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Development of bingeing in rats altered by a small operant requirement

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HIGHLIGHTS

- Response cost attenuates binge-type eating.
- Binge size is context and response-cost dependent.
- Extended shortening abstinence does not increase binge size.
- 24-h food-deprivation increases binge size.
- A history of home cage access alters subsequent operant performance.

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ABSTRACT

Previous studies have shown that providing an optional food for a brief period of time to non-food deprived rats on an intermittent basis in the home cage engenders significantly more intake (binge-type behavior) than when the optional food is provided for a brief period on a daily basis. Experiment 1 examined the effects of placing a small operant response requirement on access to an optional food (vegetable shortening) on the establishment of binge-type behavior. Experiment 2 examined the effects of different schedules of reinforcement, a period of abstinence from shortening, and 24 h of food deprivation on established binge-type behavior. In Experiment 1 the group of rats with 30-min access to shortening on an intermittent basis in their home cages (IC) consumed significantly more shortening than the group with 30-min daily access in the home cage (DC). The group with 30-min intermittent access in an operant chamber (IO group) earned significantly more reinforcers than the group with 30-min daily access in an operant chamber (DO). In Experiment 2, the IO group earned significantly more reinforcers than the DO group regardless of the response cost, the period of shortening abstinence, and overnight food deprivation. These results demonstrate that while intermittent access generates binge-type eating, the size of the binge (intake) can be altered by different contingency arrangements.

1. Introduction

Binge eating in humans is defined as consuming more food in a discrete period of time than would normally be consumed during the same period of time under similar circumstances accompanied by a sense of loss of control during the binge episode [1]. A behavioral model of binge-type eating in non-food deprived rats has been developed in which intermittent (Monday, Wednesday, Friday) access to an optional food provided in the home cage for a brief period of time from 20 min [2] to 2 h [3] promotes significantly greater (excessive) intake relative to daily access for the same brief period. These optional foods have included vegetable shortening containing trans fat [4], vegetable shortening devoid of trans fat [5], lard [6], liquid sucrose [7], different concentrations of semi-solid fat emulsions [8], different concentrations of fat/sucrose dispersions [9], and different fat concentrations in emulsions made with different biopolymers [10].

While this animal model has examined bingeing primarily in the home cage context, several studies have also examined operant performance after the establishment of bingeing in the home cage where either shortening [11–13], or cocaine after a history of shortening intake, [14] served as the reinforcer. Common to all of these studies is the finding that the intermittent groups earned significantly more reinforcers (either shortening or cocaine) than the daily groups under a variety of different schedules of reinforcement. Additionally, the number of shortening reinforcers earned during a session (i.e., amount of shortening consumed) is less than the amount of shortening that is normally consumed in the home cage. Furthermore, both the intermittent and daily groups consume additional shortening in the home cage 30–40 min after an operant session. This finding indicates that the rats are

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not sated during the operant sessions and the requirement of an operant contingency reduces shortening intake relative to home cage access.

The present study addressed two questions. The first was whether bingeing on shortening will develop or be altered when rats without a history of intermittent access to shortening in the home cage are required to lever press for a specified amount of shortening per delivery from the start of the study. Stated otherwise, would adding a small response requirement (Fixed Ratio 1) prevent the development of bingeing in the intermittent operant group relative to the daily operant group, and would intake in the operant chamber equal intake in the home cage? The second question was whether altering environmental contingencies (schedules of reinforcement, abstinence from shortening and 24-hr food deprivation) would alter binge-type behavior.

2. Material and methods

2.1. Animals

Forty eight male Sprague Dawley (Harlan, Indianapolis, IN) rats, 60 days of age and weighing 277–310 g (295.8 ± 0.97 g) at the start of the study, were individually housed in hanging stainless steel wire cages in a temperature- and humidity-controlled environment placed on a 12:12 light:dark cycle in the same animal colony room. All rats had continuous access to tap water and to a nutritionally complete commercial laboratory rodent chow (Laboratory Rodent Diet 5001, PMI Feeds, Richmond IN; percent of calories as protein: 28.05%, fat: 12.14%, carbohydrate: 59.81%; 3.3 kcal/g) placed in hanging metal food hoppers at the front of the cage throughout the study, except for 2–3 sessions when two groups were trained to lever press in an operant chamber. All rats were allowed to adapt to the vivarium and light cycle for 7 days prior to the start of the study. All procedures were approved by the Pennsylvania State University Institutional Animal Care and Use Committee.

