Progressive ratio (PR) schedules and the sipometer: Do they measure wanting, liking, and/or reward? A tribute to Anthony Sclafani and Karen Ackroff

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ABSTRACT

This paper honors the contributions made by Anthony (Tony) Sclafani and Karen Ackroff to both the Columbia University Seminar on Appetitive Behavior and to the field of ingestive behavior in general. We review their use of the progressive ratio (PR) licking paradigm, to determine whether the taste of sucrose, independent of its post-ingestive effects, is always positively reinforcing in animals. They demonstrated a monotonic increase in licking as concentration increased, and obtained results identical to those obtained with a lever-pressing paradigm, but licking was easier and more natural than lever pressing. The PR paradigm was translated to evaluate liquid food reward value in humans. An instrument (the sipometer) was devised that initially permitted a few seconds access to small amounts of a sweet beverage as the participants increased the time to obtain it in 3–5-sec increments. The device went through two refinements and currently delivers the reinforcer and measures the pressure exerted to obtain it. The sipometer is compared with other techniques for measuring motivation and reward. The use of the sipometer and the PR method are discussed in relation to the theoretical challenges inherent in measuring motivation and pleasure, from both psychological and behavioral economics perspectives, and why it is or is not important to separate these processes for both theoretical and practical applications.

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1. Introduction

This is the last paper in a series that honors the contributions of Anthony (Tony) Sclafani and Karen Ackroff both to the Columbia University Seminar on Appetitive Behavior and to the field of ingestive behavior in general. The previous papers in this series have described Tony’s and Karen’s work primarily in animals, with little translation to humans. In order to achieve balance and to highlight recent applications of their work, this paper describes how and why the application of the progressive ratio (PR) licking technique for measurement of reward value in rodents was applied to the development of a human analog, the sipometer (Hogenkamp, Shechter, St-Onge, Sclafani, & Kissileff, 2017). The following topics will be presented: a) a description of the animal studies that led to the development of the sipometer; b) the evolution of the sipometer with its advantages and limitations; c) the theoretical constructs underlying the interpretation of the data collected; d) comparison of the sipometer with other methods; and e) problems with existing techniques and future design of experiments that employ both natural and arbitrary, effort-requiring tasks.

2. Progressive ratio licking in rats: How and why it was employed for measuring reward value of sucrose

In order to test the hypothesis that sweet taste reward increases monotonically with concentration of sucrose solutions, and thereby demonstrate that reinforcing value of sweet taste, rather than post-ingestional effects, was driving rats’ increased responses to obtain a sweet taste, Sclafani and Ackroff (Sclafani & Ackroff, 2003) utilized a novel progressive ratio licking task. Their goal was to verify, with a simpler procedure than had been used in the past (e.g. alley running (Sheffield, Roby, & Campbell, 1954) or lever pressing (Guttman, 1953)) that sweet taste is always positively motivating, and that intake measures mask the motivating effects because increased satiation at high sucrose concentrations reduces intake. The PR licking task minimizes intake, but increases the ratio of work output to reinforcer obtained. (It should be noted that the terms “reinforcement” and “reinforcer” have historically been
defined differently in the psychological and behavioral economics literature. This issue is discussed in more detail in section 4.2.) This task was built on the original demonstration of Hodos (Hodos, 1961) that progressive increase in both the number of lever presses and the break point (the number of presses at which responding stopped) increased with the concentration of the milk used as reinforcer. Subsequently, Reilly (Reilly, 1999) applied the PR lever-pressure technique to sweet caloric (sucrose) and non-caloric (saccharin) solutions. McGregor et al. (McGregor, Saharow, Hunt, & Topple, 1999), were the first to use a PR operant licking task in a study that compared the motivation of rats to consume alcoholic (beer) and non-alcoholic (sucrose) solutions. It remained for Sclafani and Ackroff (Sclafani & Ackroff, 2003) to demonstrate that both intake and breakpoint increased with sugar concentration when sucrose solutions were the reinforcers in the PR-licking task, whereas in a fixed ratio (FR) task, intake increased then decreased with concentration. The advantage of the licking over the lever-pressing task and runway tasks was that it required no learning or transfer of the animal to a special cage. Sclafani and Ackroff demonstrated that the progressive licking technique produced identical results to lever-pressing, and was easier to use. Their report ends with the prescient comment that “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.”

