Separating the Actions of Sweetness and Calories: Effects of Saccharin and Carbohydrates on Hunger and Food Intake in Human Subjects

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Received 19 January 1989

INTENSE sweeteners, such as saccharin, cyclamate, aspartame and acesulfame-K, provide a means of sweetening food without adding significantly to its energy value. They can be used as experimental tools in the study of appetite control, and in a wider context they are perceived by consumers as aids to dietary control. Therefore understanding the influences of intense sweeteners on human appetite has both theoretical and practical significance. Two issues which require clarification concern the role of sweetness and the role of caloric content. The addition of an intense sweetener to a food increases its sweetness without altering its energy value. On the other hand, the substitution of an intense sweetener for sugar in a food reduces the food’s energy value while maintaining its sweetness. Many studies have failed to distinguish between the logical consequences of these manipulations [see (5)].

A majority of the experimental studies which have examined the effects of covertly substituting an intense sweetener for sucrose in foods and beverages found that voluntary food intake increased to compensate, at least partially, for the lower energy value of the item(s) containing intense sweeteners [reviewed in (31)]. This demonstrates that ingested calories suppress appetite. However, nothing can be concluded about the role of sweetness from this comparison, because sweetness was not systematically varied. Results from studies which included a comparison between different sweetness levels (same caloric value) indicate a stimulatory effect of sweetness on appetite. For example, compared with the

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1Preliminary reports of this study were presented at a meeting of the North American Association for the Study of Obesity, Boston, MA, October, 1987 ([5], includes part of the data from the first replication only], to the Association for the Study of Obesity, London, April 1988, and at a Conference on the Psychobiology of Eating Disorders, New York Academy of Sciences, New York, October, 1988.

2PJR is supported by the Agriculture and Food Research Council
The present study sought to further investigate the role of sweetness and energy content in the control of appetite by varying these parameters in a balanced 2 × 2 cell design (5). Hunger motivation and food intake were assessed following the consumption of four types of low-fat yogurt snack (preload) unsweetened, and the same yogurt sweetened to equal intensity with saccharin or glucose, or supplemented with starch. Yogurt provides an excellent medium for these manipulations since it is commonly eaten in unsweetened and sweetened forms. Screening ensured that participating subjects liked these types of yogurt equally, so that differences in sweetness and energy content would not be confounded with differences in palatability.

METHOD

Subjects

Twenty-four undergraduate volunteers, 6 men and 18 women (aged 18–29 years) took part in the study. They were taking psychology as a major or subsidiary subject. Two cohorts of 12 subjects attending different classes were run 6 months apart. No monetary inducement was offered for their participation, although they were told they would receive a free lunch on each of the experimental days. All of the subjects were of normal weight for height (mean and SD Body Mass Index = 20.7 ± 1.3), and scored low or moderately low on the Herman restraint scale (mean and SD score = 11.0 ± 4.7). The restraint scale assesses behavioural and attitudinal concern about dieting and short-term weight stability. High scorers were excluded from the study during recruitment because they are known to display disturbed eating patterns. For example, highly restrained individuals have been found, paradoxically, to increase their intake of food following a preload identified as high in calories (13). Potential subjects were also screened for their food preferences, and only those who expressed a liking or better (5-point scale ranging from ‘dislike extremely’ to ‘like extremely’) for both unsweetened and sweetened yogurts and who indicated that they usually ate yogurt at least once a week were recruited.

Design and Preloads

The study took the form of a preload manipulation followed by the measurement of motivation to eat and food intake. It was conducted according to a within subjects design, and subjects were ‘blind’ to its true purpose (the study was presented as ‘an investigation of the effects of nutrients on taste perception and food choice’). As far as possible individual subjects were tested on the same day of the week, usually with one week between each treatment.

The preloads were administered in a counterbalanced order. All subjects received the following four preloads:

1) Ratings of motivation to eat were made on 100 mm visual-analogue scales (word anchored at either end) These were:

   (a) ‘How strong is your desire to eat?’ (Very strong–Very weak);
   (b) ‘How hungry do you feel?’ (As hungry as I have ever felt–Not at all hungry),
   (c) ‘How full do you feel?’ (Very full–Not at all full),
   (d) ‘How much food do you think you could eat?’ (A large amount–Nothing at all).

This last rating scale is called ‘prospective consumption’. Subjects were instructed to ‘mark the line for each question according to how you feel at this moment, and regard the dimensions as the most extreme you have ever felt.’ Measuring from the right-hand end of each scale in mm gave scores ranging from 0–100 mm. These scales were developed more than 10 years ago and have since been used in many studies. There is a large body of data supporting their validity and reliability (e.g., (30).

