A Satiety Index of common foods

Article *in* European Journal of Clinical Nutrition · September 1995

Source: PubMed

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European Journal of Clinical Nutrition (1995) 49, 675–690

A satiety index of common foods

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Objective: The aim of this study was to produce a validated satiety index of common foods.
Design and subjects: Isoenergetic 1000 kJ (240 kcal) servings of 38 foods separated into six food categories (fruits, bakery products, snack foods, carbohydrate-rich foods, protein-rich foods, breakfast cereals) were fed to groups of 11–13 subjects. Satiety ratings were obtained every 15 min over 120 min after which subjects were free to eat *ad libitum* from a standard range of foods and drinks. A satiety index (SI) score was calculated by dividing the area under the satiety response curve (AUC) for the test food by the group mean satiety AUC for white bread and multiplying by 100. Thus, white bread had an SI score of 100% and the SI scores of the other foods were expressed as a percentage of white bread.
Results: There were significant differences in satiety both within and between the six food categories. The highest SI score was produced by boiled potatoes (323 ± 51%) which was seven-fold higher than the lowest SI score of the croissant (47 ± 17%). Most foods (76%) had an SI score greater than or equal to white bread. The amount of energy eaten immediately after 120 min correlated negatively with the mean satiety AUC responses ($r = -0.37$, $P < 0.05$, $n = 43$) thereby supporting the subjective satiety ratings. SI scores correlated positively with the serving weight of the foods ($r = 0.66$, $P < 0.001$, $n = 38$) and negatively with palatability ratings ($r = -0.64$, $P < 0.001$, $n = 38$). Protein, fibre, and water contents of the test foods correlated positively with SI scores ($r = 0.37$, $P < 0.05$, $n = 38$; $r = 0.46$, $P < 0.01$; and $r = 0.64$, $P < 0.001$; respectively) whereas fat content was negatively associated ($r = -0.43$, $P < 0.01$).
Conclusion: The results show that isoenergetic servings of different foods differ greatly in their satiating capacities. This is relevant to the treatment and prevention of overweight and obesity.
Sponsorship: This study was financed by research grants from Kellogg's Pty Ltd, Australia and the University of Sydney.
Descriptors: energy intake, obesity, satiety, satiety index

Introduction

Despite concentrated public health campaigns, the incidence of obesity and overweight has continued to rise in Western populations over the last 10 years (Brownell & Wadden, 1992; Laurier, Guiguet & Chau, 1992). Weight control diets focus on decreasing total fat and energy intakes but this is difficult when the environment contains an abundance of readily available, palatable, energy-dense foods. The kilojoule counter tables that are widely used

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Received 19 December 1994; revised 28 February 1995; accepted 14 March 1995

Table 1 Description and preparation of the test foods

Food	*Variety, manufacturer or place of purchase*	*Preparation*
Fruits		
Black grapes	Waltham cross	Fresh, trimmed of stem, served whole
Apples	Red delicious	Fresh, cut into eight segments including skin
Oranges	Navel	Fresh, peeled, cut into eight segments
Bananas	Cavendish	Fresh, peeled, cut into six segments
Bakery products		
Croissants	Grocery wholesalers Pty Ltd, NSW	Stored frozen, reheated at 180°C for 6 min, served warm
Iced chocolate cake	White Wings foods, NSW	Prepared according to manufacturer's directions, stored at 4°C up to 2 days before serving at room temp.
Doughnuts with cinnamon sugar	Supermarket	Prepared by supermarket from commercial recipe, stored frozen, reheated at 180°C for 5 min, served warm
Chocolate chip cookies	Arnott's biscuits Ltd, NSW	
Water crackers	Grocery wholesalers Pty Ltd, NSW	
Snack foods and confectionery		
Mars bar™	Mars confectionery Australia, VIC	
Yoghurt	Strawberry fruit yoghurt, Australian Co-operative Foods, NSW	Served cold (5°C)
Ice cream	Vanilla ice cream, Dairy bell, NSW	Stored frozen and served cold
Jellybeans	Grocery wholesalers Pty Ltd, NSW	
Potato crisps	Salted roasted peanuts, Grocery wholesalers Pty Ltd, NSW	
Peanuts	Salted roasted peanuts, Grocery wholesalers Pty Ltd, NSW	
Popcorn	Microwave cooked popcorn, Uncle Toby's company Ltd, VIC	Prepared according to manufacturer's directions shortly before serving
Protein-rich foods		
Cheese	Mature cheddar cheese, Grocery wholesalers Pty Ltd, NSW	All serves cut from same large block, stored at 4°C, served cold
Eggs	Poached hens eggs	Poached the day before serving and stored at 4°C, reheated in microwave oven for 1.5 min before serving
Lentils	Served in a basic tomato sauce	Recipe ingredients: 350 g dried green lentils, 15 ml olive oil, 120 g onion, 1 clove garlic, 410 g canned tomatoes, 1 tspn black pepper, stored at 4°C up to 2 days, reheated in a microwave oven for 2 min
Baked beans	Canned beans in tomato sauce, Franklins, NSW	Heated on hotplate for 5 min before serving
Beef steak	Topside beef fillets, purchased in bulk from supermarket	Trimmed of all visible fat, stored frozen, grilled the day before serving and stored at 4°C. Cut into bite-sized pieces and reheated in microwave oven for 2 min
Fish	Ling fish fillets, purchased in bulk from Sydney fish markets	Stored frozen, steamed the day before serving, and stored at 4°C overnight. Cut into bite-sized pieces and reheated in microwave oven for 2 min
Carbohydrate-rich foods		
White bread	Fresh sliced wheat flour bread, Quality Bakers Aust Ltd, NSW	Served plain at room temp.
Wholemeal bread	Fresh sliced bread made from wholemeal wheat flour, Riga bakeries, NSW	Served plain at room temp.
Grain bread	Fresh sliced rye bread containing 47% kibbled rye, Tip Top Bakeries, NSW	Served plain at room temp.

