International Journal of Obesity (1997) 21, 37–42
 0307–0565/97 $12.00

The effect of sucrose- and aspartame-sweetened drinks on energy intake, hunger and food choice of female, moderately restrained eaters

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Objective: To compare the effects of aspartame-sweetened and sucrose-sweetened soft drinks on food intake and appetite ratings of female restrained eaters.
Subjects: Fourteen female students, shown to have eating restraint.
Methods: Subjects were given four drinks (330 ml) of aspartame-sweetened lemonade, sucrose-sweetened lemonade and carbonated mineral water on three separate days. Seven of the subjects were informed of the drink type they were consuming on each occasion.
Measurements: Appetite ratings were recorded and energy and macronutrient intakes were measured during the study day and day after leaving the department.
Results: During the first study day energy intake was lower whilst drinking the sucrose-sweetened lemonade compared with the aspartame-sweetened lemonade, although neither differed significantly from energy intakes during the day they drank water. When the calories from the sucrose-sweetened lemonade were included (1381 kJ, 330 Kcal) energy intake did not differ between treatments. The following day energy intake was significantly higher after the aspartame-sweetened lemonade compared with both sucrose-sweetened lemonade and the water due to an increase in the amount of carbohydrate consumed and resulted in a higher total energy intake over the two days studied. Knowledge of the drink types had no effect on energy intake or macronutrient intake. Appetite ratings did not differ between drinks and were not affected by knowledge of the drink types.
Conclusion: These results suggest that in females with eating restraint, substituting sucrose-sweetened drinks for diet drinks does not reduce total energy intake and may even result in a higher intake during the subsequent day.

Keywords: aspartame; sucrose; appetite; energy intake; restrained eaters

Introduction

Energy ingested in the form of carbohydrate has an important effect on appetite regulation. Previous studies have shown that calories ingested in carbohydrate supplemented preloads were accurately compensated for by a reduction in intake from a subsequent test meal when compared with preloads containing artificial sweeteners or left plain.[1,2] Thus there was no overall difference in energy consumption when the preload and test meal intake were summed. Furthermore, in some studies, sweetness in the absence of calories has been shown to stimulate appetite: Rogers *et al*[3] and Blundell *et al*[4] have shown that ingestion of concentrated solutions of sweeteners increases motivation to eat compared with water and, similarly, Tordoff and Alleva[5] found that chewing gum sweetened with aspartame increased hunger compared with a non-sweet control.

Most previous studies in this area have examined the effects of covert ingestion of sweeteners on the short-term eating behaviour of normal subjects with low dietary restraint. Restrained eaters exert a high degree of cognitive control over food intake and many replace high calorie products with reduced calorie alternatives as a simple means of reducing energy intake.[6] It is not known how consumption of artificially sweetened products would affect later intake in restrained eaters nor how knowledge of consumption of low calorie items would influence eating behaviour.

Since many artificial sweeteners are ingested in the form of soft drinks,[7] the aim of the present study was to compare the effects of soft drinks containing sucrose versus aspartame on appetite ratings and 48 h energy and macronutrient intake of healthy females of moderate dietary restraint and also to determine how knowledge of the drink type affected these measures. Food intake over 48 h was studied, as energy compensation may not be detected during

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Received 22 May 1996; revised 20 September 1996; accepted 23 September 1996

consumption of a single test meal and may only become evident later under ad-libitum conditions.

Methods

Subjects

Studies were carried out on fourteen healthy, normal weight female university students recruited by posters placed throughout the University of Sheffield and by word of mouth. Potential subjects completed the Three-Factor Eating Questionnaire (TFEQ)[8] and were asked questions about their eating patterns. Subjects were selected if their scores on the TFEQ indicated dietary restraint (cognitive restraint score > 10 out of a possible 21, [13.3 ± 0.6; mean ± s.e.]), but were excluded if they were currently dieting or if they reported, in a question added to the TFEQ, that their eating patterns were markedly affected by their menstrual cycle.

