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PAPER

An investigation of the role of oro-sensory stimulation in sugar satiety[†]

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OBJECTIVE: To investigate whether oral factors stimulated by the presence of sucrose in the mouth are involved in the suppression of appetite following sucrose ingestion.
DESIGN: Ten male and 10 female healthy volunteers participated in four experimental conditions designed to provide differing levels of oro-sensory stimulation. Appetite and energy intake from a test meal were measured after subjects chewed and ingested sucrose-containing pastilles over a 10 min period, consumed a sucrose-containing jelly over a 5 min period, consumed a sucrose-containing drink within 2 min and drank plain water within 2 min. The three sucrose-containing preloads were similar in nutrient composition, each containing 251 kJ.
RESULTS: Ratings of hunger and fullness did not differ between the four conditions following ingestion of the preloads. However, energy intake from a test lunch was significantly reduced after consuming the pastilles when compared with the plain water and equicaloric sweet drink conditions.
CONCLUSION: These results suggest that enhanced oro-sensory stimulation from chewing the sweet food was involved in the suppression of food intake.
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Keywords: sucrose; sweetness; appetite suppression; oro-sensory stimulation

Introduction

Results from our previous study[1] demonstrated a greater suppression of appetite following ingestion of a sucrose solution compared with a maltose solution when given as an oral preload but not when administered directly into the stomach. This suggested that oral factors were involved in the greater suppression of appetite by sucrose.

The involvement of oro-sensory factors in the normal postprandial satiety response has been previously demonstrated. In early clinical studies it was observed that patients given food directly into the stomach via a gastric fistula failed to feel as satiated as they did when food was also tasted.[2,3] Laboratory studies also found that normal ingestion of meals resulted in greater suppression of appetite compared with the same meals infused directly into the stomach or duodenum, thus highlighting the contribution of oral factors in the development of satiety.[4,5] Studies in rats also demonstrated that stimulation from oral glucose enhanced the satiating effect of hepatic glucose infusions.[6] More specifically, some studies have shown that sweet taste can result in reductions in subsequent food intake and/or appetite.[7–9]

The aim of the present study was to further investigate the role of oro-sensory stimulation in the process of appetite suppression following ingestion of sugar-containing foods. It was hypothesised that sugar-containing foods requiring a greater amount of chewing, and hence being present in the mouth for longer, would provide enhanced oro-sensory stimulation resulting in a greater suppression of appetite.

Methods

Subjects

Subjects were 10 male and 10 female healthy volunteers. All subjects were non-smokers, had body mass index (BMI) within the range 19.8 – 27.7 kg/m^2 (23.7 $\pm$ 0.7; mean $\pm$ s.e.) and scored less than 12 (5.0 $\pm$ 0.7; mean $\pm$ s.e.) on the

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restraint scale of the Eating Inventory Questionnaire.[10] Female subjects were studied between days 7 and 18 of the menstrual cycle when food intake was less likely to be influenced by menstrual symptoms.[11]

Protocol

Each subject was studied on four separate occasions at least 3 days apart. Subjects came to the Centre for Human Nutrition at 11.30 am after having consumed a standard breakfast (eg cereal and milk or toast and jam) before 9.00 am. They were asked to consume the same breakfast at the same time on every study day and this was confirmed by the subjects on arrival at the Centre. At 11.40 am subjects were asked to rate their level of hunger and fullness on 10 cm line visual analogue scales (VAS). The scales were anchored with the descriptors 'not at all' and 'extremely' at the left- and right-hand sides respectively and subjects were instructed to place a vertical mark at the appropriate point on the scales to indicate their current feelings. After completion of the VAS, subjects were given one of four preloads. These were a sucrose-containing drink, sucrose-containing jelly, sucrose-containing pastilles and water (control condition).