2.2. Operant chambers

Rats were tested in twelve identical operant chambers (Model H10-11R-TC; Coulbourn Instruments, Allentown, PA) located in a room adjacent to the vivarium. The back wall of each chamber contained a house light (Model H11-01R) located at the top of the middle panel of the chamber. The front wall of each chamber contained a response lever (Model H21-03R) located in the middle panel and a triple cue lamp (H11-02R) located above it. Located in the right panel was a lip to collect shortening delivery and a triple cue light above the tray to indicate shortening delivery. Whipped vegetable shortening was used as the reinforcer for lever pressing. Whipped shortening was delivered in 0.1 g units from a 20 ml glass syringe (Popper & Sons, New Hyde Park, NY) driven by an infusion pump (Model E73-01-3.3 rpm) into a receptacle located below the triple cue lamp adjacent to the response lever. Care was taken to minimize any air pockets in the 20 ml syringe that would affect the amount delivered. This was accomplished by placing whipped shortening into a self-lock plastic bag and then squeezing the shortening into a 60 ml syringe. 20 ml of shortening from the 60 ml syringe was then squeezed into a 20 ml syringe. The plunger of the 20 ml syringe was then used to compact the shortening up to the 20 ml marker thereby removing air pockets. The presence of air pockets in the 20 ml syringe affects the amount of shortening delivered. Without the removal of air pockets reinforcer magnitude would randomly change throughout the session. When a reinforcer was scheduled to be delivered all three cue lamps flashed for 2 s prior to the start of the reinforcer delivery, during the 2 s while the whipped shortening was being delivered, and for 1 s after the delivery. All experimental contingencies were programmed with Graphic State 2™ state notation (Coulbourn Instruments, Allentown, PA).

2.3. Establishment of shortening as a reinforcer

In order to establish shortening as a reinforcer [15–16] all rats were provided with solid vegetable shortening (Crisco® All-Vegetable shortening, J.M. Smucker Co., Orrville, OH) in glass jars clipped to the front of the cage for three overnight periods. Each period was separated by 24 h without shortening available. Following the three overnight access periods, all rats were then provided with daily 1-hr access to shortening in their home cages for seven consecutive days. Body weights were recorded on the eighth day. Four groups (N = 12 each) were then matched by body weight (group ranges 323.8 g ± 3.1 to 325.6 g, ±2.9) [($F(3,47) = 0.10$, $p = 0.9570$] and perfectly matched on the average amount of shortening consumed (group ranges 2.2 g ± 0.4 to 2.2 g ± 0.3) for the last three days [($F(3,47) = 0.0$, $p = 1.000$].

2.4. Operant training procedure

After grouping the rats, one group was allowed to adapt to the operant chamber for one, 1-h session and then overnight food-deprived. They were then trained to consume 0.1 g of shortening delivered from a syringe every 40 s for 30 min and were provided 5–7 g of chow after the session. During the next one to two sessions all rats were trained to lever press with 0.1 g of shortening serving as the reinforcer. After lever pressing was established, all rats were returned to ad libitum chow for 3 days. On the fourth day, they were overnight food deprived again and placed on a Fixed Ratio 1 (FR1) schedule of reinforcement. Following this session they were then returned to ad libitum chow for the remainder of the study. This procedure was then repeated for a second group of rats. After all lever press training was completed, these two groups of rats had at least 7 days of ad libitum chow with no shortening available before the start of the experimental procedures. The other two groups of rats were not given shortening during the lever press training of the first two groups of rats and were also food deprived (15 g chow) for two successive days in tandem with each of the operant groups. The 15 g of chow had the approximate caloric value of 3 g of shortening plus 7 g of chow received by the operant groups during training. In summary, food deprivation was imposed during the lever training sessions and all rats had ad libitum access to chow for the remainder of the study with the exception of the last condition of the study.

For the entire study, either chow was singularly available or shortening was singularly available, but not both at once. Stated otherwise, chow hoppers were removed for all groups during home cage shortening access, and chow/food pellets were not available during operant sessions.

2.5. Experiment 1

2.5.1. Home cage access vs. operant access

Seven days following lever press training one of the two non-lever trained groups was provided 30-min of shortening access in their home cages on an intermittent basis (Mondays, Wednesdays, and Fridays [MWF]) for the remainder of the experiment and was designated "IC". The second non-lever trained group was provided 30-min of shortening access in their home cages on a daily basis (7 days/week) for the remainder of the experiment and was designated "DC". These two groups were considered control groups for any effects of time across the 8 weeks of the study, and to be sure that this batch of rats responded as has been reported previously to the limited access protocol.