Table 1 *(continued)*

Food	*Variety, manufacturer or place of purchase*	*Preparation*
Carbohydrate-rich foods (continued)		
White rice	Calrose rice (Sunwhite™)	Boiled 12 min and stored overnight at 4°C, reheated in microwave oven for 1.5 min before serving
Brown rice	Calrose rice (Sunwhite™), Ricegrowers' Co-operative Ltd, NSW	
White pasta	Spirals	Boiled 8 min and stored overnight at 4°C, reheated in microwave oven for 1.5 min before serving
Brown pasta	Wholemeal spirals, San Remo macaroni company, NSW	
Potatoes	Russet potatoes	Peeled, boiled for 20 min and stored overnight at 4°C, reheated in a microwave oven for 2 min before serving
French fries	Oven fries, McCain's Foods (Aust), NSW	Stored frozen, cooked in conventional oven for 15 min before serving
Breakfast cereals		
Cornflakes™	Kellogg's Aust Pty Ltd, NSW	All cereals were served with 125 ml reduced fat (1.5%) milk
Special K™	Toasted flakes made from wheat and rice high in protein	
Honeysmacks™	Puffed whole wheat coated in honey	
Sustain™	A mixture of wheat, corn and rice flakes, rolled oats, dried fruit and almond flakes	
All-Bran™	A high-fibre cereal made from wheat bran	
Natural muesli	Uncle Toby's company Ltd, VIC	Based on raw rolled oats, dried fruits and nuts
Porridge	Uncle Toby's company Ltd, VIC	Prepared from raw rolled oats and cooked in a microwave oven according to manufacturer's directions; served without sweetener with 125 ml reduced fat (1.5%) milk

by the weight-conscious do not necessarily reflect the physiological effects of the foods. Not all kilojoules are treated equally by the body. Energy-equivalent loads of the different nutrients can have different effects on satiety, thermogenesis, carbohydrate and fat storage. We have only a limited understanding of the complex interacting mechanisms of satiation. Few studies have examined the effects of individual foods and food components. A number of experiments have shown that different types of nutrients and foods satisfy hunger to varying extents but there have been no large-scale systematic comparisons of isoenergetic portions of common foods. Such information would help to elucidate the general mechanisms by which diet composition can affect satiety and body weight regulation. It would be valuable to have tables showing the energy-satiety ratio of all common foods to indicate their potential for causing overnutrition (Heaton, 1981).

The aim of this study, therefore, was to produce a satiety index of common foods. The hypothesis tested was that on an isoenergetic basis some foods are more satiating than others, judged by both subjective and objective criteria. A secondary aim was to determine whether differences in satiety relate to nutritional and hedonic properties of the foods. To test our hypothesis, 1000 kJ portions of 38 different foods, separated into six food categories, were fed to groups of 11–13 subjects. White bread was used as the reference food in each group (=100%) and the satiety responses of all the other foods were expressed as a percentage of that produced by white bread.