The three sucrose-containing preloads were flavoured with blackcurrant and were similar in nutrient composition, each containing 251 kJ. The sucrose-containing drink and the plain water drink each weighed 150 g. The pastilles and jelly preloads were made up to a total weight of 150 g with an additional drink of water (Table 1). Subjects were instructed to chew the pastilles over 10 min, eat the jelly within 5 min and consume the drinks within 2 min. The preloads were presented at different times so that they were all consumed by 11.55 am.

After consuming the preloads the subjects were presented with a second set of VAS and asked to rate their level of hunger, level of fullness, how much they had liked the preload and how sweet they had found the preload. At 12.00 subjects were presented with a test meal in quantities in excess of what they would normally be expected to eat and invited to eat as much as they wished. The test meal consisted of separate servings of pasta, a tomato-based sauce, French bread, butter and water. The weight of each food eaten was recorded and energy and macronutrient intakes determined using manufacturer product information and COMP-EAT diet analysis software (COMP-EAT, Lifeline Nutritional Services Ltd, London, UK). After completion of the test meal at 12.30 pm subjects were presented with a final VAS questionnaire on which they recorded their level of hunger and fullness and how much they had liked the test meal.

Statistical analysis

Statistical analysis was performed using SPSS for Windows version 6.0 (SPSS Inc., USA). Results are expressed as mean $\pm$s.e.m. In all tests, probability values of $P<0.05$ were regarded as statistically significant. Data were analysed using one-way repeated measures analysis of variance (ANOVA) with study condition as a within-subject factor. Following ANOVA, *post hoc* tests were performed using Tukey's procedure. Hunger and fullness ratings were analysed as change from baseline (ie rating score after consuming the preload minus rating score before consumption of the preload).

Pearson's correlation was used to examine whether energy intake from the test meal was related to how much the subjects liked the preloads or how sweet they had found the preloads. An analysis of the correlation between pre-test meal hunger rating and test meal energy intake was also performed with Pearson's correlation.

Results

Repeated measures ANOVA revealed a significant difference in subjective rating of sweetness of the preloads ($F(3, 57)=115.17$, $P<0.001$). *Post hoc* analysis showed that the three sucrose-containing preloads were all rated as tasting sweeter than the water ($P<0.05$) and the pastilles and drink were rated sweeter than the jelly ($P<0.05$; Table 2). There was also a significant difference in the liking of preloads ($F(3, 57)=9.13$, $P<0.001$), with subjects not liking the sweet drink as much as the other three preloads ($P<0.05$; Table 2).

The change in hunger ($F(3, 57)=2.30$, $P=0.09$) and fullness ($F(3, 57)=1.25$, $P=0.30$) immediately after consuming the preloads did not differ significantly between the four conditions (Figure 1). However, energy intake from the test meal was shown to differ between the four study conditions ($F(3, 57)=3.50$, $P<0.05$). *Post hoc* tests showed that energy intake was significantly lower following the consumption of the pastilles compared with both the water and sweet drink conditions ($P<0.05$; Table 3). Intake of carbohydrate ($F(3, 57)=3.86$, $P<0.02$) and fat ($F(3, 57)=3.30$, $P<0.05$) from the test meal was also found to differ between the study conditions. Subjects ate significantly less carbohydrate from the test meal after consuming the pastilles compared with

Table 1 Nutrient composition of preloads

Preload	*Weight (g)*	*Energy (kJ)*	*Fat (g)*	*Carbohydrate (g)*	*Protein (gelatin) (g)*	*Additional water (g)*	*Total weight (g)*
Pastilles	23.7	251	0	14.7	1.2	126.3	150
Jelly	100	251	0	14.7	1.2	50	150
Drink	150	251	0	14.7	1.2	0	150
Water	150	0	0	0	0	0	150

Table 2 Visual analogue scale ratings of preloads

	Visual analogue scale rating score (cm)			
	Sweetness		*Liking*	
Preload	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*
Pastilles	8.60*†	0.22	7.55‡	0.53
Jelly	7.15*	0.47	6.85‡	0.59
Drink	8.56*†	0.37	4.03	0.61
Water	0.80	0.29	6.12‡	0.36

