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Reinforcement value of sucrose measured by progressive ratio operant licking in the rat

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Abstract

Progressive ratio (PR) schedules, which require increasing numbers of responses for successive reinforcements, are widely used to measure the reward value of foods, fluids, and drugs in operant lever-pressing tasks. The present study evaluated a PR operant licking task as a measure of sweet taste reward. In Experiment 1, food deprived rats were offered sucrose to drink on PR lick or fixed ratio (FR) lick schedules (30 min/day). In Experiment 2, nondeprived rats were offered sucrose to drink on PR or FR schedules and free access to water and food 23 h/day. In both experiments, the FR rats increased and then decreased their sucrose solution intake as concentration increased from 1% to 32% or 64%. The PR rats, in contrast, showed a near-linear increase in sucrose solution intake, lick rates, and break points (highest ratio completed) as a function of sucrose concentration. The PR rats drank less sucrose than did the FR rats although they emitted more total licks at the highest concentration tested. These results are similar to those reported with PR lever-pressing tasks. Thus, PR operant licking, which requires minimal training and equipment, is a useful alternate measure of fluid reward in rodents.

Keywords: Bottle tests; Operant licking; Progressive ratio; Fixed ratio; Reward value

1. Introduction

Various operant procedures are used to measure the reinforcement value of foods, fluids, and drugs in animals with the most common one being lever pressing on some partial reinforcement schedules. Different schedules of reinforcement have been used for this purpose and many recent studies, particularly those involved with drugs of abuse, have involved some form of a progressive ratio (PR) schedule [1,14,17,22]. With this schedule, the response requirement to obtain successive reinforcements increases according to some rule throughout the test session until the subject stops responding. The highest ratio completed in the session is referred to as the "break point" and provides a measure of reinforcer value. The PR schedule was first introduced by Hodos [9] in a study of lever pressing by rats for milk rewards. He reported a near-linear relationship between the concentration of the milk solution and the magnitude of the break point. More recently, Reilly [16] documented that PR performance provides a measure of the reward value of taste stimuli. Rats lever pressed for brief access (2 s) to a sipper spout containing preferred (sucrose or saccharin) or unpreferred (sodium chloride, citric acid, and quinine) solutions on a PR-3 schedule in which the response requirement increased by three for each successive reinforcement. As the concentration of sucrose or saccharin increased, the PR break point increased; whereas as the concentration of sodium chloride, citric acid, or quinine increased, the break point value decreased.

In a variation of the typical PR operant task, McGregor et al. [13] combined an operant lick procedure with a PR schedule to compare the reinforcement value of sucrose and beer in rats. In this case, rats licked at a sipper spout that provided 0.1 ml units of liquid reinforcement on a exponential PR schedule. The schedule was designed so that the rats would reach a break point before consuming enough solution to be satiated. The results revealed that rats displayed comparable total licks and lick break points for 8.6% sucrose and beer (2.7% ethanol). Other studies from the same laboratory used the PR lick schedule to evaluate drug effects on the rat's motivation to drink beer [7,8]. Potential advantages of an operant lick task over a lever-pressing task

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are that it does not require special training because licking is a natural response of rats and, in principle, can be conducted in the animal's home cage as well as in operant test cages. However, it is not known if PR licking shows the same sensitivity to variations in reinforcement value as does PR lever pressing [9,16]. Note that whereas the lever-pressing task involves two spatial locations (the operant lever and reward spout), the operant lick task used by McGregor et al. [13] involved a single location and the operant and consummatory responses are the same, i.e., licking. The present study sought to determine if PR licking produces concentration–response functions similar to those previously observed with lever-pressing tasks for sucrose solutions over a wide range of concentrations.

In Experiment 1, operant licking was measured in test cages during short-term sessions (30 min/day), which are typical for operant experiments. The rats were food restricted and were given their food ration and ad libitum water in their home cages after the daily sessions. As in the prior PR lever-pressing study using sucrose rewards [16], the PR session was terminated after the animal stopped responding for 3 min. In Experiment 2, rats were tested in their home cages with 23 h/day access to food, water, and a sucrose solution available on an operant PR licking schedule. In both experiments, the rats were first given traditional two-bottle choice tests between water and sucrose solutions at various concentrations and then divided into two groups equated for their sucrose preference. The impact of a PR schedule on sucrose intake and licking was then determined in one group while the second group was tested with a fixed ratio (FR) licking schedule designed to approximate normal licking from a drinking bottle.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Sixteen adult male Sprague–Dawley rats born in the laboratory from stock obtained from Charles River Laboratories (Wilmington, MA) were used. The rats were singly housed in a vivarium under a 12:12 h light–dark cycle at 21 °C and were fed powered chow (No. 5001, PMI Nutrition International, Brentwood, MO) and tap water.