Methods

Test foods

Thirty-eight different foods were tested in total and were categorised into six food groups:

1. Fruits: grapes, bananas, apples, oranges.
2. Bakery products: croissant, chocolate cake with icing, doughnuts with cinnamon sugar, chocolate chip cookies, water crackers.
3. Snack foods and confectionery: Mars bar™,

Table 2 The nutritional composition of the test foods per 1000 kJ

Food	Serving size (g)	Fat (g)	Protein (g)	Carbohydrate Sugars (g)	Carbohydrate Starch (g)	Fibre (g)	Water (g)
Fruits							
Grapes	395	0.4	3.2	56.9	0.0	3.6	317.0
Bananas	279	0.3	4.7	47.2	8.4	6.1	210.1
Apples	435	0.0	1.3	56.5	2.2	9.1	360.9
Oranges	625	0.6	6.9	50.6	0.0	12.5	539.4
Bakery products							
Croissant	61	14.4	6.1	3.1	18.6	1.8	13.5
Cake[a]	64	11.9	4.3	20.1	10.5	0.7	10.7
Doughnuts	65	13.4	4.3	8.9	17.0	1.4	16.1
Cookies[a]	51	10.9	2.4	18.7	16.2	1.0	2.1
Crackers	58	5.4	5.8	1.3	40.2	1.6	2.2
Snacks and confectionery							
Mars bar[a]	54	9.4	2.9	36.7	1.1	1.7	3.5
Yoghurt[a]	241	5.3	11.8	37.6	0.0	0.5	187.0
Ice cream	120	13.4	5.2	25.8	0.0	0.0	74.2
Jellybeans	88	0.0	5.3	44.6	11.5	0.0	12.2
Peanuts	38	20.1	9.6	1.7	3.7	2.4	0.6
Chips	44	16.2	2.7	0.2	22.1	2.4	1.1
Popcorn[a]	47	13.0	4.6	2.1	25.3	6.2	1.7
Protein-rich foods							
Cheese	59	20.0	15.0	0.1	0.0	0.0	20.9
Eggs	159	17.9	19.6	0.5	0.0	0.0	119.4
Lentils	253	4.6	19.4	4.2	24.9	11.4	222.0
Baked beans	351	1.7	16.1	16.1	23.2	16.8	267.1
Beef steak	158	7.7	42.0	0.0	0.0	0.0	104.3
Ling fish	333	1.0	56.3	0.0	0.0	0.0	250.0
Carbohydrate-rich foods							
White bread[a]	94	2.1	8.5	1.8	44.1	3.3	36.1
Wholemeal bread[a]	101	2.6	7.6	1.7	43.7	6.6	40.3
Grainy bread[a]	108	5.4	9.4	2.4	37.6	6.5	41.4
White rice[a]	203	0.5	5.0	0.1	56.0	0.4	140.0
Brown rice[a]	148	2.1	5.2	0.5	52.6	1.4	93.9
White pasta	201	0.8	7.8	2.0	47.1	3.5	134.8
Brown pasta[a]	218	1.6	11.3	0.7	47.8	10.9	132.6
Potatoes	368	1.0	10.0	3.1	45.9	9.2	290.8
French fries[a]	93	8.7	3.9	1.1	35.4	3.5	33.8
Breakfast cereals							
Cornflakes[a]	170	2.1	8.4	10.2	36.1	1.5	110.9
Special K[a]	172	2.1	15.3	14.0	27.2	1.4	111.2
Honeysmacks[a]	172	2.2	8.7	31.1	17.0	2.6	115.0
Sustain[a]	168	3.1	9.7	13.7	29.1	3.2	119.1
Muesli[a]	175	6.1	10.7	17.1	19.8	6.6	114.1
Porridge[a]	383	6.2	10.9	7.5	29.0	4.7	333.7
All-Bran[a]	174	2.9	11.7	13.9	29.4	14.1	111.0

[a]Figures were calculated from food tables or manufacturer's data.

strawberry yoghurt, vanilla ice cream, jelly-beans, salted roasted peanuts, plain potato crisps, plain popcorn.
4. Protein-rich foods: cheddar cheese, poached eggs, boiled lentils, baked beans, beef steak, white fish.
5. Carbohydrate-rich foods: white bread, wholemeal bread, rye grain bread, white rice, brown rice, white pasta, brown pasta, boiled potatoes, French fries.
6. Breakfast cereals: Cornflakes™, Special K™, Honeysmacks™, Sustain™, All-Bran™, natural muesli, oatmeal porridge.

Each food was served as a standard 1000 kJ portion with 220 ml water to aid ingestion. White bread was used as the reference food for each food group. Thus, results for 43 foods will be presented. The foods were selected to represent a range of natural and processed foods commonly eaten in developed countries. They covered a wide range of textural and hedonic characteristics. Table 1 lists the foods and their preparation methods. When possible, foods were bought in large batches to minimise variations in composition and were served in standard sized pieces. Table 2 lists the nutritional composition of each food per 1000 kJ as calculated from food tables or manufacturer's data.

