which the correlation between the number of licks and amount drunk is lowered (.77, .57). It is interesting to note that this relationship was evident for the low FR requirements but not for the FR 150 contingency.

Specifically, the FR 150 represented an average increase of 61.20 licks per pellet (range 44-128) over the FR-Ind contingency. According to motivational explanations for the development of schedule-induced polydipsia, an emotional state produced in the animal by intermittent or spaced food presentation results in increased drinking behavior (e.g., Segal et al, 1965; Falk, 1964; Denny & Ratner, 1970). Denny & Ratner (1970) have referred to polydipsia under intermittent reinforcement conditions as "displacement activity" elicited by frustration. Such an explanation is supported by the FR 150 licking performances of rats in the present study.

A motivational analysis of the results of the present study would maintain that an emotional state produced by the "low-ratio" schedule of reinforcement (i.e., FR-Ind) was increased as the spacing of food pellets was increased by switching Ss to a "high-ratio" reinforcement schedule (FR 150). Such an explanation is supported by the relatively high (.92) correlation between licks and milliliters consumed under the FR 150 condition, i.e., increase in milliliters consumed between pellets as a function of increased frustration produced by having to wait longer between pellets. Further support is provided by the licking performances of the same Ss when returned to a "low-ratio" (FR 90) schedule of reinforcement. Decreased fluid consumption on the FR 90 was indicated by the lowered correlation between licks and amount consumed (.57).

These data suggest a relationship between FR schedule demands and the amount of water consumed per lick by food-deprived rats. Such a relationship can be interpreted as evidence that the efficiency of the rat's operant licking response is related to the amount of frustration produced by the intermittent reinforcement schedule. Clearly, if an explicit lick contingency is arranged, it is more economical for the S to drink less as it licks. It would appear, however, that under the FR 150 contingency Ss licked-to-drink (inefficiently) rather than licked-to-eat (efficiently), as was indicated by their performances on the FR-Ind and FR 90 schedules.

The lick-to-drink characteristic of the FR 150 licking performances is further illustrated by a comparison of the correlations between licks and amount consumed for the FR 150 and baseline conditions. The original baseline condition must be considered a lick-to-drink situation since licking (drinking) typically occurred only after the Ss' eating of the 100 pellets in the food magazine. The .92 correlation between licks and amount consumed compares favorably with the correlation of .91 for the FR 150 condition. It would appear, therefore, that although the FR 150 was programmed as a lick-to-eat contingency, the frustration produced by its increased schedule demands resulted in the Ss' lick performances being more representative of a lick-to-drink contingency. In addition, when the FR 150 is considered a lick-to-drink contingency, data are consistent with the suggestion that correlations between

licks and amount consumed will be high for the lick-to-drink conditions (i.e., baseline, FFI 60-sec, and FR 150) and relatively low for the lick-to-eat conditions (i.e., FR-Ind, FR 90).

The results are further interpreted as direct support for the findings of Christian & Schaeffer (1973b) concerning the significant relationship between the sucrose concentration of dry food pellets and the water intakes generated on a FFI 60-sec schedule of reinforcement. The polydipsic intakes generated by the lick-contingent FR schedules support Christian & Schaeffer's (1973b) observation that sugar in a Noyes pellet, whether it is glucose or sucrose, results in reduced fluid intakes relative to those obtained using Noyes sugarless pellets. Additionally, the present experiment has presented further evidence that the type of sugar contained in the food pellet (i.e., glucose or sucrose) has a definite effect on the water intake levels produced by free and response-contingent schedules. Specifically, Ss receiving the standard 7.5% glucose pellet consumed more water than Ss receiving sucrose pellets throughout the experiment. This difference between sugars, as well as the effects of the sugars themselves, is a relevant concern for future research in SIP, since previous investigators have mistakenly used sucrose pellets containing glucose (Burks et al, 1967) and have introduced sucrose pellets after generating SIP using pellets containing glucose (Falk, 1964).

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