2.1.2. Apparatus

The animals were tested in eight identical drinking cages ($23 \times 24 \times 31.5$ cm) located in a room adjacent to the vivarium. Fluid was available from one or two stainless steel sipper spouts through holes at the front of the cages. The sipper spouts were attached to motorized retractor units (ENV-252M, Med Associates, Georgia, VT) that automatically positioned the spouts at the front of the cages at the beginning and withdrew them at the end of the test session. Licking behavior was recorded using electronic drinkometers and a microcomputer. During initial training, the sipper spouts were attached to bottles. During the operant phase of the experiment, each sipper spout was connected via tubing to a 30 ml syringe mounted in a syringe pump (A-99, Razel Scientific Instruments, Stamford, CT) set at a 1.3 ml/min pump speed. The Tygon tubing (06419-14, Cole Parmer, Chicago, IL) was fitted into the sipper spout and held in place with plastic ties. As the animal licked on the sipper spout, the microcomputer counted all licks and every 3 s turned the syringe pump on if the accumulated licks equaled or exceeded the FR or PR requirement. In this case, the pump remained on for 3 s delivering approximately 0.065 ml of solution to the tip of the drinking spout, and the rat's lick "counter" was reduced by the FR or PR lick requirement.

2.1.3. Procedure

The rats were familiarized with sucrose by giving them overnight access to a 4% sucrose solution (w/v) in addition to water and food in their home cage. They were then adapted to the test cages by housing them overnight in the cages with access to 4% sucrose, water, and chow. The sucrose and water sipper spouts were attached to bottles and were inserted at the front of the test cages for 30 min every hour. The rats were then food restricted and maintained at 90% of their ad lib body weight for the remainder of the experiment.

The rats were adapted to drink 4% sucrose in the test cages during four daily 30-min sessions. They were then given two 30-min sessions each with sucrose at concentrations of 1%, 2%, 4%, 8%, 16%, and 32% (w/v) in that order. During these sessions, the sipper spouts were attached to bottles containing the appropriate sucrose solution. The sipper spouts were then connected to the syringe pumps and the rats were given another three sessions (30 min/day) with 4% sucrose available on a FR schedule of 20 licks (FR-20) for each 0.065-ml reinforcement. The rats were then divided into two groups ($n = 8$ each) equated for body weight and their intakes of sucrose solutions during the bottle and FR licking sessions. The two groups were then tested, for three 30-min sessions each, with sucrose solutions of 1%, 2%, 4%, 8%, 16%, 32%, and 64%, in that order, delivered to the sipper spouts by the syringe pumps. The rats in the FR group continued to have the sucrose solutions available on the FR-20 lick schedule, and sipper spouts remained available throughout the 30-min sessions. The rats in the PR group were tested with a PR schedule (PR-1) in which the number of licks required to obtain successive sucrose reinforcements was increased by 1 starting at 20 licks, i.e., 20, 21, 22, 23, etc. If the rat stopped licking for 3 min, the sipper spout was retracted for the remainder of the 30-min session.

Sucrose solution intakes (ml) during the bottle tests were averaged over the two sessions at each concentration. The intake and lick data during the operant tests were averaged

over the last two sessions at each sucrose concentration. These data were evaluated using analysis of variance; individual differences were evaluated with simple main effects and Newman–Keuls tests. The lick break point was defined as the highest ratio schedule completed by rats on the PR schedule.