One of the groups trained to lever press was exposed to 30-min operant sessions on an intermittent basis (MWF) for four weeks under a FR1 schedule of reinforcement, and was designated as "IO". The other group trained to lever press was exposed to 30-min operant sessions on a daily basis (7 days/week) under a FR1 schedule of reinforcement and was designated as "DO". During these 4 weeks the only shortening the two operant groups consumed was that which they earned in the operant chambers, i.e., no additional shortening was provided in the

home cages after an operant session. These 2 groups were considered the experimental groups in these studies.

Shortening was provided 1 to 2 h prior to the start of the dark cycle. The IC group received their shortening while the IO group was in the operant chambers, and the DC group received their shortening while the DO group was in the operant chambers. The IO and DO groups alternated as to which group started first on Mondays, Wednesdays and Fridays.

2.5.2. Home cage access

After the fourth week of the study, the two operant groups were no longer placed in the operant chambers and shortening was provided in their homes cages for three weeks (weeks 5 through 7) on the same presentation basis as the non-lever trained home (IC and DC) groups.

2.5.3. Home cage access vs. operant access

After the home cage exposure to the bingeing protocol, the IO and DO groups were again placed on a FR1 schedule of reinforcement for 30-min sessions for one week (week 8) on either an intermittent or daily basis, respectively. This was done in order to determine if the history of home cage access would influence subsequent operant responding. In summary, an ABA design was used for the operant rats (IO and DO groups): A) FR1; B) home cage access; A) FR1. The IC and DC groups were maintained under home cage access throughout the experiment.

2.5.4. Statistics

The number of reinforcers earned was multiplied by 0.1 (0.1 g/reinforcer delivery) in order to obtain intake in grams for the operant groups. These data were then converted to kcal and normalized to body weight$^{0.67}$ [17], in order to facilitate comparisons across weeks, while controlling for the possible influence of body weight gain across the study. Weekly averages utilized the M, W, and F data for both the 30-min home cage and 30-min operant sessions for respective groups.

Separate 2-way analyses of variance (ANOVA) were used to assess differences between groups and across time in the IO and DO groups, and in the IC and DC groups. Significant differences within weeks between IO and DO groups, and between IC and DC groups, were then determined using 2-tailed independent t-tests. Differences within each group across weeks were determined by 1-way repeated measures ANOVA, followed by Tukey's Studentized Range (HSD) test.

A two-way repeated measures ANOVA (3-minute bin X group, with bin as the repeated measure) was used to analyze the distribution of reinforcers across the operant sessions for weeks 4 and 8 (pre- and post-home cage access) in the IO and DO groups. Two-tailed independent t-tests were then used to determine significant differences between IO and DO groups within each bin. Repeated measures 1-way ANOVA was used to assess differences among conditions within each group, followed by Tukey's HSD. Total reinforcers for all three of the Mon., Wed., and Fri. sessions in week 4 and in week 8 were used in these analyses.

3. Results (Experiment 1)

3.1. Operant groups

Intakes of the IO and DO rats differed both within and among weeks (main effect of access schedule $F(1,22) = 12.01$, $p < 0.01$; main effect of week $F(7, 154) = 25.98$, $p < 0.0001$; interaction $F(7154) = 2.29$, $p < 0.05$; see Fig. 1, Top panel). Specifically, the intermittent group consumed significantly more shortening during the operant sessions than the daily group in every week of the study except week 5, when the conditions were switched from operant sessions to home cage access (2-tailed independent t-tests, $p < 0.05$ for all, except week 5). Thus, bingeing, operationally defined as Intermittent intake > Daily intake, occurred even when a small response requirement was imposed.