*Significantly different from water condition, $P<0.05$, Tukey's procedure.
†Significantly different from jelly condition, $P<0.05$, Tukey's procedure.
‡Significantly different from drink condition, $P<0.05$, Tukey's procedure.

the amount consumed after both the water and sweet drink preloads ($P<0.05$). They also ate significantly less fat following the pastilles when compared with the sweet drink condition ($P<0.05$; Table 3). Ratings of hunger ($F(3, 57)=1.11$, $P=0.35$) and fullness ($F(3, 57)=0.19$, $P=0.90$) after consumption of the test meal did not differ between the four study conditions (Figure 1).

Pre-test-meal hunger rating was positively correlated with energy intake from the test meal ($r+=0.333$, $P<0.01$). There was no significant relationship between how sweet the subjects rated the sucrose-containing preloads and energy intake from the test meal ($r-=0.041$, $P=0.863$, pastilles; $r-=0.361$, $P=0.188$, jelly; $r+=0.101$, $P=0.673$, sweet drink). Nor was there a significant relationship between how much the subjects reported liking each preload and energy intake from the test meal ($r+=0.044$, $P=0.852$, pastilles; $r-=0.013$, $P=0.955$, jelly; $r+=0.003$, $P=0.991$, sweet drink; $r+=0.192$, $P=0.418$, water).

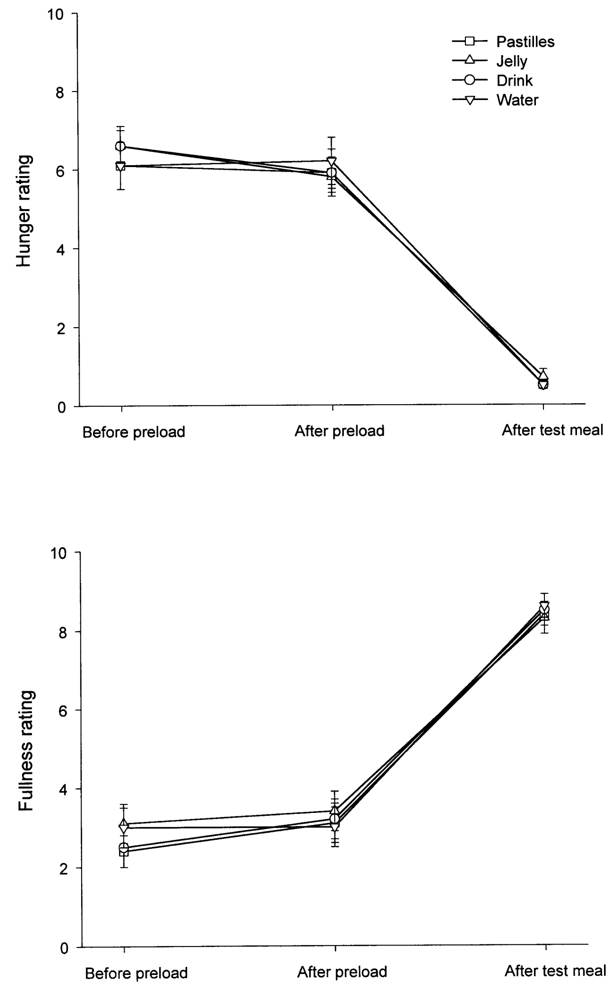

Figure 1 Ratings of hunger and fullness.

