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Research Report

Deconstructing the vanilla milkshake: The dominant effect of sucrose on self-administration of nutrient–flavor mixtures

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Abstract

Rats and humans avidly consume flavored foods that contain sucrose and fat, presumably due to their rewarding qualities. In this study, we hypothesized that the complex mixture of corn oil, sucrose, and flavor is more reinforcing than any of these components alone. We observed a concentration-dependent increase in reinforcers of sucrose solutions received (0%, 3%, 6.25%, and 12.5%) in both fixed ratio and progressive ratio procedures, but with equicaloric corn oil solutions (0%, 1.4%, 2.8%, and 5.6%) this finding was replicated only in the fixed ratio procedure. Likewise, addition of 1.4% oil to 3% or 12.5% sucrose increased fixed ratio, but not progressive ratio, reinforcers received relative to those of sucrose alone. Finally, addition of 3% vanilla flavoring did not change self-administration of 3% sucrose or 3% sucrose + 1.4% oil solutions. These data suggest that, calorie-for-calorie, sucrose is the dominant reinforcing component of novel foods that contain a mixture of fat, sucrose, and flavor.

Keywords: Self-administration; Sucrose; Fat; Reinforcement; Macronutrients; Flavor

Introduction

What makes us drink a vanilla milkshake? Is it the sugar, the fat, the flavor, or the unique combination of all three? Rewarding properties of foods are partially attributed to their fat and carbohydrate content (Levine, Kotz, & Gosnell, 2003). Increases in the content of these nutrients in the modern food supply may contribute to the obesity problem the developed world is experiencing (Drewnowski, 2003) and therefore it is important that we understand their impact on our intake and our desire to obtain and consume them. Although some milkshake-like beverages are used as a meal replacement for weight loss (Drewnowski & Bellisle, 2007), sodas and other high-calorie beverages are consumed *in addition* to regular meals, and studies show that consumers do not fully compensate for the additional calories, leading to weight gain (Raben, Vasilaras, Moller, & Astrup, 2002; Tordoff & Alleva, 1990). In addition to their abundance and relative low cost (Drewnowski & Bellisle, 2007), these beverages are also easy to consume, requiring no food preparation or even chewing. One needs expend very little work to consume these calories.

Many studies indicate that fat and carbohydrates (particularly sugars) are rewarding in humans and in animals (Levine et al., 2003; Sclafani, 2004). However, fat and sugar are rarely, if ever, consumed in isolation from other nutrients or flavors and most palatable foods are not mixtures of nutrients alone, but have some flavor added to them. This can be studied using rats working for delivery of nutrient solutions. For example, we have observed in our laboratory that rats consistently consume more, and work

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harder for, chocolate Ensure than they do for pure sucrose solutions (unpublished data). Ensure differs from sucrose solutions in both macronutrient composition and oral qualities (i.e. texture) that resemble a milkshake. We became curious about which component(s) of complex highly palatable liquid foods evoke the most motivation in the rats. Nutrients and their rewarding properties have been extensively studied in animal models. Sucrose and fat have both been shown independently to be rewarding and motivating in several paradigms, including self-administration (Freed & Green, 1998; Grimm, Fyall, & Osincup, 2005), conditioned place preference (Figlewicz et al., 2004; Figlewicz, Higgins, Ng-Evans, & Havel, 2001), conditioned flavor preferences (Ackroff, Rozental, & Sclafani, 2004; Sclafani, Nissenbaum, & Ackroff, 1994) and intake tests (Corwin, 2004; Zhang & Kelley, 1997).