2) Food intake was measured in a ‘test’ meal eaten at lunchtime. Subjects were presented individually with a tray containing the following preweighed foods 16 sandwich quarters (wholemeal bread, spread with margarine and containing 2 cold fillings chosen from turkey, roast beef, roast pork, ham, tuna, salmon, cheddar cheese, cottage cheese and peanut butter); tomato, cucumber and lettuce, 6 chocolate covered digestive biscuits or 4 small portions of apple pie; fresh fruit (one of apple, banana and orange). Still mineral water was available to drink with the meal. Individual subjects’ menus were chosen according to their preferences stated at the beginning of the study, and they received the same menu on each of the 4 or 5 occasions. The amount of food offered (>1,500 kcal) was such that the subjects would not normally be expected to eat it all. They were told that the meal was being provided as a reward for participating in the study and that they should eat to
satisfaction. The meals were eaten in groups of 4 to 6 subjects and
in a relaxed setting, but at all times they were closely supervised.

3. Eating following the test meal was assessed using diary
records. Subjects were provided with type-written sheets contain-
ing instructions and spaces for recording the following informa-
tion: time at which a meal, snack or drink was consumed, a detailed
description of the food or drink, and the amount eaten expressed as
a weight (from packaging or kitchen scales) or in household
measures.

4. Sensory and affective ratings of the yogurt preloads were
made on 100 mm visual-analogue scales. There were 8 scales:
sweetness, sourness, bitterness, thickness, smoothness, sharpness,
pleasantness, and fillingness.

Procedure
Subjects were instructed to eat their normal breakfast, but not
to eat after 9:30 a.m. The timetable of subsequent events is set out
in Table 1. Subjects were asked to eat all of the preload, and this
took between 3 and 7 minutes. Mineral water was available to
drink with the preload. On leaving the laboratory at 12:05 p.m.
subjects were instructed not to eat or drink (except water) again
until they returned for lunch. They were also provided with a set
of motivation rating scales and told that they should complete them
at 12:30 p.m. Following the test meal subjects were asked to
record on the diary record sheet all food and drink taken up to the
time they went to bed that night.

Ratings of sweetness, pleasantness, etc. of samples of the
yogurt preloads were made by the first cohort of subjects once
after the main part of the study had been completed. After tasting
and swallowing a small amount (<20 ml) of yogurt the subjects
immediately completed all 8 ratings before tasting the next
sample. The order of presentation of the different yogurts was
counterbalanced across subjects. The second cohort of subjects
made these ratings during the experimental sessions, immediately
following consumption of the entire yogurt preload.

On completion of each half of the study debriefing meetings
were held in which the subjects were fully informed of the purpose
and nature of the experimental manipulations. The study was
approved by the Leeds University, Department of Psychology
Ethics Committee.

Data Analysis
The initial scoring of the motivation rating scales and analysis
of the diary records was carried out blind to the identity of the pre-
load conditions. Energy intakes were computed from the diary
records with reference to standard food composition tables and
supplements (26, 34, 38), and manufacturers’ data. One subject
(female) failed to complete the motivational ratings as instructed,
and one female and two male subjects failed to return a full set of
diary records. Therefore, the results for the motivational ratings
and food intake are based on data from 23 and 21 subjects,
respectively. Statistical analysis was carried out using repeated
measures ANOVA, and planned a priori two sample comparisons
were made using Student’s paired t-test (two-tail probabilities).

RESULTS

Motivational Ratings
The effects of consuming the various preloads on ratings of
motivation to eat are shown in Fig. 1. ANOVA revealed a
significant effect of calories for desire to eat and prospective
consumption, a significant effect of time for all ratings, a
significant sweetness × time interaction for desire to eat and
hunger, and finally a significant 3-factor interaction for desire to
eat (Table 2). There were three clear findings. First, the high-
calorie preloads brought about a greater reduction in appetitive
motivational ratings (particularly desire to eat) than the low-calorie
preloads. Second, during the 60 minutes following the consump-
tion of the preloads and prior to lunch there was a recovery in appetitive motivational ratings and a
decrease in fullness. Third, the recovery in desire to eat and
hunger was greatest following the sweet preloads, with saccharin
producing the largest effect (accounting for the sweetness × time
and sweetness × calories × time interactions). Note that the
initial effect of consuming the saccharin preload was not signifi-
cantly different from any of the other preloads. Subsequently,
however, only the appetitive motivational ratings made following
the consumption of the saccharin preload increased to above
baseline (Fig. 1).

Food Intake
The results for food intake are shown in Fig. 2. ANOVA of the
cumulative food intakes revealed significant effects of calories,
FIG 1 The effects of consuming four types of yogurt preload on subjective motivational ratings. Statistically significant (t-test, p<0.05) changes from baseline (i.e., ratings made immediately before the preloads were eaten) are indicated by closed symbols. Means within the same interval sharing common letters are significantly different (p<0.05).

sweetness and time, but no significant interaction effects (Table 2). Food intake was lower following the high-calorie preloads compared with the low-calorie preloads by an amount that fully compensated for the difference in their energy values. This is confirmed by the finding of a nonsignificant effect of calories when the preloads were included in the calculation of the cumulative food intakes. The significant effect of sweetness was due to higher food intake following the saccharin preload and, to a lesser extent, the glucose preload.