The selected subjects were asked to choose an evening meal from a menu list and were randomly assigned to either an informed or uninformed study group. The informed group were told the nature of the drink they were consuming on each occasion. Each subject gave written consent to participate in the study, the protocol for which was approved by the Local Research Ethical Committee Northern General Hospital, Sheffield. In order to disguise the true purpose of the study, the subjects were told that it was an investigation into the effects of soft drinks on performance and arousal and asked to complete simple computer tasks and questionnaires throughout the study day.

Protocol

Subjects came to the Centre for Human Nutrition at 9.00 am on three occasions, each exactly one week apart, after they had consumed their usual breakfast. They were given a different drink type on each test day in a randomised order. These were normal sucrose-containing lemonade, diet aspartame-containing lemonade and carbonated mineral water (Safeway, Table 1). Subjects attending the Centre on the same day were in the same study group thus preventing the uninformed group obtaining information of the drink type from the informed group.

Drinks (330 ml) were administered to the subjects at 09.30 h, 11.30 h, 14.00 h and 16.00 h and were consumed within 15 min. A selection of high carbohydrate and high fat snacks were provided for each subject between 09.30 h and 12.30 h and again between 13.30 h and 17.30 h. A self-selection cold lunch was presented between 12.30 h and 13.00 h, and a pre-selected evening meal was served between 17.30 h and 18.00 h. Subjects were served with the same evening meal on each of the three study days.

All foods were weighed before and after presentation and were provided in amounts in excess of that which subjects would normally be expected to eat. Subjects were instructed to eat until comfortably full. On departure from the Centre at 19.00 h subjects were provided with a set of weighing scales and food diaries to record all further intake for the remainder of the evening and the following day. Energy intake and percentage energy provided by the macronutrients from the meals consumed at the centre and those recorded in the food diaries were calculated using information obtained directly from product packages and the COMP-EAT dietary analysis package (COMP-EAT, Lifeline Nutritional Services Ltd, London, UK).

Ratings of hunger, fullness and prospective food consumption were indicated on 100 mm visual analogue scale questionnaires administered at hourly intervals from 09.00 h until 12.00 h and from 13.30 h onwards, and in addition, five minutes prior to and every 15 minutes in the hour following the lunch time and evening meals. The last scale being administered at 19.00 h. The scales were adapted from a questionnaire previously published.[9]

In between meals subjects were free to read, work or watch television.

Statistical Analysis

Statistical analysis was performed using SPSS for windows v. 6.0 (SPSS Inc., USA). Repeated measures analysis of covariance (ANCOVA) was applied to ratings of hunger, fullness and prospective consumption, with drink type and time of rating as within-subject factors and knowledge of drink type as a between subject factor. Baseline ratings were used as covariates. Energy and macronutrient intakes were evaluated using analysis of variance (ANOVA) with drink type as a within-subject factor and knowledge as a between subject factor. Post hoc Scheffe tests were employed when differences due to drink type were observed. A P value of < 0.05 was considered significant.

Table 1 Nutritional composition of the test drinks (expressed as total intake, 4 × 330 ml)

Drink	*Nutritional composition/1320 ml*			
	Energy (kJ)	*Carbohydrate (g)*	*Fat (g)*	*Protein (g)*
Aspartame-sweetened lemonade	< 42	0	0	0
Sucrose-sweetened lemonade	1381	79.2	0	0
Carbonated mineral water	0	0	0	0