Subjects
11–13 healthy subjects were recruited for each food group. In total, 41 subjects participated. One subject ate all of the foods and 15 other subjects were involved in two or more food groups. All subjects were university students and some of their relevant characteristics are listed in Table 3. Potential subjects were excluded if they were smokers, showed impaired glucose tolerance, were taking medications or had irregular eating habits. None of the subjects were dieting or showed excessive concern with eating or body weight, as determined by an interview and the restraint and disinhibition subscales of the three-factor eating questionnaire (Stunkard & Messick, 1985). Apart from three subjects who were overweight [BMI (kg/m^2): 26–29, one of whom was a stocky, muscular male], all other subjects were within the healthy weight range (BMI: 19–25). A power calculation (90%), using data from our previous studies, indicated that groups of at least 12 subjects would be sufficient to determine a 50 AUC unit difference in satiety, assuming an s.d. of 50 AUC units on the rating scale used to measure satiety. Two food groups have data for only 11 subjects because one subject from each withdrew during the course of the study.

Protocol
Subjects were not informed of the true purpose of the study until after they had finished participating. They were told that the aim of the study was to examine metabolic responses to foods in order to establish which foods would be suitable for diabetic diets and athletic performance. Subjects were given information sheets before their first experimental session, outlining experimental procedures including the use of the rating and visual analogue scales for subjective assessments and the procedure for the weighed food records. All testing procedures were approved by the Medical Ethical Review Committee of Sydney University.

Table 3 Subject characteristics for each food group (mean ± s.d.)

Food group	*Subjects*	*Females*	*Age (years)*	*BMI (kg/m^2)*	*Restraint (TFEQ score)*[a]	*Disinhibition (TFWQ score)*[a]
Fruits	11	5	22.9 ± 3.9	22.9 ± 1.4	5.3 ± 4.2	4.3 ± 2.4
Bakery products	12	6	22.2 ± 3.7	23.1 ± 2.7	5.5 ± 5.1	4.2 ± 2.8
Snacks & confectionery	12	5	21.0 ± 1.2	22.9 ± 3.5	6.3 ± 5.6	4.0 ± 3.0
Protein-rich foods	11	5	22.4 ± 2.8	24.3 ± 3.1	6.6 ± 4.6	4.4 ± 3.2
Carbohydrate-rich foods	13	5	21.0 ± 1.9	23.0 ± 1.9	5.2 ± 2.8	2.8 ± 2.2
Breakfast cereals	11	5	22.8 ± 3.9	22.8 ± 1.4	4.6 ± 4.1	3.2 ± 2.6

[a]TFEQ score refers to the average score from the Three Factor Eating Questionnaire. The maximum possible scores for the restraint and disinhibition subscales are 21 and 16 respectively.

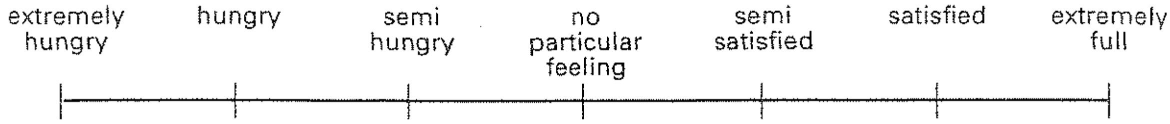

Figure 1 The rating scale used to assess subjective satiety.

At the start of each study, subjects were given a 1000 kJ portion of white bread to confirm normal glucose tolerance. This food was also used as the reference food to which all other foods were compared, in a similar manner to that used for calculating the glycaemic index of foods (Wolever & Jenkins, 1986), in which white bread served as the reference food controls for differences in satiety between individuals, resulting from factors such as weight, activity levels, etc.

1000 kJ portions of the test foods were fed to the subjects in random order on separate mornings after a 10 h overnight fast. Within each food group, each subject acted as his or her own control, being tested at the same time of day and under as similar conditions as possible. Subjects were asked to keep similar activity patterns the day before a test and to eat a similar meal the night before every test. A fasting finger-prick blood sample was collected and subjects completed a short questionnaire assessing recent food intake and activity patterns, and fasting levels of hunger. The subjects were then given the test food and 220 ml water (0 time). Where feasible, foods were presented under a large opaque plastic hood with a hole through which volunteers pulled out pieces of the test food. This was an attempt to minimise subjects' preconceptions of the hedonic and satiating properties of the foods. However, this was not feasible for liquid foods (yoghurt, ice cream), foods served in a sauce (baked beans, lentils), and all the breakfast cereals, which were presented in standard bowls without the hood.