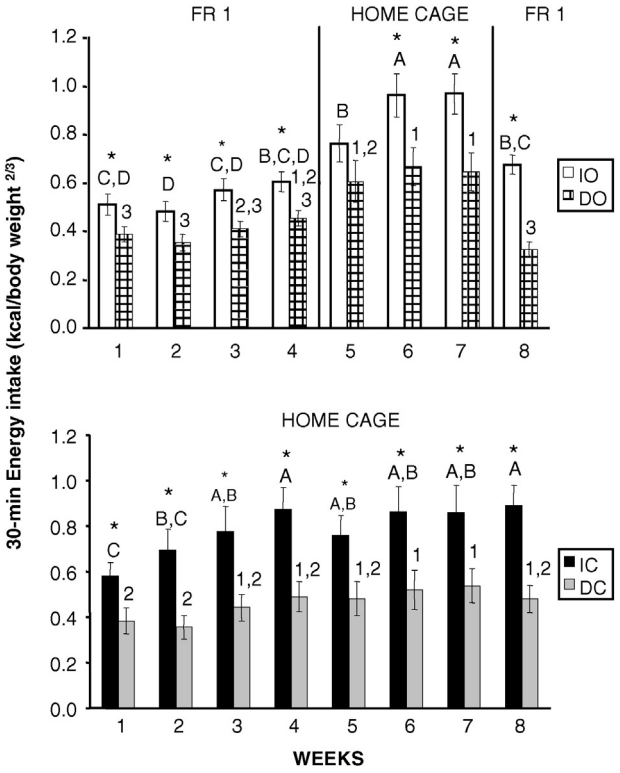

Fig. 1. Shortening intake (Experiment 1). Top panel: Shortening intake during operant sessions or in the home cage for the IO and DO groups. Asterisks indicate significant differences between the groups within each week. Different letters indicate significant differences among weeks for the IO group; different numbers indicate significant differences among weeks for the DO group. Bottom panel: Shortening intake in the home cage for the IC and DC groups. Asterisks indicate significant differences between the groups within each week. Different letters indicate significant differences among weeks for the IC group; different numbers indicate significant differences among weeks for the DC group.

However, across the initial FR1 period (weeks 1–4), there was no significant escalation of intake [18], in either group (see Fig. 1, Top panel). Thus, bingeing, operationally defined as an escalation of intake did not occur.

When the shortening was available in the home cage and the operant response was no longer required, intake in the IO group increased significantly relative to week 4 (the last week of the initial FR1 period). This did not occur in the DO group. Although intake in the DO group increased slightly in the home cage context, this was not significantly different from intake during week 4 of the operant context. In short, only the IO group responded significantly to the removal of the FR1 response requirement.

Finally, when the rats were returned to the operant context in week 8, intake in both groups decreased significantly (relative to week 7), and returned to levels that were not significantly different from those of week 4 (the last week of the initial FR1 period). That is, after a history of free access, the imposition of a small response requirement reduced consumption in both groups [1-way repeated measures ANOVA for weekly effects: IO $F(7,77) = 23.69$, $p < 0.0001$; DO $F(7,77) = 7.96$, $p < 0.0001$; Tukey's HSD $p < 0.05$ for significant differences among weeks].

3.2. Home cage groups

Intakes of the IC and DC rats also differed both within and among weeks, but unlike the operant rats, the changes across weeks were similar between these groups (main effect of access schedule $F(1,22) = 8.43$, $p < 0.01$; main effect of week $F(7, 154) = 11.14$, $p < 0.0001$; no interaction; see Fig. 1, Bottom panel). Specifically, the intermittent home cage group consumed significantly more shortening than the daily

home cage group in every week of the study indicating that this batch of rats responded to intermittency in a manner consistent with our previous reports [e.g.,3,18] (2-tailed independent t-tests, $p < 0.05$ for all).

Across the initial FR1 period (weeks 1–4), there was a significant escalation of shortening intake [18] in the intermittent group (IC), but not in the daily group (DC), (see Fig. 1, Bottom panel). [1-way repeated measures ANOVA for weekly effects: IC $F(7,77) = 7.92$, $p < 0.0001$; DC $F(7,77) = 4.21$, $p < 0.001$; Tukey's HSD $p < 0.05$ for significant differences among weeks.] Thus, bingeing, when defined as an escalation of intake occurred in the IC group.

Relative to week 4, intakes in the IC and DC groups did not significantly change for the remainder of the study. This indicates that the changes that occurred in the IO and DO groups (above) were not a function of time, but were due to the changes in the context governing shortening availability.

3.3. Distribution of reinforcers; pre- and post-home cage access

Prior to home cage access, there were no differences in the distribution of reinforcers throughout the session between the IO and DO groups. Although the IO group earned significantly more reinforcers overall (main effect of group $F(1,22) = 7.00$, $p < 0.02$), the differences between the IO and DO groups within each bin were not significant (interaction NS; t-tests NS). For both groups more reinforcers were earned in earlier bins than in later bins (main effect of bin $F(9198) = 26.35$, $p < 0.0001$; Top panel Fig. 2).

After home cage access, there were differences in the distribution of reinforcers throughout the session between the IO and DO groups (interaction between group and bin $F(9198) = 2.39$, $p < 0.02$), due to the fact that the IO group earned significantly more reinforcers during bin 3 ($p < 0.001$), bin 5 ($p < 0.01$), bin 6 ($p < 0.0001$), bin 7 ($p < 0.05$), and bin 8 ($p < 0.01$). Main effects were similar to those obtained prior to home cage access, i.e. the IO group earned significantly more reinforcers overall (main effect of group $F(1,22) = 44.96$, $p < 0001$) and both groups earned more reinforcers in earlier bins (main effect of bin $F(9198) = 26.35$, $p < 0.0001$; Bottom panel Fig. 2).