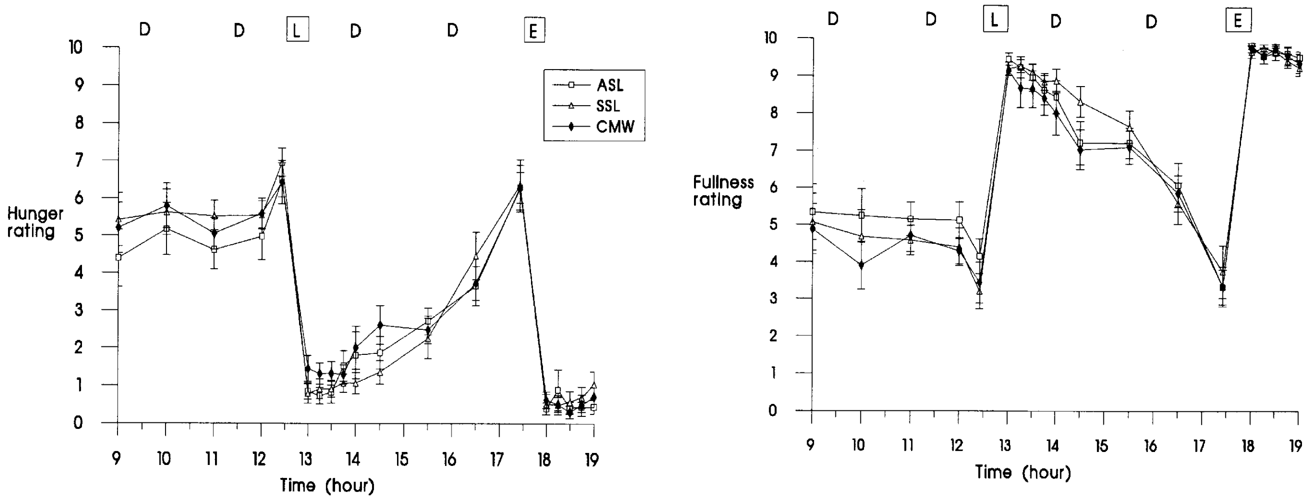

Figure 1 Hunger and fullness ratings during the first study day. ASL = aspartame-sweetened lemonade, SSL = sucrose-sweetened lemonade, CMW = carbonated mineral water. D = test drink, L = lunch meal, E = evening meal.

Results

Analysis of variance revealed no effect of knowledge of the drink type on appetite ratings, energy intake or macronutrient intake throughout the study. Therefore the data from the informed and uninformed groups are combined and presented as results for all 14 subjects.

Appetite ratings
Ratings of hunger, fullness and prospective consumption (data not shown) throughout the first study day were no different whilst consuming the different drinks (Figure 1).

Energy intake and macronutrient selection
Energy intake from the snacks and test meals provided in the department (during the first study day) was lower whilst consuming the sucrose-sweetened lemonade compared with the aspartame-sweetened lemonade ($P < 0.01$; Figure 2). However, neither energy intake during these two treatments were significantly different from that observed during the day they were consuming carbonated water. When the energy from the sucrose-sweetened lemonade (1318 kJ, 330 kcal) was accounted for there was no difference in overall energy intake between the three treatments (Figure 2). There were significant decreases in the absolute amounts of fat ($P < 0.01$) and protein ($P < 0.01$) consumed whilst drinking the sucrose-sweetened lemonade compared with the aspartame-sweetened lemonade and a non-significant decrease in the amount of carbohydrate ($P = 0.1$) consumed but no difference in macronutrient intake when expressed as percentage total energy intake (Table 2).

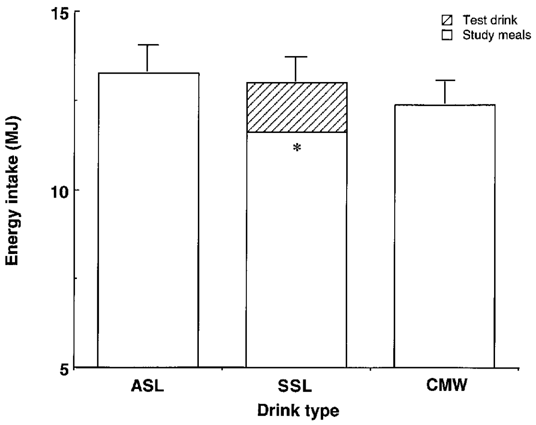

Figure 2 Energy intake during the first study day. ASL = aspartame-sweetened lemonade, SSL = sucrose-sweetened lemonade, CMW = carbonated mineral water. Study meals includes snacks, lunch and evening meal provided in the department. *Significantly lower than ASL (not including the energy provided by sucrose), $P < 0.01$.