Subjects were asked to eat the food and drink the water at a comfortable rate but to try and finish within 10 min. Subjects were seated at tables in a quiet, non-stressful environment and were not permitted to eat or drink until the end of the session (120 min). Subjects read, talked quietly or listed to a radio but did not compare their individual responses. After 120 min, subjects ate freely from a range of standard foods and drinks and the amount consumed was recorded. Subjects could choose from several breakfast cereals, bread or toast with margarine, jam or vegemite, biscuits, fruit cake, tea, coffee, milk, orange juice, and water.

Finger-prick blood samples were obtained from warmed hands using an automatic lancet device (Autoclix™, Boehringer Mannheim Australia™, Boehringer Mannheim Australia, Castle Hill, NSW) immediately before the meal and at 15, 30, 45, 60, 75, 90, 105, 120 min after beginning the meal. The blood samples were analysed for plasma glucose and insulin (data to be published in another paper).

Subjective assessment of satiety/hunger and hedonic properties of the foods

On arriving in the morning, subjects began filling in a questionnaire by describing the previous evening's meal and rating their recent food intake and activity levels on equilateral five-point rating scales (anchored from 'much less than usual' to 'much more than usual'). Subjects also assessed their feelings of hunger/satiety immediately before each blood sample using an equilateral seven-point rating scale (Figure 1) which had been used in previous studies (Holt & Brand Miller 1994, 1995). This scale was anchored at –3 ('extremely hungry') with a midpoint at 0 ('no particular feeling') through to +3 ('extremely full'). Subjects did not discuss or compare their hunger ratings with each other and did not refer to their previous ratings when marking the scale.

Biological and sensory responses to the same stimulus will vary between people and within a person on different occasions. In our previous study (Holt & Brand Miller, in press), nine subjects with a mean ± s.d. age of 22.8 ± 3.6 years, and a mean ± s.d. BMI of 22.6 ± 2.5 kg/m^2, consumed equal portions of white bread on two separate occasions ~2 months apart. Satiety responses obtained with the rating scale were found to have greater retest reproducibility than satiety responses obtained with 100 mm visual analogue scales (Figure 2). In addition, food intake immediately after the 120 min experimental sessions correlated negatively with the rating scale satiety scores, thereby supporting

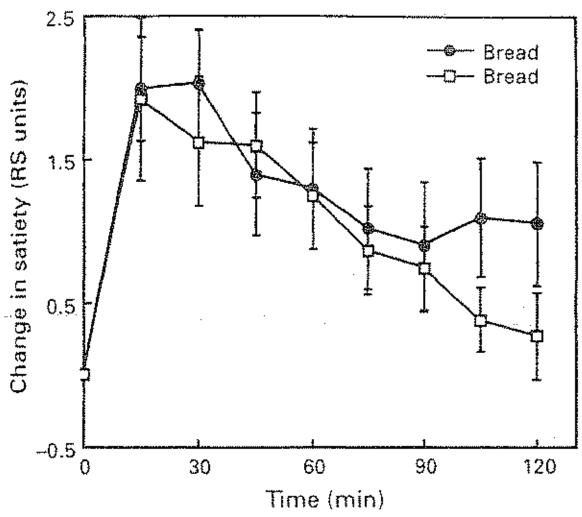

Figure 2 The mean changes in satiety responses over 120 min to white bread on two separate occasions (n = 9).

the rating scale. Subjects also claimed that the rating scale was easier to use and understand than visual analogue scales when assessing hunger or satiety sensations. Thus, we used the rating scale in this study.

Immediately after eating the food, the subjects' recorded the time taken to eat the food and assessed the palatability of the food on a seven-point rating scale [dislike very much (−3), neither like nor dislike (0), like very much (+3)]. The meaning of the term 'palatability' can be interpreted differently between subjects. Thus, we used a rating scale similar to one commonly used by the food industry with specific categories of response in order to standardise the definition of palatability.

Subjects answered the following questions using 100 mm visual analogue scales (VAS) (words anchored at each end):

1. How difficult was the food to eat? (Not at all difficult – Very difficult);
2. Was the serving size sufficient? (Not enough – Far too much);
3. How much more of this food would you like to eat? (prospective consumption 1) (Nothing at all – A large amount);
4. Do you feel like something else? (Nothing at all – A whole meal);
5. Do you feel like something sweet? (Not at all sweet – Very sweet);
6. Do you feel like eating something savoury? (Not at all savoury – Very savoury).

Before eating at 120 min, subjects were also asked 'How much would you like to eat now?' (prospective consumption 2) (Nothing at all – A large amount).