In the present study, we aimed to determine whether fat, sucrose, a mixture, or a flavored mix is most reinforcing, using the self-administration procedure. Flavor preferences can be conditioned by intra-gastric infusion of either sweet or fat solutions. This finding suggests that macronutrient nutritive qualities alone can be positively associated with oral experiences of flavor (Sclafani, 2004). Other studies show that the nutrients' pre-absorptive properties contribute to consumption, including some showing rats' positive responses to non-nutritive fats (Ackroff, Vigorito, & Sclafani, 1990; Elizalde & Sclafani, 1990). While these studies demonstrate that there are various ways in which individual macronutrients confer reward, they do not explain which part of a mixture of macronutrients is most reinforcing. This kind of analysis requires systematic dismantling of a rewarding solution into its components. In such a study using bottle-choice tests, Kimura, Okada, Endo, and Fujimoto (2003) showed that rats prefer a mix of sucrose and fat in a liquid diet, relative to either sucrose or fat alone. In this study, rats habituated to an evaporated milk-based diet were subjected to one- and two-bottle tests of evaporated milk solutions enriched with corn oil only, sucrose only, or a mixture of corn oil and sucrose. In both one- and two-bottle intake tests, rats consumed significantly more of the fat + sucrose solution than of the sucrose-only solution. When the fat-only solution was presented with the sucrose-only solution, the sucrose was preferred. This study and others indicate that fat alone is less preferred than sucrose, but that it has a facilitative effect on ad libitum intake when added to sucrose (Takeda, Imaizumi, & Fushiki, 2000).

No studies have yet tested whether flavor added to the mixture makes a solution more rewarding, although this may seem intuitively obvious. In the Kimura study above, nutrients were added to milk, which may have confounded results, considering the sugars, fats and flavors inherent to milk. Furthermore, it seems possible that milk resembles mothers' milk closely enough for rats that it recalls reward experienced in early life. In order to completely differentiate between responses to fat, sucrose, and flavor, we used emulsions of corn oil, sucrose and/or vanilla flavoring in water, rather than in milk. This design allowed us to test the relative reinforcing properties of each individual macronutrient, rather than the complex combination of milk plus nutrient.

We also wanted to determine the amount of work fully sated animals were willing to expend in order to obtain fat, sucrose, a mix, or a flavored mix. This is a different measure than mere consumption of each nutrient. Self-administration chambers, in which rats press a lever to obtain a small amount of reinforcer, allow measurement of the degree to which they will work for such a reinforcer. Using fixed ratio (FR) reinforcement (FR1: one sucrose reinforcer for each lever press), we were able to ascertain the amount of each solution animals consumed. Using a progressive ratio (PR) schedule, in which each successive sucrose reinforcer requires more lever presses than the previous one, we determined the degree of motivation rats expressed for each solution. The PR schedule is thought to be the best way to determine the relative reinforcing strength of different reinforcers (Arnold & Roberts, 1997; Hodos, 1961; Richardson & Roberts, 1996). Note that we will use the term "motivation" here to refer to the amount of work animals will expend for a limited amount of reinforcer, as in our PR procedure. See reviews by Wise and Hoffman (1992) and Arnold and Roberts (1997) for expanded discussion of the concepts of reward, reinforcement, and motivation.

In our attempt to "deconstruct the vanilla milkshake", we hypothesized that a combination of fat and sucrose (in the form of emulsified corn oil and sucrose in water) would elicit more self-administration responding than either nutrient alone. In addition, we hypothesized that adding flavor to the mix would make the solution even more rewarding. Using standard self-administration chambers, we analyzed FR and PR responding for a series of solutions containing combinations of sucrose, corn oil, and vanilla.

Methods

Subjects

Subjects were male Albino rats (350–450 g) from Simonsen (Gilroy, CA). Rats were maintained on water and chow ad libitum at all times. They were maintained on a 12:12 h light–dark cycle with lights on at 6 AM. All procedures performed on the rats followed the NIH guidelines for animal care, and were approved by the Animal Care and Use Sub-Committee of the Research and Development Committee at the VA Puget Sound Health Care System or the WWU Animal Care and Use Committee. Each subject only underwent one round of training and testing, as described below.

Apparatus

Med Associates (Georgia, VT) self-administration chambers, controlled by a Med Associates integrator system,