There were no differences in energy intake, macronutrient selection or alcohol intake during the remainder of the evening after leaving the department. The following day after consuming the aspartame-sweetened lemonade energy intake was higher when compared with both the sucrose-sweetened lemonade ($P < 0.01$) and water ($P < 0.05$; Figure 3). This was due to increase in the amount of carbohydrate consumed during the day following consumption of aspartame-sweetened lemonade ($P < 0.02$) but no difference in the amount of fat, protein or alcohol consumed. There was however, a decrease in protein intake after the aspartame-sweetened drink ($P < 0.05$; Table 2) when expressed as percentage energy consumed. Total energy ($P < 0.01$) and absolute carbohydrate ($P < 0.02$) intake over the two days studied was higher following the aspartame-sweetened drink compared with the two other treatments. Absolute fat intake was also higher after the aspartame-sweetened lemonade compared with the sucrose-sweetened lemonade ($P < 0.01$) but not carbonated mineral water. However, there were no differences in total macronutrient intake when expressed as percentage energy consumed over the two study days (Table 2).

Table 2 Energy and macronutrient intake whilst consuming aspartame-sweetened lemonade (ASL), sucrose-sweetened lemonade (SSL) and carbonated mineral water (CMW)

	g			*% energy*		
	ASL	*SSL*	*CMW*	*ASL*	*SSL*	*CMW*
First study day:						
Energy (MJ)	13.3±0.9†	11.6±0.9	12.4±0.8			
Fat	168.0±11.9†	140.1±11.6	151.6±12.8	45.7±0.8	43.6±1.4	44.1±1.4
Carbohydrate	338.6±19.1	316.7±21.7	326.7±14.2	40.7±0.8	42.3±1.8	42.7±1.6
Protein	123.4±8.3†	105.2±8.3	115.7±7.7	14.1±1.1	14.4±0.4	15.2±0.6
Remainder of evening:						
Energy (MJ)	0.9±0.3	0.8±0.2	0.6±0.2			
Fat	6.4±3.4	4.6±1.9	3.6±1.9	28.4±15.0	22.7±9.6	24.2±12.2
Carbohydrate	17.6±6.4	24.4±8.3	15.9±5.6	32.6±11.8	50.5±17.2	43.9±15.4
Protein	3.3±1.0	4.6±2.2	3.1±1.0	6.6±2.0	10.3±4.9	9.2±3.1
Alcohol	9.4±6.6	4.4±2.0	4.3±2.3	32.4±22.4	17.1±7.6	22.0±9.9
Following day:						
Energy (MJ)	8.4±0.7†*	6.4± 0.7	6.8±0.5			
Fat	68.8±9.2	61.5±9.1	63.5±5.7	32.5±3.2	34.8±2.9	34.9±1.9
Carbohydrate	254.8±21.3†*	191.1±18.6	201.4±16.1	46.5±2.7	47.1±3.1	46.2±0.9
Protein	61.2±6.9	63.0±6.3	60.2±4.9	12.3±0.9†*	16.1±0.8	15.1±1.0
Alcohol	22.0±9.6	5.9±4.2	8.5±3.9	7.1±3.3	2.0±1.2	3.8±1.9
2 day total:						
Energy (MJ)	22.5±0.9†*	18.8±0.8	19.8±0.8			
Fat	236.7±12.5†	201.7±10.7	215.2±11.6	39.0±1.3	40.6±1.3	40.8±1.2
Carbohydrate	593.4±26.6†*	507.8±20.0	528.7±20.3	44.2±1.2	45.5±1.1	44.9±1.2
Protein	184.6±8.7	168.1±8.7	177.3±9.8	13.8±0.5	15.0±0.5	14.9±0.6
Alcohol	31.4±11.6	10.4±5.3	12.8±5.3	4.0±1.5	1.5±0.7	1.8±0.8

Data does not include energy and macronutrient intake from the test drinks.
*Significantly different from carbonated mineral water, $P<0.05$.
†Significantly different from sucrose-sweetened lemonade, $P<0.05$.