2.2. Results

Fig. 1 summarizes the intake data from the sucrose bottle tests. The intakes of the two groups, which were treated identically in these tests, were well matched and changed as a function of sucrose concentration [$F(5,70) = 89.258$, $P < .001$]. In particular, the concentration-intake profile of the rats was $1\% < 2\% < 4\% < 8\% \leq 16\% > 32\%$ where $<$ and $>$, but not $\leq$, indicate significant differences at $P < .05$. When next tested with a range of sucrose concentrations in the operant licking tests, the rats in the FR group consumed substantially more sucrose than did the rats in the PR group [$F(1,14) = 84.601$, $P < .001$], and the difference increased with concentration [$F(6,84) = 29.978$, $P < .001$; Fig. 2A]. As in the bottle tests, the FR rats increased and then decreased their sucrose solution intake with increasing concentration ($1\% < 2\% < 4\% \leq 8\% \geq 16\% \geq 32\% > 64\%$). In contrast, the PR rats increased their sucrose solution intake as concentration increased ($1\% \leq 2\% < 4\% < 8\% \leq 16\% \leq 32\% \leq 64\%$). Overall, the groups did not differ in their total 30-min licks, but there was a Group × Concentration interaction [$F(6,84) = 13.741$, $P < .001$]. As illustrated in Fig. 2B, the PR rats emitted fewer ($P < .05$) licks than did the FR group at sucrose concentrations of 4–16%, an equal amount at 32%, and more ($P < .05$) licks than the FR group at the 64% concentration. The lick break points of the PR group also increased with sucrose concentration [$F(6,42) = 44.048$, $P < .001$]. Fig. 3 plots the lick break point data along with the break point data reported by Reilly [16] for food-restricted rats lever pressing for sucrose at concentrations

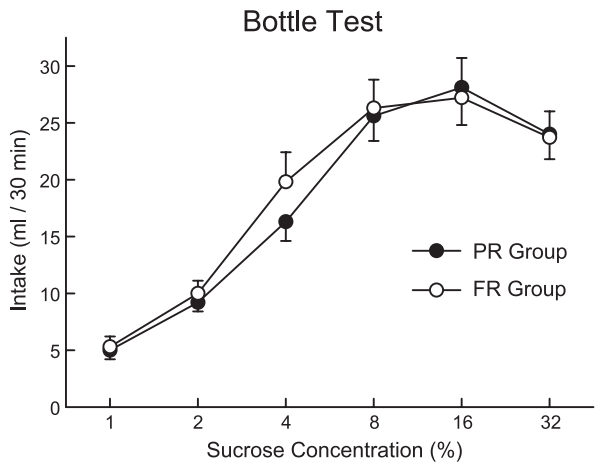

Fig. 1. Mean (±S.E.) sucrose solution intakes of PR and FR groups during 30 min/day bottle tests at concentrations of 1–32%. The groups were treated identically in these tests.

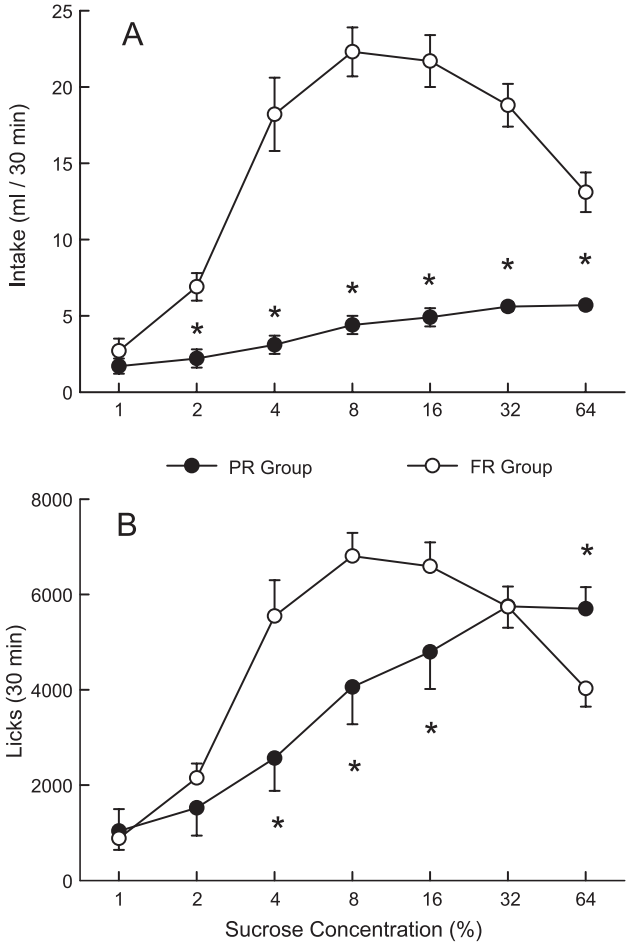

Fig. 2. Mean (±S.E.) sucrose solution intakes (A) and licks (B) of PR and FR groups during 30 min/day operant lick tests at concentrations of 1–64%. The PR rats were tested with a PR-1 schedule while the FR rats were tested with an FR-20 schedule for successive sucrose reinforcements. An asterisk denotes a significant ($P < .05$) difference between the PR and FR groups.

