Physiology & Behavior 165 (2016) 77–85

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Intermittent access to a sucrose solution for rats causes long-term increases in consumption

Roelof Eikelboom *, Randelle Hewitt

Department of Psychology, Wilfrid Laurier University, Waterloo, ON, Canada

HIGHLIGHTS

- Rats were given continuous or second-, third-, or fourth-day access to 4% sucrose.
- Access every fourth day led to sucrose consumption twice that of continuous access.
- When moved to alternate-day access, rats maintained differences for 24 days.
- Elevated sucrose intake reduced chow intake, and rats' weights were unaffected.
- Increased sucrose intake was due to larger sucrose meals, suggesting delayed satiety.

ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form 28 June 2016
Accepted 5 July 2016
Available online 6 July 2016

Keywords:
Sucrose solutions
Rats
Intermittent access
Feeding
Bingeing

ABSTRACT

Intermittent access to palatable food can elevate consumption beyond an animal's immediate needs. If adult male rats (with *ad lib* access to food and water) are provided with a 4% sucrose solution, daily sucrose consumption is determined by the sucrose access schedule: access that is intermittent leads to high levels of consumption. In Experiment 1, sucrose solutions were first provided continuously or every second, third, or fourth day for 23.5 h over 49 days. Continuous-access sucrose consumption averaged 102 g per day, while that for access every fourth day averaged 294 g. Daily consumption averages for access every second and third day fell between these two extremes. When all rats were then given alternate-day access to sucrose for 24 days in Phase II, the previously established consumption differences were maintained. Body weight was unaffected by sucrose access; rats adjusted their food consumption so that total calorie intake remained constant. In Experiment 2, compared to continuous 4% sucrose solution access, access every third day markedly elevated daily sucrose consumption after only four sucrose exposures. With this shorter Phase I, sucrose intake in the continuous group increased markedly when in Phase II all rats were given alternate day access. In Experiment 3, a lick-by-lick analysis of the difference in sucrose consumption between access every third day and continuous access revealed that all rats were consuming a similar number of sucrose meals; however, the meals were larger both in the first hour and over the whole 24 h with intermittent access. This suggests a change in satiety as a mechanism underlying sucrose consumption difference.

1. Introduction

It has been known for a long time that intermittent access to food and drink has a profound effect on consumption. In the early 1970s, it was shown that rats could be induced to drink large amounts of high-ethanol (20%) alcohol solutions by making the solution available intermittently [1–3] or on an alternate-day schedule [4]. Intermittent access similarly increased consumption of palatable non-nutritive (saccharin) and mildly aversive (quinine) solutions [5]. The use of this procedure to increase the amount of alcohol consumed to psychoactive levels has continued [6–8]. Yet the role of access schedule in increasing the consumption of palatable solutions has only been explored in more complicated protocols, making access effects difficult to disentangle.

Since the early work, a number of rodent protocols have used a variety of intermittent-access procedures with appetitive substances and have found increases in feeding and drinking [9]. These protocols were established to explore factors contributing to obesity and eating disorders. Several of these protocols have found that intermittent access may lead to addiction-like consumption [10–13], resulting in binge eating and perhaps ultimately obesity. The protocols differ in specific foods used, the schedule of access, the involvement of food deprivation, and other factors, such as stress induction [9]. Nevertheless, all suggest that the intermittent nature of the access is a critical aspect of the elevated consumption.

* Corresponding author at: Department of Psychology, Wilfrid Laurier University, 75 University Ave. West, Waterloo, ON N2L 3C5, Canada.
E-mail address: reikelboom@wlu.ca (R. Eikelboom).

http://dx.doi.org/10.1016/j.physbeh.2016.07.002
0031-9384/

The most studied intermittent-access protocol is that of 12 h sucrose and food access with 12 h food/sucrose deprivation, for which the neurological mechanisms have been extensively explored [10,14]. In this preparation, the experimental group of rats receive food and a 10 or 25% sucrose solution only 12 h a day, while the control animals have *ad lib* 24 h access to both food and sucrose. The intermittent access is started a few hours into the dark cycle, which is when the majority of consumption occurs. In this procedure, intermittent-access rats develop binge-like eating patterns, consuming large sucrose "meals" when sucrose is first made available. (A "meal" is defined here as a period of sustained drinking before the rat stops for an extended break). These rats come to consume as much sucrose in the 12 h of access as the control rats consume over 24 h. The emphasis in this work has been on exploring the neural systems involved in binge drinking and their relation to the brain reward or pleasure systems involved in drug addiction and the neurotransmitters that are important in these systems: dopamine, endorphin, and GABA [15,16].