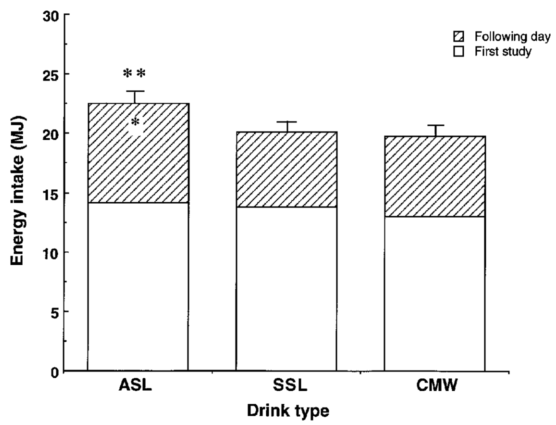

Figure 3 Total energy intake over the two study days. ASL = aspartame-sweetened lemonade, SSL = sucrose-sweetened lemonade, CMW = carbonated mineral water. First study day includes study meals provided in the department, test drinks and foods consumed during the remainder of the evening. *Energy intake the following day significantly higher after ASL compared with SSL and CMW, $P<0.05$. **Total 2 day energy intake significantly higher when consuming ASL compared with SSL and CMW, $P<0.01$.

Discussion

This study showed that, in females with moderate eating restraint, drinking diet lemonade sweetened with aspartame increased energy intake compared with ingestion of regular lemonade sweetened with sucrose. This effect only became evident on the day after the drinks were consumed. The fact that we did not observe any differences in appetite ratings may have been due to the snacks being freely available to the subjects throughout the study, thus any changes in appetite may have been immediately compensated for by an appropriate change in food intake.

Energy intake

The increase in energy intake of approximately 1633 kJ (390 kcal) on the test day when consuming aspartame-sweetened lemonade was similar to the 1381 kJ (330 kcal) consumed from the sucrose-sweetened lemonade. Therefore, when the intakes from the test drinks and study meals were summed there was no difference in total energy consumption, indicating that accurate caloric compensation for the sucrose calories had occurred. Restrained eaters tend to have a high intake of artificially sweetened products[6] and are likely to use them as a means of reducing energy intake. However, our observation that energy intake was not decreased when consuming aspartame-sweetened lemonade suggests that this strategy would be futile unless the rest of the diet was more strictly controlled.

Compensation for caloric dilution has been observed in previous studies on non-restrained eaters. In a study of 2–5 y old children, Birch *et al*[2] found intake from a test lunch was reduced following caloric sweet drinks compared with aspartame-sweetened drinks and water by amounts very similar to the energy value of the caloric preloads. Similarly, although Rolls *et al*[10,11] reported that non-dieting adults showed only a non-significant reduction in energy intake from a test meal following sucrose compared with aspartame-sweetened preloads, the observation that total energy intakes were no different implied that some compensation must have occurred. Anderson *et al*,[12] however, found no evidence of caloric compensation for a 837–1004 kJ (200–240 kcal) difference between aspartame and sucrose sweetened drinks in 9–10 y old children.

Because energy intakes when consuming either aspartame-sweetened lemonade or sucrose-sweetened lemonade did not differ significantly from those recorded when subjects ingested carbonated mineral water, it is impossible to deduce whether the difference in energy intake between the two sweetened drink treatments was due to a satiating effect of the sucrose or stimulation of appetite by aspartame. Probably both were operating since there was a non-significant reduction in energy intake with sucrose-sweetened lemonade and a non-significant increase with aspartame-sweetened lemonade. This pattern would be in accordance with the results of a number of studies by Rogers and Blundell[13,14] indicating that calories ingested as carbohydrate suppress appetite whereas sweetness tends to stimulate appetite.