3. Development and evolution of the sipometer

3.1. First attempt

Tony asked the first author of this paper shortly after the PR licking paper (Sclafani & Ackroff, 2003) was published, whether he would be interested in testing the PR licking concept in humans. Since he was already doing human feeding studies and had extensive prior experience with reward concepts based on speed of eating in humans (Bobroff & Kissileff, 1986), he agreed to test any device Tony could build. In 2006 Kissileff and Sclafani began testing the concept that sipping on a straw could be an indicator of motivation and/or reward value. Tony constructed a device that utilized pulling on a straw as a proxy measure for sipping. The participant was positioned in front of a box from which the straw emerged. The straw was connected to tubing that passed through a solenoid situated in a micro-switch, which was activated when the straw was pulled forward. A computer monitored switch activated and opened the solenoid to allow reinforcer flow through the straw, depending upon the reinforcement schedule, when the subject exerted sufficient pressure. On the Continuous Reinforcement (CR) schedule, the solenoid was opened as long as the switch was activated. On the PR 5-sec schedule, the switch had to be activated by pulling on the straw for successive periods increasing by increments of 5 s (i.e. 5, 10, 15, etc.), to open the solenoid for a 2-sec period during which the reinforcer was available. The reinforcer was a strawberry-flavored yogurt shake that was unsweetened or sweetened with aspartame (12 g Equal1 per 1106 g shake). The human and animal paradigms differed slightly in that effort in human procedures would be captured by progressive increases in the amount of time the response must be sustained, while in animal PR procedures, the effort is measured by the number of responses, not the amount of time responding. Eight men and eight women were studied under two schedules of sipping (CR and PR) and two levels of sweetness (sweet and non-sweet shakes) presented in counterbalanced order by means of a Latin square for each group of four.

Since it was not feasible to test several concentrations, as in the animal work, Kissileff and Sclafani chose a sweeteren difference (non-sweet vs. optimally preferred sweet based on previous studies) (e.g. Bobroff & Kissileff, 1986; Drewnowski, Grinker, & Hirsch, 1982)) that would be expected, based on liking ratings, to generate intake differences in humans. The prediction was that on the PR compared to the CR schedule, participants would sip significantly longer and therefore consume more, when they received the sweet, compared to the non-sweet shake, but that overall, intake would be reduced on the PR schedule, thereby reducing post-ingestional effects.

The result was not exactly what we had expected (all values from (Gondek-Brown et al., 2007). Under both CR and PR conditions, subjects rated liking of the sweet shake significantly higher than the non-sweet by 2.55 units ± 0.575E (p < 0.0001; t39 = 4.46), and on average, consumed approximately 100 g per unit difference on a 9 point scale of liking (Peryam & Pilgrim, 1957), thus replicating a previous finding (Bobroff & Kissileff, 1986). However, intake of the sweet shake was significantly higher than that of the non-sweet shake only under the CR condition (208 g ± 68 g SE; p = 0.004; t39 = 3.07), and not the PR (56 ± 68 SE; p = 0.41; t39 = 0.83). In addition, there was an unanticipated sex × treatment interaction, such that the intake difference in males was greater than that of females under both conditions combined by 240 g ± 96 SE (p = 0.02; t39 = 2.5). Presaging future findings, there were significant regressions of intake from palatability ratings taken after the meal. The slopes of intake by liking rating were 65 g/unit ±22 SE (p = 0.02; t = 2.99) for CR and 30 g/unit ± 9 SE; p = 0.02; t = 3.24), for PR.

A second study (see (Hogenkamp et al., 2017) for details) with the sipometer was more consistent with expectations. Subjects consumed more of a yogurt shake drink when it was offered ad libitum after 21 h, than 1 h, of food deprivation, but when they were required to work on PR schedule, they worked harder (i.e. spent more time sipping), but did not consume more after 21 h than 1 h of deprivation. There was no difference in rated liking between the deprivation conditions. Thus deprivation changed the motivational, but not the hedonic aspects (see below for further discussion of this issue) of ingestion, and the sipometer was able to measure the motivational effect.

3.2. The second model

As a consequence of the first study, it was decided that a device that required detection of actual sipping, not simply moving the straw, might be a better measure of the reward value. Tony was able to arrange for a new pressure sensing device to be constructed at the Pierce Laboratory with the help of Dana Small, who supervised the construction by engineer John Buckley. We piloted a limited number of subjects (6 female and 4 male) with a chocolate milkshake and found that, as in the first study, sweet intake was significantly higher than non-sweet intake for the CR (difference = 170 g, ± 75 SE, t (41) = 2.27, p = 0.03) but not PR (difference = 61 ± 75 SE). Although the results were similar to those in the first study, participants consumed more sweet shake than non-sweet shake per second of reinforcement. This behavior resulted in differences in reward size, that depended on the sweetness of the shake, so we decided that a third modification was necessary.

3.3. The current sipometer

The sipometer went back to the Pierce Lab in 2011, and was modified so that liquid reinforcement was delivered at a fixed rate using a peristaltic pump. Two types of studies were conducted with the new device. In the first (Hogenkamp et al., 2017), eight women were tested in a sham-drinking paradigm (i.e., sip and spit) with an aspartame sweetened Kool-Aid compared to an unsweetened Kool-
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