Food intake in the test meal was significantly higher following the saccharin preload compared with the plain preload, and Fig. 2 shows that saccharin appeared to promote further increases in food intake during subsequent intervals. Although this was not evident from the 3-factor ANOVA, a supplementary analysis comparing only the saccharin and plain preloads (2-factor ANOVA preload and time) confirmed a significant preload × time interaction, F(3,60) = 2.81, p<0.05, in addition to significant main effects of preload, F(1,20) = 20.23, p<0.001, and time, F(3,60) = 122.9, p<0.001.

Combined Saccharin and Starch Supplement

Both desire to eat and hunger were significantly higher 60 minutes following the saccharin plus starch preload compared with the starch preload, smallest t(11) = 2.40, p<0.05, whereas there were no reliable differences between the effects of these preloads on ratings made immediately after their consumption, largest t(11) = 1.41, p>0.1. Food intake in the test meal was higher following the saccharin plus starch preload than following the starch preload, although the difference was only marginally significant [mean difference = 176 kcal, t(9) = 2.04, p<0.01]. At the end of the last measurement period (i.e., 1:30 a.m.), this difference was 390 kcal, t(9) = 2.05, p<0.1. The corresponding differences between the starch and glucose preloads were 134 and 146 kcal, respectively, largest t(9) = 1.23, p>0.1. Thus the effects of adding saccharin to the starch-supplemented preload were similar to the effects of adding saccharin to the low-calorie (plain) preload.

Preload Ratings

Although the procedures differed, no clear differences were evident between the sensory and hedonic ratings made by the two cohorts of subjects, and therefore their data were combined. These data were analysed using single-factor ANOVA and the results are shown in Table 3. It can be seen that the preloads differed significantly in sweetness, sourness, bitterness and thickness. There were no significant differences in ratings of smoothness, sharpness, pleasantness and fillingness. There were no differences on any of the ratings between the two sweetened preloads and also between the two unsweetened preloads, except for thickness. The glucose preload and, to a smaller extent, the starch preload were rated as less thick than the plain and saccharin preloads, which were rated as similar on this dimension.

DISCUSSION

The present study has revealed several notable findings. Supplementing the yogurt preload with carbohydrate suppressed motivational ratings and food intake, whereas raising the level of sweetness appeared to increase appetite. Furthermore, saccharin had a particularly pronounced effect, promoting increases in food intake both in the test meal and during subsequent intervals. (Note that this later effect of saccharin cannot simply be attributed to possible inaccuracies in the diary method of recording food intake. In a within-subjects design any lack of precision in this measurement should not create systematic bias towards one treatment over another. Instead it would be expected to contribute noise to the
SACCHARIN AND FOOD INTAKE

FIG 2 Food intake at intervals following the consumption of four types of preload unsweetened yogurt (plain), and the same yogurt sweetened to equal intensity with glucose or saccharin, or supplemented with starch. Subjects ate the lunchtime meal beginning at 1:00 p.m., one hour after the preload was eaten. These cumulative intake data include the preloads (indicated by the stippled areas). The standard errors ranged between ±54 starch and ±128 (saccharin) for the intakes at 1:30 a.m. The superscripts indicate the comparisons between plain, starch or glucose versus saccharin (intakes including the preloads) which were significant or which approached significance as follows (a) t(20) = 4.22, p<0.05, (b) t(20) = 1.75, p<0.1, (c) t(20) = 3.06, p<0.01, (d) t(20) = 2.30, p<0.05, (e) t(20) = 4.11, p<0.01, (f) t(20) = 2.54, p<0.02, (g) t(20) = 1.84, p<0.1. None of the comparisons between plain, starch and glucose (preloads included) were significant (all ps>0.1).

data, which in turn would mitigate against the detection of significant treatment differences.

An important methodological aspect of the study was that the various preloads were equally preferred. Only volunteers who liked both sweetened and unsweetened yogurt were selected for the study. Consequently, the manipulations of calorie content and starch preloads and the saccharin plus starch versus starch preloads are apparently consistent with this conclusion. Food intake was also somewhat higher following the glucose-sweetened preload compared with the starch preload, but the difference was not statistically significant.