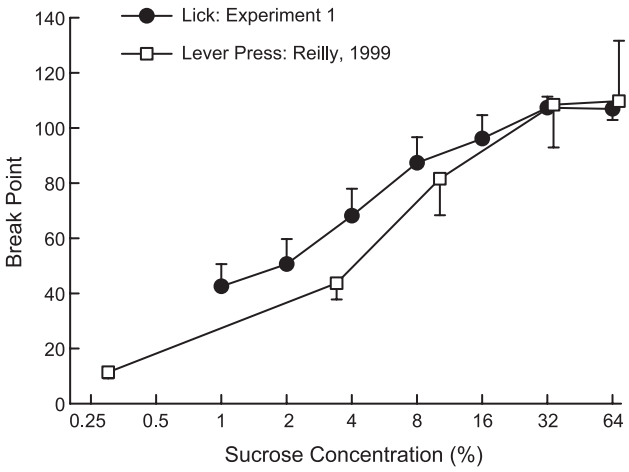

Fig. 3. Mean (±S.E.) break point values of PR group during 30 min/day operant lick tests at concentrations of 1–64%. Also shown are the mean (±S.E.) break point values reported by Reilly [16] for rats lever pressing for sucrose at concentrations of 0.01–2 M.

of 0.01 (.34%) to 2.0 M (68%). The lick break points differed as a function of concentration according to the following pattern: $1\% \leq 2\% < 4\% < 8\% \leq 16\% \leq 32\% \leq 64\%$, and $8\% < 32\%$, and 64%, where < indicates a difference at the $P < .05$ level. Reilly [16] reported a similar statistical pattern over a comparable range of concentrations expressed here on a w/v basis: $0.3 < 3\% < 9\% \leq 34\% \leq 68\%$, and $9\% < 68\%$.

3. Experiment 2

3.1. Method

3.1.1. Subjects

Twenty adult male Sprague–Dawley rats of the previous description were used. The rats were given ad libitum access to powdered chow and water.

3.1.2. Apparatus

The rats were housed in modified stainless steel cages (24 × 18 × 18 cm) that provided ad libitum access to chow in a food cup accessible through a hole in the back wall of the cage. Drinking fluid was available from two stainless sipper spouts located through two small holes (19-mm diameter) at the front of the cage. Licking behavior was recorded by electronic drinkometers and a microcomputer. During the operant phase of the experiment, one sipper spout on each cage was connected via Tygon tubing to a peristaltic pump (7021-20 and 7543-06 pump head and drive, Cole Parmer) with a pump rate of approximately 1.6 ml/min. The second sipper spout was attached to a water bottle. As in Experiment 1, the microcomputer counted all licks and every 3 s turned the pump on if the accumulated licks equaled or exceeded the FR or PR requirement. In this case, approximately 0.08 ml of sucrose solution was delivered to the tip of the sipper spout during the 3-s period.

3.1.3. Procedure

The rats were adapted to the living cages for 4 days with food and water available ad libitum. They were then given 23 h/day two-bottle tests with water and sucrose at concentrations of 1%, 2%, 4%, 8%, 16%, and 32%, in that order. The solutions were prepared on a w/w basis because intakes were measured in grams. Each concentration was presented for 2 days with the left–right position of the sucrose and water bottles alternated daily. The rats were then divided into two groups equated for sucrose intake, water intake, and body weight. A second set of choice tests was conducted with water versus sucrose at 1–32% concentrations (3 days at each concentration). In these operant lick tests, the sucrose was pumped into the sipper spout after the rats emitted the required number of licks, whereas water was available through a sipper spout attached to a bottle. The rats in the FR group were required to lick 20 times for each 0.08 ml sucrose reward. The rats in the PR group were tested on a PR-0.5 schedule in which the ratio requirement incremented by one after every second reinforcement; i.e., 20%, 20%, 21%, 21%, 22%, 22%, 23%, 23%, etc. This more slowly rising schedule was used because of the long session length. The sucrose sipper spouts remained available for both the FR and PR groups throughout the 23 h/day test sessions; water and food were also available ad libitum.

3.2. Results

In the two-bottle sucrose versus water choice tests, the intakes of the PR and FR groups, which were treated identically, were well matched (Fig. 4). The rats consumed almost no water in these tests and sucrose solution intake varied as a function of concentration [$F(5,90) = 272.595$, $P < .001$]. The sucrose intake-concentration pattern was $1\% \leq 2\% < 4\% < 8\% = 16\% > 32\%$, where < and >, but not ≤, indicate significant differences ($P < .05$).