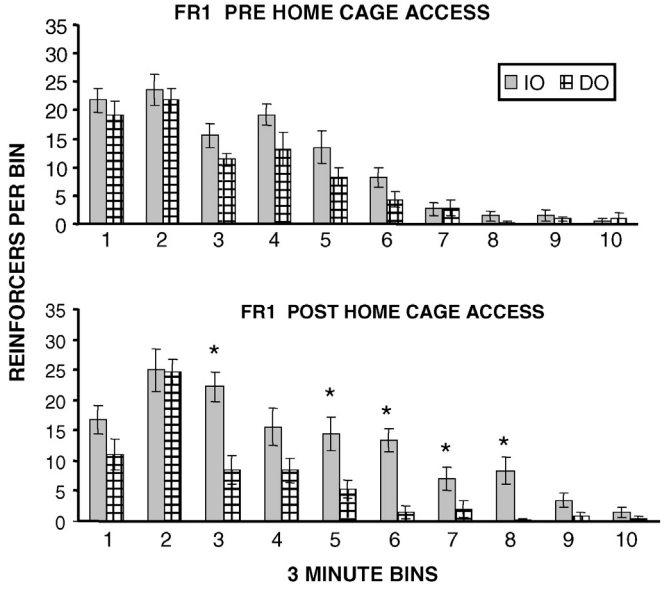

Fig. 2. Distribution of reinforcers pre- and post- home cage access (Experiment 1). Top panel: Distribution of reinforcers for the IO and DO groups earned in 30-min operant sessions prior to home cage access, expressed in 3-min bins averaged over the last 3 sessions. Bottom panel: Distribution of reinforcers for the IO and DO groups earned in 30-min operant sessions after home cage access, expressed in 3-min bins averaged over the last 3 sessions. Asterisks indicate significant differences between the groups in a 3-min bins.

4. Discussion (Experiment 1)

The results from Experiment 1 present several new findings.

1) The IO group consumed significantly less shortening under the FR1 schedule than under home cage access. That is, binge size was attenuated when a small response requirement (FR1) was placed on access to an optional food (shortening). Despite the change in the amount of shortening consumed, the IO groups still consumed significantly more shortening than the DO group. However, the difference in binge size was a function of the presence or absence of a small response requirement.
2) With respect to the IC and DC groups that had only home cage access, the IC group always consumed significantly more shortening than the DC group during all 8 weeks. Furthermore, only the IC group showed an escalation in shortening intake during weeks 1–4. Both the significantly greater consumption of shortening than the daily group and the pattern of intake escalation have been considered indices of binge-type behavior in rats [18].
3) There were significant differences in home cage shortening intakes between the IC and DC groups and between the IO and DO groups from the start of the study, i.e., week 1. This result was surprising in that the occurrence of binge-type behavior at least in the home cage from the start of the first week has only been reported in one other study [4]. Typically, binge-type behavior emerges some weeks later in the protocol [e.g.,2,3]. What differed between this study and previous reports is that all of the rats in the present study were provided with daily 1-hr home cage access for seven days prior to the start of the study to establish shortening as a reinforcer for operant responding. These results further exemplify the concepts of establishing operations [15] and potentiating variables [16]. For example one can establish or potentiate the value of a stimulus through a variety of procedures such as deprivation, access time, fading procedures or making the emission of one behavior contingent upon another [19].
   The present results in rats are also consistent with clinical recommendations in the treatment of human eating disorders. For example, the systematic incorporation of 'forbidden' foods into the diet is recommended in the treatment of bulimia nervosa, not their elimination, due to concern that attempts to restrict such foods can exacerbate the very disorder the intervention seeks to treat [20]. That is, after a history of consuming readily available and easily accessible foods, the removal of those foods may result in even greater consumption when they can be obtained in another environment.
4) The pattern of operant responding was affected by a history of home cage access. Prior to home cage access, there were no differences between the IO and DO groups in the distribution of reinforcers earned throughout the sessions as measured by 3-min bins. However, after home cage access the IO group earned significantly more reinforcers than the DO group in several of the 3-min bins. This latter result of a differential distribution of reinforcers is similar to the differential distribution of reinforcers under progressive ratio schedules after those groups had a history of home cage access [13].