Discussion

The results of this study showed that chewing sucrose-containing pastilles over a 10 min period resulted in a greater reduction in energy intake from a subsequent test meal than drinking an equicaloric sucrose-containing drink or a non-caloric water drink consumed over a 2 min period. Compared with the control (water) preload the sucrose-containing pastilles reduced energy intake by the greatest amount, more than compensating for the energy content of the preload. The sucrose-containing drink, however, produced a small increase in energy intake compared with water intake and thus test meal energy intake was significantly higher than that following the pastilles. Energy intake following the preload jelly fell in between that following the pastilles and control water preloads and was not significantly different

Table 3 Test meal energy and macronutrient intake following preload ingestion

	Energy intake (kJ)		*Fat (g)*		*Carbohydrate (g)*		*Protein (g)*	
Preload	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*	*Mean*	*s.e.m.*
Pastilles	3209*	208	18.9†	1.9	128.9*	10.8	22.8	1.5
Jelly	3432	182	20.7	2.4	141.9	6.7	24.3	1.1
Drink	3702	196	23.2	2.5	151.4	8.4	25.9	1.4
Water	3596	204	21.6	2.0	148.7	8.5	25.4	1.5

*Significantly different from drink and water conditions, $P<0.05$, Tukey's procedure.
†Significantly different from drink condition only, $P<0.05$, Tukey's procedure.

from either. Thus, ingestion of an identical amount of sucrose in different forms produced markedly different effects on subsequent intake. This may be related to the time of oral stimulation by these preloads as the time for ingestion was 10, 5, and 2 min for pastilles, jelly and drink, respectively. The reduction in energy intake from the test meal following consumption of the pastilles was through a reduction in carbohydrate and fat intake with no difference in the intake of protein.

We and others have previously shown effects of liquid carbohydrate preloads on suppression of food intake.[12–15] However, more precise adjustment in food intake to compensate for energy consumed as solid foods compared with liquids has also been reported.[16,17] Reviewing a number of studies of differing protocol, Mattes[17] reported that accurate compensation for energy presented as a solid was frequently observed, whereas compensatory adjustments after semi-solid foods were generally less precise. In these studies energy consumed as fluids was not compensated for at all. In fact, liquids tended to result in a counter-compensatory effect such that subsequent energy intake was actually increased. Our present study, in which solid, semi-solid and fluid preloads of matched nutrient composition were administered under the same protocol supports these findings. In a recent long-term study, DiMeglio and Mattes[16] also compared isoenergetic solid and liquid carbohydrate loads given daily over 4 weeks. The authors also observed accurate compensation for the carbohydrate only when given as a solid (sucrose) with the liquid (fructose) simply adding to daily energy intake and resulting in a small increase in body weight.

The results of the present study support our hypothesis that enhanced oro-sensory stimulation plays a role in the suppression of appetite. Chewing the sucrose-containing pastilles resulted in an immediate reduction in energy intake from the test meal given after only 10 min which would suggest that a pre-absorptive/cephalic mechanism was involved. It is unlikely that any potential difference in physiological responses, such as gastric emptying rate and hence gastric distension, between the solid and liquid preloads would have been large enough to influence appetite. This is due to the preloads being relatively small (150 g, 251 kJ), the short time period between preload and test meal and the fact that all the caloric preloads contained a comparable amount of gelatin.

As mentioned in our previous paper, oro-sensory stimulation is involved in a number of cephalic phase responses involved in the digestion and metabolism of food. Many of these may also be involved in the development of satiety, for example insulin and glucagon secretion.[18–21] Chewing the pastilles over a 10 min period could have provided enhanced oro-sensory stimulation compared with the other preloads both through the action of chewing and via the sucrose being present in the mouth for a longer period of time. The contribution of these two potential stimuli cannot be separated in this study but it is also possible that the combination of both was important. Most studies examining the effect of oro-sensory stimulation on cephalic reflexes have used the technique of modified sham feeding in which foods are tasted, chewed and expectorated, thus providing both stimuli. However, studies have shown that, although chewing flavoured gum is as effective as modified sham feeding in stimulating gastric acid secretion,[22] simply chewing tasteless rubber has no effect.[23]

Haber *et al*,[24] linked the chewing of food with the development of satiety. They demonstrated that apples could be ingested at a much faster rate and were also less satiating when they had been pureed and even more so when liquidised, which they related to the fact that, the more the fibre was disrupted, the less chewing the apples required. However, other studies investigating the effect of chewing gum sweetened with aspartame found that in general hunger was increased in subjects who had chewed sweet gum compared with those given unsweetened gum or nothing.[25] These results may suggest that the effect of chewing and sweet taste on subsequent appetite is dependent on whether food is also ingested. Further studies examining the effect on appetite of chewing sucrose-sweetened food without ingesting or looking at the effect of chewing non-sweet pastilles would provide further information regarding the roles of chewing and sweet taste independently.