A second intermittent-access protocol compares daily (seven days a week) 2 h access to fat with intermittent 2 h access (three days a week, usually Monday, Wednesday, and Friday). Over a few weeks, the rats in the intermittent-access condition come to consume much more fat in the 2 h than rats with daily access [17]. This protocol does not use any food deprivation; all rats have access to *ad lib* food and water; thus fat consumption occurs in addition to any normal feeding. Note that, in both groups, the access is limited. The difference lies in the intermittent group, whose rats do not have regular daily access to the very palatable fat food source. The effect is not specific to fat; similar increases in consumption have been shown using a sucrose-fat mixture [18] and a sucrose solution [19]. With this protocol, the rats with intermittent access are said to binge because their 2 h fat consumption increases over the weeks relative to fat consumption by rats with daily 2 h access. The intermittent-access rats will also work to a higher breakpoint on a progressive ratio schedule for the fat [20], suggesting it becomes more attractive to the rats, though the binge size is sensitive to operant requirements [21].

Both of these protocols are complex, involving food deprivation and limited daily access or intermittent-*versus*-daily 2 h access to palatable foods. We wanted to develop a simpler intermittent protocol that paralleled earlier work with intermittent access. Thus we explored either continuous or intermittent full-day sucrose access with the expectation that intermittent access would elevate consumption. We wanted a protocol where consumption could be both increased or decreased, so we used a concentration of sucrose that was on the ascending arm of the concentration consumption function [22,23].

Based on the earlier research with alternate-day access schedules, we explored the effects of intermittent periods of daylong (23.5 h) access. We looked at the effects of weak sucrose solutions on consumption in young adult rats while maintaining *ad lib* access to food and water. Our preliminary work suggested that making the solutions available every second, third, or fourth day might have a profound effect on consumption. We used a low-calorie 4% (weight/volume) sucrose solution. Previous work with sugar solutions found that the volume consumed becomes sensitive to satiating effects at about 8%, and with concentrations higher than 8%, the volume consumed dropped (but the calories consumed still increased) [22,23]. Thus using a 4% solution would permit the rats to both increase or decrease their consumption without concerns about ceiling or floor limits. Our interest in these experiments was the nature of the increased consumption induced by intermittent access.

One possible explanation for any increased consumption by rats with intermittent access is that they are balancing out or averaging the amount consumed across the multiple days of the schedule. If rats normally consume a certain amount of a solution daily, and are then given access on an alternate-day schedule, they might double consumption when the solution is available. Averaged over days, the consumption with alternate-day access would match that of daily access. This seemed to occur with the protocol of 12 h deprivation and 12 h sucrose and food access, in which the amount of sucrose consumed in the first hour of access has a binge-like profile but the total amount consumed across the 12 h of access was similar to the amount consumed with *ad lib* access [24,25]. If an averaging occurred with multiple-day access schedules, it would lead us to ask how rats integrate consumption over multiple days. It might also suggest that there is no actual excessive consumption. If, however, rats are truly increasing their consumption with intermittent access, it suggests that the value of, or learning about, the solutions is different with intermittent access. We explored this notion in three rat experiments.

To explore if the rats were simply averaging consumption over multiple days, in Experiment 1 rats were given a Phase I of either intermittent or continuous access, followed by a Phase II with a uniform alternate-day access schedule. We choose an alternate-day schedule for Phase II so that there was an access change for rats in both the continuous-access and the longer intermittent groups. If the animals were simply averaging consumption over multiple days, the amount consumed would soon become similar in both groups despite their previous access history. Alternatively, if the access schedule from Phase I induced a long-lasting change in sucrose perception or value, then differences between the access groups might be maintained when all animals were put on a uniform schedule in Phase II. If this happened, there would be follow-up questions. First, how stable or permanent is the change in consumption induced by the original schedule? Second, how many intermittent exposures in Phase I would it take to induce a longer-lasting change? The effects of a shorter Phase I duration of intermittent access were explored to address these questions in our second experiment.

The excessive consumption seen with intermittent sucrose access also raised questions regarding how food and water consumption are changed and if there are longer-term effects on weight. Earlier work with sucrose solutions found that obesity was induced only by higher concentrations of sucrose solutions [26–28]; thus it was expected that, with a 4% solution, there would be little effect on body weight. We were not sure, however, how regular food consumption would be affected by the intermittent or continuous access to sucrose. In our first experiment, we analyzed food consumption when both sucrose solution and food consumption had stabilized in Phase I by comparing animals in the intermittent and continuous conditions (and with a control group that had no sucrose access).

The findings of other intermittent-schedule procedures suggest that introduction of intermittent palatable food or solution may elicit binge consumption only at the start of each access period [9,10,14]. This would suggest that a finer-grain analysis of the consumption profile might be helpful in determining the nature of the change in consumption. Like most animals, rats drink in meals (usually composed of several drinking bouts and clusters, periods of relatively continuous high licking followed by longer periods of no drinking). In our third experiment, we explored intermittent- and continuous-access rats' sucrose meal profiles on the first day of sucrose access and on the sixteenth day of the experiment, when the difference in consumption caused by intermittent access was well established.

2. General materials and methods

All experiments and procedures were reviewed and approved by the Wilfrid Laurier University Animal Care Committee according to the guidelines and policies of the Canadian Council on Animal Care (WLUACC Protocol R06005).

2.1.1. Subjects

Male Sprague-Dawley rats from Charles River Canada, St. Constant, Quebec, weighing 200–225 g (48–50 days old) at arrival, were housed individually in plastic shoebox cages (20 × 24 × 45 cm). Experiments