Several suggestions have been made concerning the mechanisms by which sweetness could be expected to influence appetite [e.g., (4,8)]. Most relevant to the present findings is the possible involvement of preabsorptive digestive responses. These refer to reflexive changes in pancreatic and gastrointestinal secretions triggered by sensory contact with food (intestinal, as well as visual, olfactory and oral mediation may be involved (24, 25, 27)). As well as facilitating the disposal of food by the body, it has been proposed that these reflexes, and in particular the palatability dependent cephalic-phase insulin response, play an important role in modulating food ingestion (8, 20, 27, 28). Therefore, the sweet taste of saccharin might promote increases in hunger and food intake by stimulating preabsorptive insulin secretion. Supporting this interpretation is evidence that saccharin ingestion stimulates insulin release in humans (12) and rats (2, 28, 37); but see (10)]. Furthermore, other studies have found a decline in blood glucose levels following oral saccharin, also in humans (1, 16, 17) and in rats (7,35). This may implicate increased insulin secretion, although insulin levels were not measured. [At least one study (9) which has been quoted as not replicating these findings used only 4 subjects and a small 30 mg dose of saccharin. There was, nonetheless, a 5% decline in blood
glucose levels and a 30% increase in insulin secretion over baseline). Jorgensen's study (16) is particularly noteworthy. A reanalysis of his data conducted by the present authors revealed that a significant decrease (6%) in blood glucose occurred after the ingestion of 45 mg saccharin dissolved in 80 ml water, and also when the same solution was tasted but not swallowed (11% decrease). In contrast, neither the ingestion of water nor saccharin introduced into the duodenum by tube had detectable effects. Hence, the taste of saccharin appears to be a sufficient stimulus to produce a fall in blood glucose. Another important aspect of these results is that the maximum changes in blood glucose levels occurred at between 20 and 60 minutes after saccharin ingestion (1, 9, 16, 17) which corresponds closely with the time course of saccharin's stimulatory effect on hunger observed in this and a previous study (32).

Tordoff also proposes the involvement of a cephalic-phase neural reflex underlying saccharin-induced increases in food intake observed in rats (36). In short-term tests rats allowed to drink a saccharin solution eat 10–15 percent more food than when given only water to drink. The evidence to date, however, supports a role for a cephalic-phase reflex that directly influences liver metabolism, while findings indicate that cephalic-phase insulin secretion in rats drinking saccharin is unrelated to subsequent increases in food intake (36).

The above discussion has focussed on the effects arising from tasting saccharin. However, in addition to the stimulation of orosensory receptors, possible postigestive actions of saccharin should be considered. Saccharin might, for example, trigger receptors within the alimentary canal (24, 25) or it might act on orosensory receptors, possible postingestive actions of saccharin. However, an addition to the stimulation of taste saccharin. As yet there appears to be no increased the release of insulin from isolated pancreatic islets (15), not metabolised, saccharin injected parentally has been shown to affect potency insulin-induced hypoglycemia (23), and may influence glucose metabolism through an ability to inhibit the activity of glucose-6-phosphatase [(21), but see (22)]. Furthermore, a recent study found that low concentrations of saccharin increased the release of insulin from isolated pancreatic islets (15), and a similar result has been reported for the structurally related sweetener acesulfame-K (18, 19). As yet there appears to be no direct evidence to link any of these findings with saccharin's effects on appetite. Nonetheless, in the present study, as well as short-term effects, saccharin stimulated increases in food intake beyond the test meal, many hours after the consumption of the preload. This strongly suggests the involvement of a postigestive action(s) of saccharin. It seems unlikely that the taste of saccharin could have produced such pronounced effects. On the other hand, the slow rate of absorption of saccharin from the gut is consistent with a delay between the ingestion of saccharin and the occurrence of postabsorptive effects. Although Jorgensen (16) detected no changes in blood glucose following an intraduodenal saccharin load, measurements were continued for only one hour.

The possible existence of postigestive influences of saccharin complicates the interpretation of the findings with respect to the role of sweetness. (Note also that the glucose and starch preloads may differ significantly in their postigestive effects due, for example, to differences in their rates of digestion). The extent to which orosensory stimulation by saccharin or some other action of this substance contributed to its observed effects on appetite cannot be definitely determined from the present study. Nonetheless, a comparison with studies on aspartame supports the conclusion that sweetness stimulates appetite, at least in the short term. As mentioned above, preloads sweetened with aspartame have also been found to promote increases in hunger and food intake (3, 11, 32). Aspartame and saccharin are, however, chemically unrelated and would therefore be expected to differ in their postigestive actions (31). Indeed, one recent study found that a moderate dose of aspartame consumed in capsules significantly reduced food intake [see (31)]. A similar investigation of the effects of ingesting saccharin without tasting may help to clarify some of the issues discussed above.

In summary, the present results confirm and extend previous findings showing that intense sweeteners do not possess the same satiating capacity as glucose and sucrose. Thus the substitution of saccharin for glucose failed to reduce overall food intake. Furthermore, the extent to which the saccharin-induced sensitivity to insulin in the rat. J Comp Physiol Psychol 86 350–358, 1974

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