The results from the food diaries would suggest that aspartame was having a greater stimulatory effect on appetite on the day after ingestion. Energy intake was higher after consumption of the aspartame-sweetened drink compared with both the sucrose-sweetened lemonade and carbonated water treatments. Rogers and Blundell[1] found a similar long term effect of saccharin in volunteers of low dietary restraint: intake was not only increased during a lunch-time test meal following ingestion of saccharin-sweetened yoghurt compared with both plain and glucose-sweetened yoghurt but the difference continued to increase over the following 13 h. The mechanism for the increase in energy intake following the aspartame is not clear. Any stimulation of appetite due to sweetness stimulating cephalic phase insulin secretion would only explain an increase in food intake over a short period of time. It might be suggested that eating behaviour was being regulated via the state of carbohydrate stores, such that when intake of carbohydrate was reduced due to artificial sweetener consumption, subsequent intake was increased in order to replenish stores. However, if this were true then it would be expected that energy intake would also have been increased following consumption of water, but this was not the case. It is possible that the subjects in the uninformed group could also taste the difference between the sucrose and aspartame sweetened drinks and therefore the reduction in energy intake may have been due to cognitive restraint following the higher calorie drink. This seems unlikely, however, as the studies were conducted in random order at least a week apart and the subjects were not told that they would be given three different drink types. Furthermore, it is doubtful that cognitive mechanisms would operate to affect energy intake on the subsequent day.

Previous studies have not shown similar increases in energy intake following aspartame ingestion: Although Rogers and colleagues[3] showed that aspartame-sweetened water increased appetite ratings compared with unsweetened water there was in fact, a small, although non-significant, decrease in subsequent energy intake from a test meal presented one hour later. It has been suggested that this biphasic response to aspartame occurs due to an initial stimulatory effect of its sweet taste followed by an inhibitory postingestive action. Studies in which aspartame is delivered in capsules, without being tasted, reduces energy intake from a test meal,[15] suggesting a physiological action due to the effect of aspartame on gastrointestinal receptors. Since the amino acid sequence of aspartame is the same as the C terminal dipeptide of cholecystokinin (CCK) Rogers and colleagues[16] have suggested that aspartame may act on receptors in the gut either to cause satiety or to stimulate CCK release. Our results did not confirm any satiating action of aspartame. However, as has been suggested by Rogers and colleagues,[15] concurrent ingestion of food may slow gastric emptying and thus delay the delivery of aspartame to the upper small intestine, possibly preventing the post ingestive anorexic effect.

Macronutrient selection

The decrease in energy intake observed during the first study day when drinking sucrose-sweetened lemonade compared with aspartame-sweetened lemonade was associated with a significant decrease in the amount of fat and protein consumed. However, as carbohydrate intake also tended to decrease then it would suggest that the reduced energy intake was not due to any specific changes in macronutrient choice. In fact, there were no differences in the percentage energy provided by the macronutrients between the three treatments. Our findings support the results of previous studies in which no changes in macronutrient selection were observed following aspartame and sucrose-sweetened preloads.[11,12]

The increase in energy intake during the day following the aspartame-sweetened lemonade compared with the two other treatments was due to an increase in the absolute amount of carbohydrate consumed but no difference in the amounts of fat and protein eaten. A slight, although non-significant increase, in intake of alcohol would also have contributed to the increased energy intake. It has been reported that compared with unrestrained eaters, restrained eaters show a strong tendency to avoid fat.[6] Therefore it is possible that when the subjects were overeating following aspartame they were still controlling their fat intake but over consuming carbohydrate. Perhaps the subjects overconsumed on all foods due to the experimental conditions in first study day, when a number of appetising foods and snacks were freely available, but then re-established control of fat intake when they returned to their normal environment, instead overeating carbohydrate. Some support for this suggestion comes from the observation that the subjects mean energy intake for all 3 treatments during the study day (12.9 MJ, 3081 kcal) was much greater (160%) than would normally be expected from this age group (8.1 MJ, 1940 kcal/d).[17] However, the following day, when back in their normal environment, their energy intake was reduced to more expected levels (7.2 MJ, 1717 kcal). When the results were expressed as percentage energy, however, there was a decrease in percentage energy provided by protein following the aspartame-sweetened drink.