Analysis of data

The satiety response to a food was quantified as the incremental area under the 120 min response curve (AUC), calculated using the trapezoidal rule with fasting levels as the baseline and truncated at zero. Any negative area was ignored. Satiety index scores (SI%) were obtained by dividing the satiety AUC value for the test food by the mean of the group's response to white bread and expressed as a percentage as follows:

$$\text{Individual score} = \frac{\text{Area under the 120 min satiety curve to 1000 kJ of the test food} \times 100}{\text{Group average area under the 120 min satiety curve for 1000 kJ of white bread}}$$

The denominator differs slightly from that used in glycaemic index methodology, where the denominator is each individual's AUC for the reference food. The adjustment was necessary because some of our volunteers gave almost zero results for white bread. The mean ± s.e. SI score for each test food was obtained by averaging all of the 11–13 subjects' SI scores for that food. Four subjects were fed white bread on two occasions and their average results for white bread were used in the calculation of the group mean AUC.

Analysis of variance and the Fisher PLSD test for multiple comparisons were used to determine statistical differences among the foods within each food group. The mean white bread results for each food group were included for statistical analysis, so correlations have been made with 43 values. Linear regression analysis was used to test associations between satiety responses and other parameters. Energy and macronutrient intakes from the meals immediately after each 120 min test and the subjects' food diaries were calculated using Diet 3.2.1 software (Xyris software, Highgate Hill, QLD, Australia) based on data from Australian food composition tables and food manufacturers.

Results

Subjective satiety responses

Within each food group, there were no significant differences between the mean activity patterns over the last week or between mean fasting satiety ratings or plasma glucose and insulin levels.

The SI scores of all the foods tested are shown in Figure 3. The mean satiety AUC and SI score for each food and the average SI score of all the test foods within each food group calculated without bread are shown in Table 4. The highest average food group SI score was produced by fruits and the lowest by the bakery products.

Within the fruit group, bananas had a significantly lower SI score than apples and oranges ($P < 0.05$) which were also twice as satiating as white bread ($P < 0.05$). Within the