As indicated in Fig. 5, the PR and FR groups differed substantially in their sucrose solution and water intakes during the operant licking tests [$F(1,18) = 20.017$, $P < .001$]. At all concentrations, the FR rats consumed more sucrose solution and less water than did the PR group [Group × Solution intake $F(1,18) = 97.428$, $P < .001$]. Analysis of the FR data revealed that the rats drank more sucrose solution than water at all concentrations, although the difference was not significant at 1% [Fluid × Concentration interaction, $F(5,45) = 25.679$, $P < .001$]. Percent of total intake consumed as sucrose ranged from 69% to 95% as concentration increased from 1% to 32%. In contrast, the PR rats consumed more ($P < .05$) water than sucrose solution at 1–4% concentrations, comparable amounts at the 8% concentration, slightly more sucrose at the 16% concentration, and significantly ($P < .05$) more sucrose than water at the

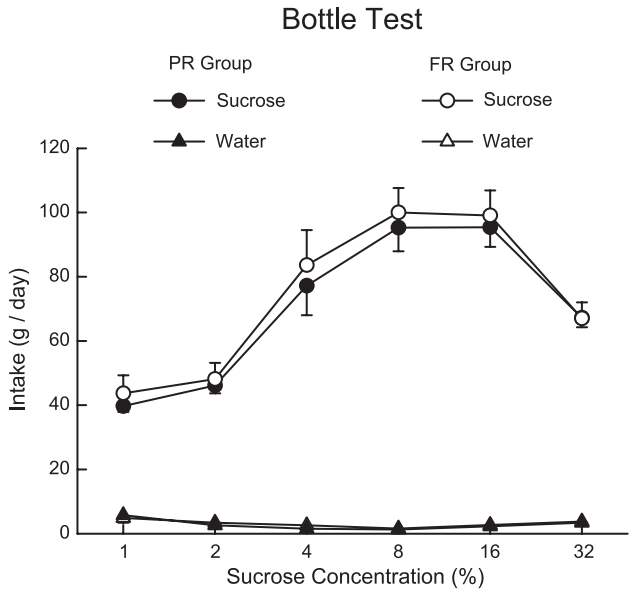

Fig. 4. Mean (± S.E.) sucrose and water intakes of PR and FR groups during 23 h/day two-bottle tests at sucrose concentrations of 1–32%. The groups were treated identically in these tests.

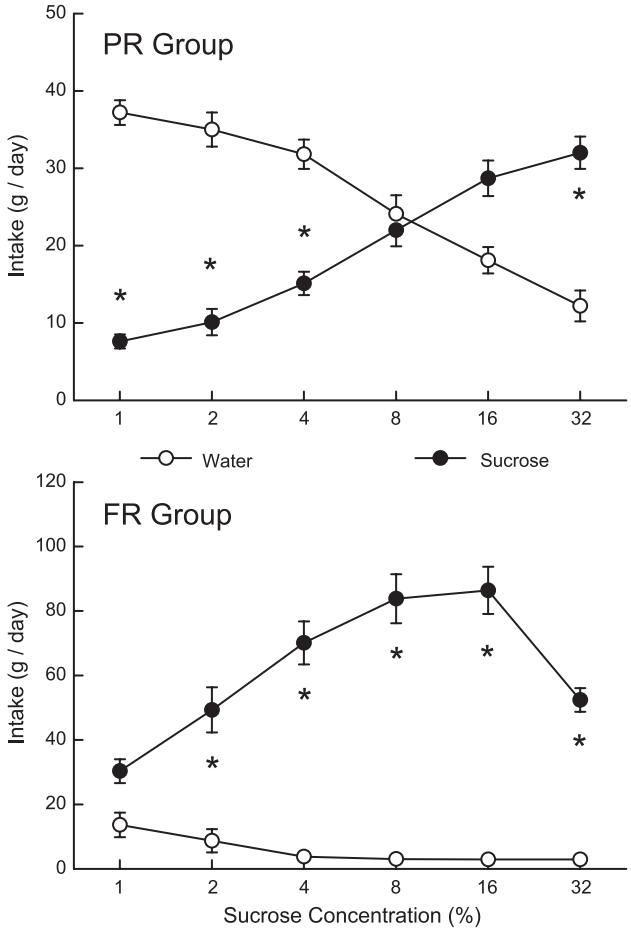

Fig. 5. Mean (±S.E.) sucrose solution and water intakes of PR (top) and FR (bottom) groups during 23 h/day operant lick tests at sucrose concentrations of 1–32%. The PR rats were tested with a PR-1 schedule while the FR rats were tested with a FR-20 schedule for successive sucrose reinforcements. Water was freely available from a bottle. The asterisk denotes a significant ($P < .05$) difference between the sucrose and water intakes.