The above results showed that the shortening intake was affected by the response cost associated with consuming it. The differences in intake in weeks 6 and 7 vs. weeks 4 and 8 in the operant rats was clearly due to the changes in contingencies, not the passage of time, since intakes among these weeks in the home cage groups did not differ. These results are similar to a previous study in which bingeing on liquid sucrose also depended on the response cost associated with consuming it [7]. In that study, when a small sipper tube (30 cm^3 sucrose/30 cm^3 air) was used, the intermittent access group consumed no greater an amount of 10% sucrose than the daily group, i.e., no bingeing. However, when a larger sipper tube (30 mL sucrose/70 mL air) was used, the intermittent group consumed significantly more sucrose than the daily group, i.e., they binged. It was suggested that in a closed system, the

2.5× increase in air volume exerted a greater pressure on the sucrose, thus increasing the volume per lick, i.e., decreasing the response cost.

The intake of shortening for the DO group across the operant chamber and home cage contexts is different from the results of a study that compared 24-hr access to chow under free-feeding conditions and when a FR1 response cost was imposed [21]. While there was an increase in the number of short pauses in feeding when the operant requirement was imposed, the chow intake for both conditions was identical. In the present study, shortening intake in the DO group significantly decreased in week 8 when a response cost was again imposed after a period of free access. The differences in our results and those of [21] may be due to the fact that shortening in the present study was provided in addition to chow, whereas in the previous study [21], chow was the only food available.

Experiment 2 addressed whether altering environmental contingencies (schedules of reinforcement), abstinence from shortening and 24-hr food deprivation would also alter shortening intake under intermittent and daily conditions within the operant context.

5. Experiment 2

5.1. Animals

The IO and DO groups from Experiment 1 served as subjects. One of the IO subjects died in the middle of the experiment; as a result this subject's data are not included in the analysis of the last 5 conditions.

5.2. Re-establishment of lever pressing

In previous studies where shortening served as a reinforcer in non-food deprived rats [11–13] experimental sessions were conducted on Mondays, Wednesdays and Fridays for both the intermittent and daily groups, and supplemental shortening was provided to both groups post session for 30 min, starting 40 min after the operant sessions. On the other non-operant days of the week, only the daily groups were provided home cage access to shortening for 30 min. Experiment 2, in part, mimics these procedures in that supplemental shortening was provided after an operant session.

In the present experiment, both groups were exposed to the following sequence of reinforcement schedules for a minimum of six sessions: FR1, Variable Interval 5″ (VI5″; 1–10 s range), Random Ratio 5 (RR5; 1 to 10 response range), and VI5” to assess the effects of response cost on operant performance. Stability criteria for these sessions were defined as 3 consecutive sessions with no significant differences in the number of earned reinforcers within the groups.

Following the above series of exposures, both groups were maintained on chow only for 3 weeks. Previous research in the home cage context [4] showed that after a period of shortening abstinence, shortening intake increased on the first exposure after the abstinence in both intermittent and daily groups, but the intermittent access group still consumed significantly more shortening on this day than the daily group.

After 3 weeks of shortening abstinence in Experiment 2, both groups were exposed to a VI5” schedule of reinforcement. After six sessions of exposure to the VI5″ schedule of reinforcement, the effects of 24-hr food deprivation were assessed. Both groups were 24-hr food-deprived prior to only the first VI5″ session. The VI5″ schedule of reinforcement was in effect with no food deprivation for six additional sessions. These manipulations addressed the issue of shortening deprivation (abstinence) versus energy deprivation (caloric).

5.3. Statistics

2-way repeated measures ANOVAs (group X condition) were used to assess the number of reinforcers earned by each group under the first 4 conditions (FR1, VI5″#1, RR5, VI5″#2), and under the last 5 conditions (VI5″#2, VI5″ on the first post-abstinence day, VI5” averaged over the last 3 sessions post-abstinence, VI5” on the first day post-food-deprivation, VI5″ averaged over the last 3 sessions post-food-deprivation). Two-tailed independent t-tests were used to determine differences between groups within each condition. Repeated measures 1-way ANOVA followed by Tukey's HSD was used to determine significant differences among conditions.

6. Results (Experiment 2)

During the first 4 conditions, IO earned significantly more reinforcers under all conditions than DO [main effect of group $F(1,22) = 63.88$, $p < 0.0001$; 2-tailed independent t-tests $p < 0.05$ for all.] In addition, responding in both groups varied among conditions as a function of schedule value [main effect of condition $F(3,66) = 26.42$, $p < 0.0001$] (Fig. 3, Top panel). Specifically, responding under RR5 was significantly lower than the other three conditions (Tukey's HSD $p < 0.05$).