Although the pastilles, jelly and sucrose-containing drink all contained an identical amount of sucrose, the pastilles and sweet drink were both rated as tasting sweeter than the jelly. Previous studies have suggested that the perceived intensity of sweetness may influence appetite and feeding.[26,27] However, there was no correlation between perceived sweetness of the preloads and subsequent energy intake in the present study. Furthermore, differences in energy intake were observed between the pastilles and sweet drink condition although these two preloads were not reported to differ in how sweet they tasted. There were also differences in the subjects' liking of the preloads but again this was unlikely to have influenced food intake at the test meal. Subjects reported liking the drink less than the other three preloads but rather than this causing subjects to eat less from the test meal due to any aversive response they actually ate more after this preload. Furthermore, statistical analysis revealed there was no correlation between how much the subjects reported liking the preloads and subsequent energy intake.

Although differences were observed in test meal intake, there were no differences in the change in hunger or fullness between preload conditions. It is possible that the preloads were not large enough to affect VAS assessment of appetite. Previous studies have found VAS ratings of hunger and fullness to be less sensitive to caloric manipulation than actual test meal intake.[28,29] This is supported in the present study by the relatively low (although significant) positive correlation between pre-meal hunger ratings and test meal energy intake. As discussed in our previous paper, due to sensory specific satiety[30] it is possible that greater effects may have been noted had the subjects been specifically asked to rate appetite for something sweet, or had been given a choice of sweet and savoury foods within the test meal.

In conclusion, the results of this study demonstrated that extended oro-sensory stimulation increased the satiating effect of sucrose. These data along with those of our previous study support a principal role for oral factors in the process of appetite suppression immediately following ingestion of sugar-containing foods.