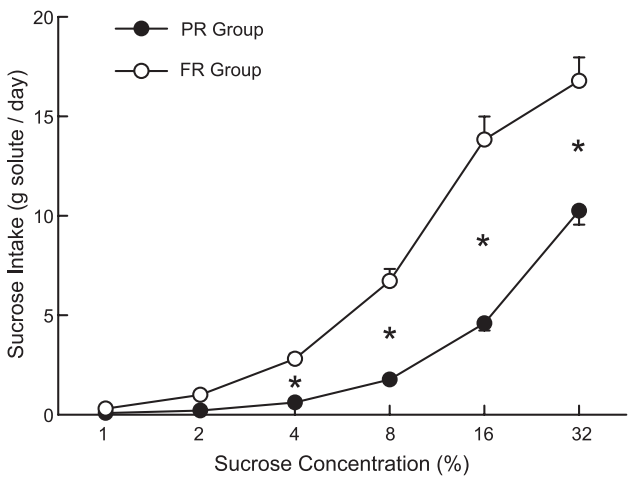

Fig. 6. Mean (±S.E.) sucrose solute intakes of PR and FR groups during 23 h/day operant lick tests at sucrose concentrations of 1–32%. The PR rats were tested with a PR-1 schedule while the FR rats were tested with a FR-20 schedule for successive sucrose reinforcements. The asterisk denotes a significant ($P < .05$) difference between the PR and FR groups.

32% concentration [Fluid × Concentration interaction, $F(5,45) = 82.778$, $P < .001$]. The percent sucrose intakes of the PR rats increased from 17% to 72% as sucrose concentration increased from 1% to 32%. A different pattern of results was obtained when sucrose intake was expressed as grams of solute rather than solution. As illustrated in Fig. 6, sucrose gram intake increased in both FR and PR groups as a function of concentration [$F(1,18) = 52.553$, $P < .001$], and the PR rats consumed less ($P < .05$) sucrose than FR rats at concentrations of 4% and higher [Group × Concentration interaction, $F(5,90) = 30.522$, $P < .001$].

Overall, the groups did not differ in total sucrose licks emitted during the operant lick tests, but there was a Group × Concentration interaction [$F(5,90) = 21.858$, $P < .001$]. In particular, the FR rats licked more ($P < .05$) for 2% and 4% sucrose, while the PR rats licked more ($P < .05$) for 32% sucrose (Fig. 7A). As indicated in Fig. 7B, the lick break points of the PR rats increased with sucrose concentration