During the last 5 conditions, IO continued to earn significantly more reinforcers than DO [main effect of group $F(1,21) = 37.84$, $p < 0.0001$], and responding in both groups varied among conditions [main effect of condition $F(4,84) = 23.16$, $p < 0.0001$]. However, unlike the first 4

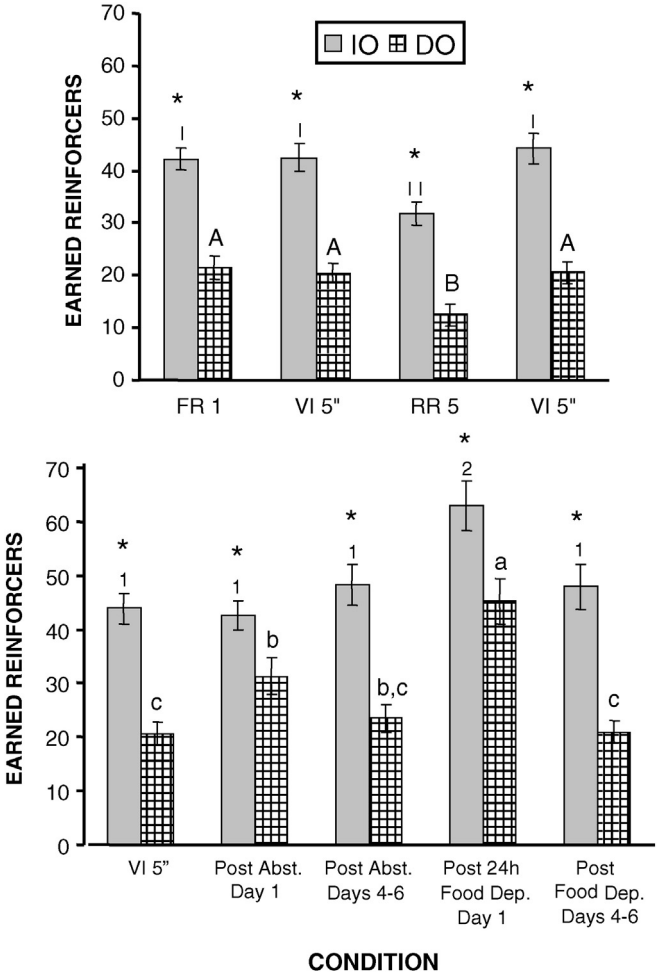

Fig. 3. Earned reinforcers under different conditions (Experiment 2). Top panel: Average number of reinforcers earned by the IO and DO groups under several different schedules of reinforcement. Asterisks indicate significant differences between the IO and DO groups within each schedule. Different Roman numerals indicate significant differences among schedules in the IO group; different capital letters indicate significant differences among schedules in the DO group. Bottom panel: Average number of reinforcers earned by the IO and DO groups under several different conditions. Asterisks indicate significant differences between the IO and DO groups within each condition. Different numbers indicate significant differences among conditions in the IO group; different small letters indicate significant differences among conditions in the DO group.

conditions, there was an interaction between group and condition [$F(4,84) = 2.91$, $p < 0.03$] as the groups responded differently to the various conditions. Both groups earned significantly more reinforcers on the first day after 24-hr food-deprivation relative to all other conditions ($p < 0.05$, Tukey's HSD). However, only the DO group earned significantly more reinforcers on the first day after a 21-day shortening abstinence period ($p < 0.05$, Tukey's HSD; Fig. 3 Bottom panel).

7. Discussion (Experiment 2)

The present findings showed that the groups differed in their responses to shortening abstinence, but responded similarly in response to changes in response cost and food deprivation. However, regardless of conditions, the intermittent (IO) group always earned significantly more shortening than the daily (DO) group. Increasing the response cost under the RR5 significantly decreased shortening intake in both groups and food deprivation significantly increased intake in both groups relative to the other schedules. The intake for the first day of post abstinence had no effect on the IO group, but significantly increased intake on the DO group. In short, both groups appeared to be sensitive to changes in the environmental contingencies, but to somewhat different degrees with respect to experimental procedures.

8. Main discussion

In addition to the findings discussed above, several other points merit consideration. The FR1 requirement not only placed a small response cost on obtaining shortening, but also limited the amount of shortening per presentation relative to the home cage and changed other variables. For instance, in the home cage context the subject determined the topography of consuming shortening, e.g., scooping it up with its paws, licking it, "teething" it. In the operant context the only topography available was to lick the shortening from the stainless steel tip of the glass syringe. In the home cage context the subject determined the amount of shortening per consummatory response. In the operant context the amount of shortening per reinforcer delivery was 0.1 g. In the home cage context the subject had more control over the rate of consumption, but in the operant context the rate of consumption was slowed down by the subject having to press the lever, wait for the shortening to be extruded from the syringe, consume it, and then go back to the lever to press again and repeat the cycle. Numerous research studies have examined the effects on food intake of manipulating the time between food pellets in animals and of altering the amount of food per bite as well as requiring pauses between bites in humans.