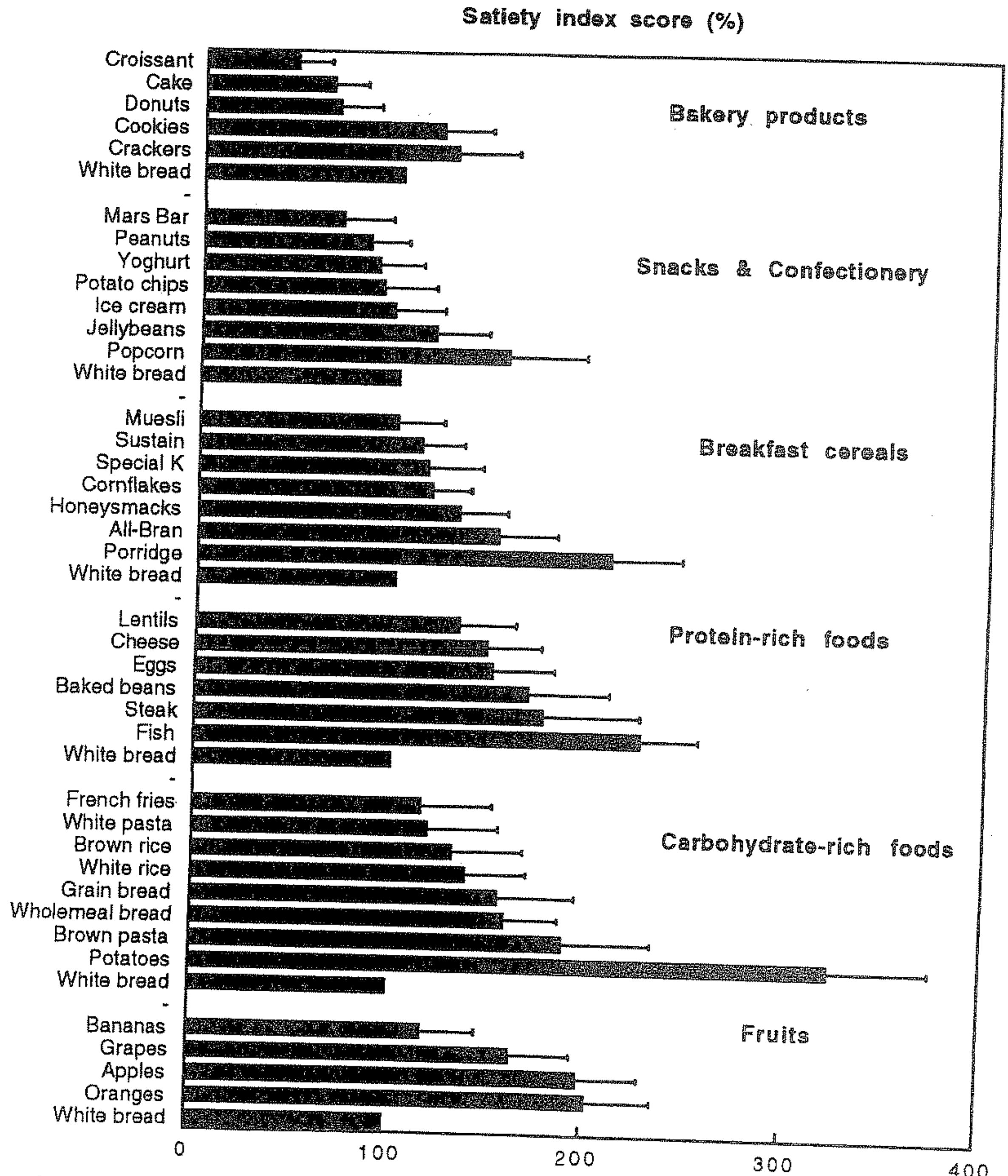

Figure 3 The satiety index score (mean ± SEM) of each food tested. White bread was the reference food, SI score = 100%.

Table 4 Area under the 120 min satiety curve responses and satiety index scores to the test foods (mean ± s.e.m.) and the average SI score for each food group

Food	*AUC (RS units.min)*	*SI score (%)*	*Average SI score (%)*
Bakery products			
White bread	140 ± 33	100 ± 0	85 ± 16
Croissant	67 ± 23	47 ± 17	
Cake	92 ± 28	65 ± 17	
Doughnuts	95 ± 28	68 ± 20	
Cookies	168 ± 34	120 ± 24	
Crackers	179 ± 42	127 ± 30	
Snacks and confectionery			
White bread	108 ± 22	100 ± 0	100 ± 10
Mars bar	76 ± 27	70 ± 25	
Peanuts	91 ± 20	84 ± 19	
Yoghurt	95 ± 25	88 ± 23	
Chips	99 ± 29	91 ± 27	
Ice cream	104 ± 28	96 ± 26	
Jellybeans	128 ± 28	118 ± 26	
Popcorn	167 ± 43	154 ± 40	
Breakfast cereals with milk			
White bread	119 ± 27	100 ± 0	134 ± 14
Muesli	119 ± 27	100 ± 23	
Sustain	133 ± 26	112 ± 22	
Special K	138 ± 32	116 ± 27	
Cornflakes	140 ± 23	118 ± 19	
Honeysmacks	157 ± 28	132 ± 23	
All-Bran	180 ± 36	151 ± 30	
Porridge	247 ± 43	209 ± 36	
Protein-rich foods			
White bread	124 ± 30	100 ± 0	166 ± 13
Lentils	164 ± 35	133 ± 28	
Cheese	181 ± 35	146 ± 28	
Eggs	185 ± 39	150 ± 31	
Baked beans	208 ± 51	168 ± 42	
Beef steak	218 ± 62	176 ± 50	
Ling fish	278 ± 37	225 ± 30	
Carbohydrate-rich foods			
White bread	77 ± 19	100 ± 0	166 ± 24
French fries	89 ± 27	116 ± 35	
White pasta	91 ± 27	119 ± 35	
Brown rice	101 ± 27	132 ± 35	
White rice	106 ± 24	138 ± 31	
Grain bread	119 ± 31	154 ± 40	
Wholemeal bread	121 ± 22	157 ± 29	
Brown pasta	145 ± 35	188 ± 45	
Potatoes	248 ± 39	323 ± 51	
Fruits			
White bread	153 ± 34	100 ± 0	170 ± 19
Bananas	181 ± 41	118 ± 27	
Grapes	248 ± 49	162 ± 32	
Apples	303 ± 50	197 ± 32	
Oranges	309 ± 52	202 ± 34	

bakery products group, crackers had a significantly higher SI score than the doughnut, cake ($P < 0.05$) and croissant ($P < 0.01$), and the SI score for cookies was significantly higher than the cake and croissant ($P < 0.05$). Within the snack food group, popcorn was twice as satiating as the Mars bar, yoghurt, and peanuts ($P < 0.05$). Within the protein-rich food group, fish had a significantly higher SI score than cheese, eggs, beans ($P < 0.05$), lentils, steak ($P < 0.01$), and white bread ($P < 0.001$). The SI scores for beans and eggs were also significantly higher than white bread ($P < 0.05$). Within the carbohydrate-rich food group, the SI score for potatoes was threefold greater than white bread ($P < 0.001$) and significantly higher than brown pasta ($P < 0.01$), wholemeal bread, grain bread, white rice, brown rice, white pasta, and French fries ($P < 0.001$). Brown pasta was also significantly more satiating than white bread ($P < 0.05$). Within the breakfast cereal group, the SI score for porridge was significantly greater than for Honeysmacks ($P < 0.01$), white bread, Cornflakes, Special K, Sustain, natural muesli and All-Bran ($P < 0.001$).