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References

1 Lavin JH, French, SJ, Read, NW. Comparison of oral and gastric administration of sucrose and maltose on gastric emptying rate and appetite. *Int J Obes Relat Metab Disord* 2002; **26**: 80–86.
2 Janowitz HD, Hollander F, Orringer D, Levy MH, Winkelstein, A, Kaufman, MR, Margolin SG. A quantitative study of the gastric secretory response to sham feeding in a human subject. *Gastroenterology* 1950; **16**: 104–116.
3 Wolf S, Wolf HG. *Human gastric function*. Oxford University Press: London; 1947.
4 Cecil JE, Francis J, Read NW. Relative contributions of intestinal, gastric, oro-sensory influences and information to changes in appetite induced by the same liquid meal. *Appetite* 1998; **31**: 377–390.
5 Jordan HA. Voluntary intragastric feeding: oral and gastric contributions to food intake and hunger in man. *J Comp Physiol Psychol* 1969; **68**: 498–506.
6 Novin D, Robinson K, Culbreth LA, Tordoff MG. Is there a role for the liver in the control of food intake. *Am J Clin Nutr* 1985; **42**: 1050–1062.
7 De Graaf C, Hulshof T, Jas P. Short-term effects of different amounts of protein, fats and carbohydrates on satiety. *Am J Clin Nutr* 1980; **55**: 33–38.
8 Poothullil JM. Oral satiation and the regulation of intake. *Physiol Behav* 1995; **57**: 349–352.
9 Warwick ZS, Hall WG, Pappas TN, Schiffman SS. Taste and smell sensations enhance the satiating effect of both a high-carbohydrate and a high-fat meal in humans. *Physiol Behav* 1993; **53**: 553–563.
10 Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res* 1985; **29**: 71–83.
11 Dye L, Blundell JE. Menstrual cycle and appetite control: implications for weight regulation. *Hum Reprod* 1997; **12**: 1142–1151.
12 Birch LL, McPhee L, Sullivan S. Children's food intake following drinks sweetened with sucrose or aspartame: time course effects. *Physiol Behav* 1989; **45**: 387–395.
13 Booth DA, Campbell AT, Chase A. Temporal bounds of post-ingestive glucose induced satiety in man. *Nature* 1979; **228**: 1104–1105.
14 Lavin JH, French SJ, Read NW. The effect of sucrose- and aspartame-sweetened drinks on energy intake, hunger and food choice of female, moderately restrained eaters. *Int J Obes Relat Metab Disord* 1997; **21**: 37–42.
15 Rogers PJ, Carlyle J, Hill AJ, Blundell JE. Uncoupling sweet taste and calories: comparison of the effects of glucose and three high intensity sweeteners on hunger and food intake. *Physiol Behav* 1988; **43**: 547–552.
16 DiMeglio DP, Mattes RD. Liquid versus solid carbohydrate: effect on food intake and body weight. *Int J Obes Relat Metab Disord* 2000; **24**: 794–800.
17 Mattes RD. Dietary compensation by humans for supplemental energy provided as ethanol or carbohydrate in fluids. *Physiol Behav* 1996; **59**: 179–187.
18 Geary N, Kissileff HR, Pi-Sunyer FX, Hinton V. Individual, but not simultaneous, glucagon and cholesystokinin infusions inhibit feeding in men. *Am J Physiol* 1992; **262**: R975–R980.
19 Teff KL, Engelman K. Oral sensory stimulation improves glucose tolerance in humans: effects on insulin, C-peptide, and glucagon. *Am J Physiol* 1996; **270**: R1371–R1379.
20 Teff KL, Levin BE, Engelman K. Oral sensory stimulation in men: effects on insulin, C-peptide, and catecholamines. *Am J Physiol* 1993; **265**: R1223–R1230.
21 VanderWeele DA. Insulin is a prandial satiety hormone. *Physiol Behav* 1994; **56**: 619–622.
22 Helman CA. Chewing gum is as effective as food in stimulating cephalic phase gastric secretion. *Am J Gastroenterol* 1988; **83**: 640–642.
23 Richardson CT, Walsh JH, Cooper KA, Feldman M, Fordtran JS. Studies on the role of cephalic–vagal stimulation in the acid secretory response to eating in normal human subjects. *J Clin Invest* 1977; **60**: 435–441.
24 Haber GB, Heaton K, Murphy D, Burroughs LF. Depletion and disruption of dietary fibre. Effects on satiety, plasma-glucose, and serum-insulin. *Lancet* 1977; **i**: 679–682.
25 Tordoff MG, Alleva AM. Oral stimulation with aspartame increases hunger. *Physiol Behav* 1990; **47**: 555–559.
26 Brala PM, Hagan RL. Effects of sweetness perception and caloric value of a preload on short term intake. *Physiol Behav* 1983; **30**: 1–9.
27 Melanson KJ, Westerterp-Plantenga MS, Campfield LA, Saris WHM. Blood glucose and meal patterns in time-blinded males, after aspartame, carbohydrate, and fat consumption, in relation to sweetness perception. *Br J Nutr* 1999; **82**: 437–446.
28 Castiglione KE, Read NW, French SJ. Food intake responses to upper gastrointestinal lipid infusions in humans. *Physiol Behav* 1998; **64**: 141–145.
29 French SJ, Conlon CA, Mutuma ST, Arnold M, Read NW, Meijer G, Francis J. The effects of intestinal infusion of long-chain fatty acids on food intake in humans. *Gastroenterology* 2000; **119**: 943–948.
30 de Graaf C, Schreurs A, Blauw YH. Short-term effects of different amounts of sweet and nonsweet carbohydrates on satiety and energy intake. *Physiol Behav* 1993; **54**: 833–843.