Knowledge

Although restrained eaters exert a high degree of cognitive control over food intake, our results show that energy intake was not influenced by knowledge of the sweetener type, suggesting a physiologic action of aspartame on energy control mechanisms. However, it is possible that the subject numbers may have been too small ($n = 7$ in each group) to test with reasonable power the effect of information on intake. Other studies have also found that subsequent intake was not altered by providing the subjects with information regarding the energy value of preloads.[11,14] Although Rolls and colleagues[11] suggested that this finding may have been due to the fact that their subjects were of low dietary restraint and therefore were not concerned about their overall calorie intake, our data show that a similar phenomenon occurs in individuals with moderate dietary restraint. These findings are not in accordance with those of Mattes[18] who found that subjects who were told that they were consuming aspartame-sweetened cereal tended to consume more in subsequent meals not only compared with intake following sucrose-sweetened cereal, but also when they were not informed of the type of sweetener used.

Conclusions

This study has shown that female restrained eaters do not automatically reduce their total energy intake when sucrose-sweetened drinks are replaced by 'diet' drinks containing aspartame. On the contrary, our data suggests that energy intake may even increase during the subsequent day.

Acknowledgements

This research was supported by The Sugar Bureau.

References

1 Rogers PJ, Blundell JE. Separating the actions of sweetness and calories: effects of saccharin and carbohydrates on hunger and food intake in human subjects. *Physiol Behav* 1989; **45**: 1093–1099.
2 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.
3 Rogers PJ, Carlyle J, Hill AJ, Blundell JE. Uncoupling sweet taste and calories: Comparison of the effects of glucose and three intense sweeteners on hunger and food intake. *Physiol Behav* 1988; **43**: 547–552.
4 Blundell JE, Rogers PJ, Hill AJ. Artificial sweeteners and appetite in man. In: Birch GG, Lindley M (eds). *Low Calorie Products* Elsevier Applied Science: London, 1988; pp 147–170.
5 Tordoff MG, Alleva AM. Oral stimulation with aspartame increases hunger. *Physiol Behav* 1990; **47**: 555–559.
6 Tuschl RJ, Laessle RG, Platte P, Pirke KM. Differences in food-choice frequencies between restrained and unrestrained eaters. *Appetite* 1990; **14**: 9–13.
7 Ministry of Agriculture, Fisheries and Food. Intakes of intense and bulk sweeteners in the UK 1987–1988. *Food Surveillance Paper No* **29**:HMSO 1990.
8 Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res* 1985; **29**: 71–83.
9 Sepple CP, Read NW. Gastrointestinal correlates of the development of hunger in man. *Appetite* 1989; **13**: 183–191.
10 Rolls BJ, Hetherington M, Laster LJ. Comparison of the effects of aspartame and sucrose on appetite and food intake. *Appetite* 1988; **11** (Suppl): 62–67.
11 Rolls BJ, Hetherington M, Laster LJ. Hunger and food intake following consumption of low-calorie foods. *Appetite* 1989; **13**: 115–127.
12 Anderson GH *et al*.. Aspartame: effect on lunch-time food intake, appetite and hedonic response in children. *Appetite* 1989; **13**: 93–103.
13 Rogers PJ, Blundell JE. Evaluation of the influence of intense sweeteners on the short-term control of appetite and caloric intake—a psychobiological approach. In: Grenby TH (ed). *Progress in Sweeteners* Elsevier Applied Science: London, 1989; pp267–289.
14 Rogers PJ, Lambert TC, Alikanizadeh LA, Blundell JE. Intense sweeteners and appetite: responses of informed and uninformed subjects consuming food sweetened with aspartame or sugar. *Int J Obes* 1990; **14**: 105.
15 Rogers PJ, Pleming HC, Blundell JE. Aspartame ingested without tasting inhibits hunger and food intake. *Physiol Behav* 1990; **47**: 1239–1243.
16 Rogers PJ, Keedwell P, Blundell JE. Further analysis of the short-term inhibition of food intake in humans by the dipiptide L-Aspartyl-L-Phenylalanine Methyl Ester (Aspartame). *Physiol Behav* 1991; **49**: 739–743.
17 Department of Health 1991 Report on Health and Social Subjects,41. Dietary reference values for food energy and nutrients for the United Kingdom. *Committee on Medical Aspects of Food policy* HMSO: London.
18 Mattes R. Effects of aspartame and sucrose on hunger and energy intake in humans. *Physiol Behav* 1990; **47**: 1037–1044.