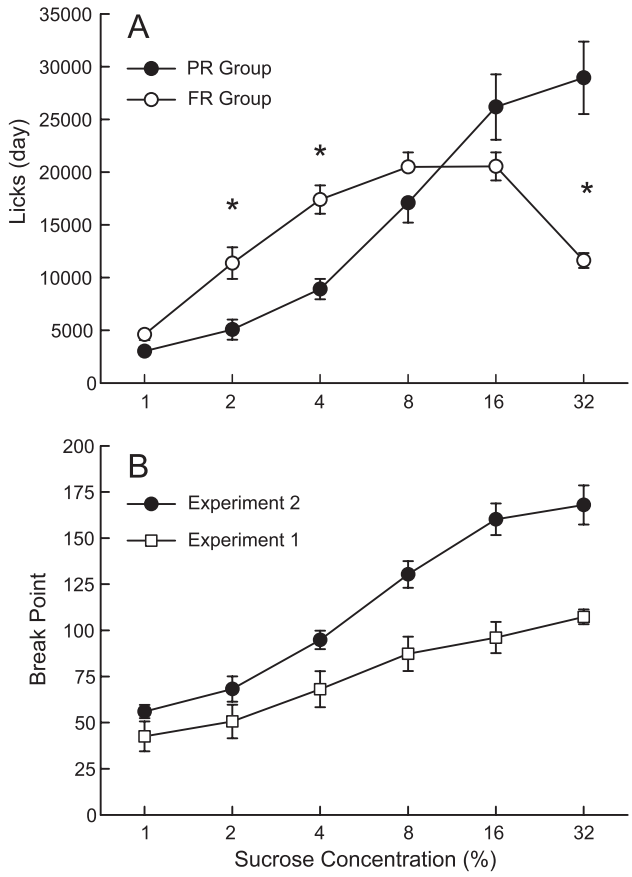

Fig. 7. (A) Mean (±S.E.) total licks for sucrose of PR and FR groups during 23 h/day operant lick tests at sucrose concentrations of 1–32%. The PR rats were tested with a PR-1 schedule while the FR rats were tested with a FR-20 schedule for successive sucrose reinforcements. The asterisk denotes a significant ($P < .05$) difference between the PR and FR groups. (B) Mean (±S.E.) break point values of the PR group of Experiment 2 during 23 h/day operant lick tests at concentrations of 1–32%. For comparison, the break point values of the PR group of Experiment 1 tested 30-min/day are also presented over the same concentration range.

[$F(5,45) = 71.663$, $P < .001$]. The lick break points differed according to the following pattern: $1\% \leq 2\% < 4\% < 8\% < 16\% \leq 32\%$ where $<$, but not $\leq$, indicates significant differences ($P < .05$). For comparison, Fig. 7B also plots the break point data of the PR rats from Experiment 1. Not surprisingly given the longer session length, the PR rats in the present experiment reached higher break points than did the rats in Experiment 1; these differences were significant ($P < .05$) at concentrations of 4% and higher [Group × Concentration interaction, $F(5,80) = 9.410$, $P < .001$].

4. Discussion

The present study demonstrates that PR operant licking in rats increases monotonically with sucrose concentration. This pattern was obtained in food-restricted rats tested 30 min/day (Experiment 1) as well as in ad libitum fed rats tested 23 h/day (Experiment 2). The break point lick data obtained with the food-restricted rats were very similar to previously published results obtained with rats lever pressing for sucrose on a PR schedule [16] and, more generally, with the original report of rats lever pressing for milk solutions of varying concentrations [9].

In the bottle tests, sucrose solution intake and licking increased and then decreased as a sucrose concentration increased from 1% to 32% or 64%. A similar pattern was observed in the FR operant licking tests, which indicates that the FR-20 lick schedule approximates the bottle-drinking condition. Note that the FR rats consumed somewhat less sucrose at the higher concentrations in the operant lick tests than in the bottle tests, which may have reflected the constraints of the FR licking schedule. However, it is possible that the FR rats' prior experience with concentrated sucrose solutions in the bottle tests suppressed intake slightly in the FR tests via a conditioned satiety process [2]. The bottle and FR data confirm many prior reports of an inverted U-shaped intake concentration function with sucrose and other sugars in freely drinking rats [20]. The decline in sucrose solution intake at high concentrations does not represent a reduction in the reward value of its sweet taste, but rather is attributed to the postingestive satiation action of the sugar. This interpretation is supported by findings obtained with rats with an open gastric fistula, which minimizes postingestive satiation: rats increase their "sham" intake of sucrose in direct proportion to concentration [15,24]. Similarly, in brief access tests, which limit sugar consumption, lick rates increase as a function of sucrose concentration [6,21].

The present study revealed the same near-linear relationship between licking and sucrose concentration in the PR operant licking. Postingestive satiation was minimized with the PR operant licking schedule because it greatly limited sucrose consumption during the test sessions. Consequently, PR licking, like sham-drinking and brief access licking, reflects the reward value of sweet taste. Another factor that constrains sugar intake in long-term tests (23 h/day) is nutrient balance [4]. At high sugar concentrations, solution intake is limited by the impact of the solute on the animal's energy and nutrient regulation. In Experiment 2, while the FR rats decreased their solution intake as concentration increased from 16% to 32%, their gram sucrose intake actually increased. The PR rats appeared to be relieved of this constraint because their gram sucrose intake was lower than that of the FR rats at the higher concentrations. Thus, PR licking can reflect the attractiveness of concentrated sugar solutions in long-term test sessions in the absence of postingestive limitations on nutrient balance.

The relationship between PR lick break point and sucrose concentration was remarkably similar to that previously reported for PR lever pressing by Reilly [16]. This similarity includes the findings that there were no differences in the PR break points for the two highest sucrose concentrations tested in the present study (32% vs. 64%) and the prior study [1 (34%) vs. 2 M (68%)]. Reilly [16] hypothesized that the failure of 2 M sucrose to further increase the break point was unlikely due to the postingestive satiating action of the concentrated sugar solution given the limited amount consumed during the test session. Consistent with this view, the PR rats in Experiment 1 consumed less than half as much 64% sucrose as did the FR rats during the 30-min test sessions. Instead, Reilly [16] suggested that rats do not readily discriminate the taste of 32% and 64% sucrose. However, brief access two-bottle tests have indicated that rats prefer 60% sucrose to 36% sucrose [25]. Perhaps there is an upper limit to the break points that rats will tolerate for sweet solutions. Note that the close similarity in the break point values obtained in Experiment 1 and by Reilly [16] may be coincidental and does not necessarily indicate that a lick and a lever press represent similar units of effort.