In animal studies, for instance, short delays between food pellet deliveries (no operant response required) decreased meal size, [22–24] while longer delays produced little additional decrease in meal size [23]. At shorter delays, meal frequency increased [22,24], but at longer delays, meal duration increased. In short, total food consumption remained unchanged over the long run, but the pattern of consumption changed.

The human literature is less clear. While bite size has been reported to alter meal duration [25], others have reported that slower rates either increase [26] or decrease [27] total amount consumed. Given the disparity of results between the human and animal literature, it is at best difficult to tease apart those environmental/behavioral variables regulating optional food intake. What is apparent is that both organisms come into a study with a history of a pattern of food intake that is both physiologically and behaviorally regulated by its consequences.

While the present study demonstrated that a small response requirement can attenuate binge size relative to home cage access when intermittent access is provided, bingeing still occurred in the IO group relative to the DO group. The question remains "What is it about intermittency that generates excessive intake both in the home cage and operant contexts"? In the operant literature there are several contingency arrangements that, in part, involve intermittency and generate excessive behavior regardless of the topography or response class. For example intermittent (60 s) pellet presentations in an operant chamber to food-deprived rats, whether response independent (Fixed Time) or response dependent (Fixed Interval), generate several classes of excessive behavior that have been labeled "schedule-induced" or "adjunctive". Some of the earliest identified classes of behaviors included polydipsia, [28], air-licking [29] wheel running [30,31], wood chewing [32], and defecation [33] among others. This literature is large and several interpretations have been presented to account for the occurrences of excessive behaviors in the context in which they occur, but without any resolution [34,35]. However, a more recent analysis of the adjunctive behavior literature [36] has led the authors to propose that adjunctive behaviors are operants in that the proximity between the response and reinforcer rather than contingency or contiguity is the key principle of association. This proposal would then suggest that bingeing in the current model might be considered as an operant (adjunctive?) behavior regardless of home cage or operant context in that both contexts occur near the time (2 h prior to the start of the dark cycle) when there is a high probability of circadian rhythm-induced food intake. In a home cage environment, rats tend to start to nibble at food prior to the start of the dark cycle, and engage in their first bout of food intake shortly after the start of the dark cycle [21,37]. Placing them in an operant chamber and requiring a small response cost simply alters the response requirement. What is different is the schedule of access, i.e., daily vs. intermittent, relative to the circadian rhythm of food intake.

Another possible variable that may start to address the question of "What is it about intermittency that engenders excessive behavior" has recently been proposed. Since intermittency presents the organism with uncertainty regarding what, when, and how much of the highly acceptable optional food is available, it has been suggested that neural mechanisms may account for the generation of excessive behavior in uncertain circumstances [38]. A recent study attempted to address the possible contribution of uncertainty to binge-type eating [13]. In that study, presentations of shortening in the home cage were made uncertain (unpredictable) for one intermittent group and certain (predictable) for another intermittent group Both of these groups consumed significantly more shortening in the home cage than the daily group. However, the group with uncertain intermittent home cage access earned significantly more reinforcers under a variety of schedules of reinforcement than either the certain intermittent access or daily access groups. This result suggests that intake in the home cage does not predict operant performance and that the variable of certainty/uncertainty may influence binge-related behavior when a response cost is imposed on obtaining a preferred commodity, i.e., behavioral context is important. The concepts of certainty/uncertainty may also be a factor influencing the occurrence of adjunctive behaviors as mentioned above.

One final concept that bears mentioning is the notion of the "behavioral stream". as characterized under the Tee–Tau Systems [39]. The main point of the "behavioral stream" is that the organism is always behaving or emitting classes of behavior regardless of their consideration by the experimenter. The experimenter intrudes into that behavioral stream, choosing a specific response class (R) for consideration and more often than not, ignoring all other response classes that are not under consideration (NOT R). However, the relationship between "R" and "Not R" as conceived by the experimenter may not necessarily be the same relationship as viewed by the organism. As such, the protocols that generate binge eating and adjunctive behavior, and the proposed explanations for those behaviors (e.g., intermittency or uncertainty) may not coincide with the "true explanations" that are told to us by the organism. As eloquently stated by Schoenfeld & Farmer [40]. "To speak of the behavioral stream is to speak of the behavioral context in which an observed R occurs."

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