In contrast to the data obtained here and by Reilly [16], Brennan et al. [3] recently reported, in rats lever pressing for sucrose, that break point increased as concentration increased from 0% to 20% but then declined at a sucrose concentration of 30%. There are several procedural differences among these studies, which may account for the discrepant results. Most notably, the rats in the Brennan study were fed ad libitum, whereas the rats in Experiment 1 and in the Reilly [16] study were food restricted. However, similar concentration–response functions were obtained with the food restricted and nonrestricted rats in Experiments 1 and 2, which suggests that deprivation state may not be the critical factor. Another consideration is that the concentration–response data of the Brennan study were based on animals that received minimal testing (a total of 4 sessions). Thus, the ability of PR schedules to discriminate among different reinforcers (e.g., sucrose concentrations) is not invariant and may depend upon testing conditions.

The present PR lick findings extend the initial report of PR operant licking of McGregor et al. [13]. Their study compared PR licking in rats reinforced with 8.6% sucrose or an isocaloric beer beverage. Overall, the two reinforcers

generated similar lick break points, which were greater when the rats were tested food deprived as opposed to food ad libitum. The sucrose break point of the deprived rats was 71 licks, which compares with the 87 lick break point obtained with 8% sucrose with the deprived rats of Experiment 1 despite the use of different PR schedules in the two studies (exponential vs. arithmetic). Which of these or several other possible schedules is the most effective in discriminating the motivational effects of different reinforcers requires parametric studies. Nevertheless, the present lick data and lever-pressing data of Reilly [16] indicate that simple arithmetic schedules are sufficient to distinguish between different sucrose solutions.

PR schedules are typically used to evaluate reinforcement value in short daily test sessions, but the present data and other recent findings [23] demonstrate that they can also be used in long-term sessions (20–23 h/day) as well. The behavior generated by PR schedules in long-term sessions can be viewed from an optimal foraging perspective [5]. The rats in Experiment 2 had two sources of nutrition: a relatively "free" nutritionally complete diet (chow) and a nutritionally incomplete but preferred food (sucrose) with a cost (i.e., PR lick requirement) that increased as it was consumed. Earlier studies have, in fact, used PR schedules to simulate patch-depletion foraging behavior in rats [10–12]; patches are sources of food (e.g., berry bush) that are depleted as the animal consumes successive food items, which become more difficult to obtain. For example, in one study, rats were required to obtain all their nutrition by lever pressing for food pellets with the cost of the pellets (lever press requirement) increasing according to a PR schedule during each meal [11]. However, unlike the situation in the present experiment, as the PR requirement became very high (the patch became depleted), the rats could end the foraging bout and begin a new one (move to a new patch) by pressing a second "patch" procurement lever, which resets the PR schedule on the first lever to its initial value. As the cost of procuring a new patch increased on a FR schedule, the animals tolerated high PR requirements before ending a meal. Thus, in addition to providing a relatively simple measure of reinforcement value, PR schedules can be used to evaluate more complex foraging strategies in animals.

In summary, the present results indicate that the PR operant licking is as effective as the operant lever-pressing procedure in measuring the reward value of sucrose solutions and presumably other solutions in rats. Preliminary results indicate that PR licking can also be used to evaluate sucrose reward in mice (Sclafani, unpublished findings). An advantage of the operant lick task is that it does not require extensive operant pretraining because licking is a natural response of rodents. It may also be useful to evaluate animals with drug- or lesion-induced motor impairments that are, nevertheless, capable of normal licking. Furthermore, the task can be accomplished with minimal equipment (lickometers and pumps) and can be conducted in the animal's home cage as well as in operant cages. A limitation of the procedure is that it requires liquid reinforcers whereas the lever-pressing method can be used with pellet as well as liquid reinforcers. PR operant "lipping" (i.e., lip contact with a drinking spout) has been used to compare the reinforcing value of drug (ethanol, phencyclidine) and sweet (saccharin) solutions in monkeys [18,19]. It is possible that a PR sipping task using an operant drinking straw may be an effective means of evaluating liquid food reward in human subjects.

Acknowledgements

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