Mean peak satiety scores (= the difference from the fasting to the highest satiety rating) correlated positively with both satiety AUC values ($r = 0.96$, $P < 0.001$, $n = 43$) and SI scores ($r = 0.76$, $P < 0.001$, $n = 38$). This suggests that the highest sensation of fullness, which was usually reached by 30 min, predicted the total satiety response.

Satiety ratings and subsequent food intake
Group mean satiety AUC values correlated with both the kJ content ($r = -0.37$, $P < 0.05$, $n = 43$) and the weight ($r = -0.30$, $P < 0.05$, $n = 43$) of the food and drinks consumed immediately after 120 min (Figure 4). AUC values were used in this analysis because they are individual subjects' results which would more closely reflect immediate food intake behaviour than SI scores which are based on the group's result for white bread. Stepwise multiple regression using all individual values ($n = 503$) indicated that the amount of energy eaten at 120 m in was highly associated with the satiety AUC scores ($P < 0.001$). Additionally, prospective consumption 1 and 2 ratings showed significant correlations with the energy content and the weight of the food eaten immediately after 120 min. Both the prospective consumption and AUC correlations with food intake suggest that the rating scale was a valid measure of subjective satiety sensations and a valid predictor of behaviour expressed as later food intake.

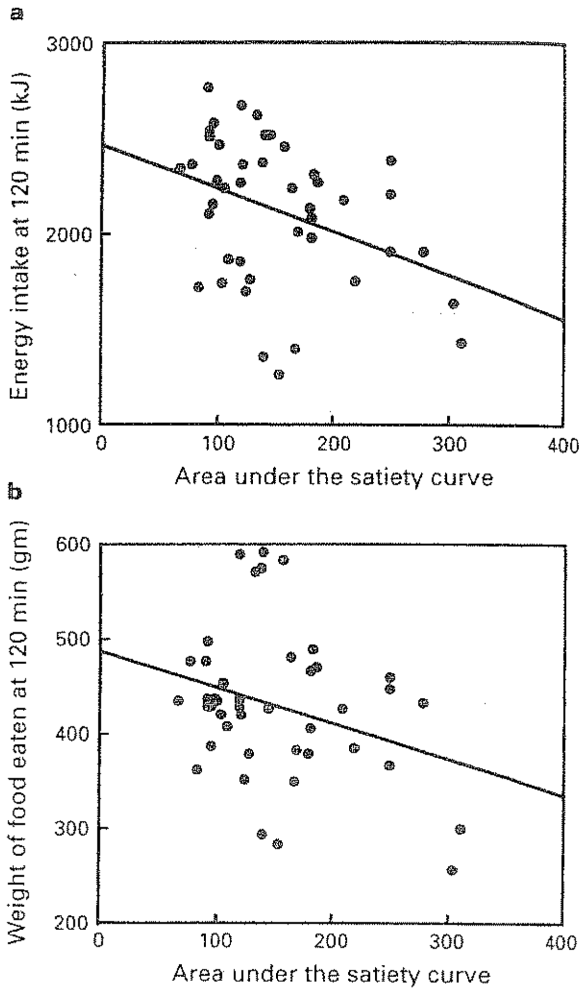

Figure 4 (**a**) Relationship between the mean satiety AUC responses and the kJ intake at 120 min. $y = 2457.0–2.2525x$, $r = 0.37$, $P < 0.005$, $n = 3$. (**b**) Relationship between the mean satiety AUC responses and the weight of the food eaten at 120 min. $y = 488.02–0.37893x$, $r = -0.30$, $P < 0.05$, $n = 43$.

Relationships between satiety and hedonic characteristics
As shown in Figure 5, SI scores were strongly related to the serving weight of the food ($r = 0.66$, $P < 0.001$, $n = 38$). Larger servings of the less energy-dense foods (lower in fat) were required to provide 1000 kJ. This was also reflected in the significant correlations between SI scores and the time taken to eat the food ($r = 0.68$, $P < 0.001$, $n = 38$) and the subjects' perception of the difficulty in eating the food ($r = 0.72$, $P < 0.001$, $n = 38$).

A significant inverse correlation was found between the palatability ratings and SI scores, so that more palatable foods were generally less satiating ($r = -0.64$, $P < 0.001$, $n = 38$) (Figure

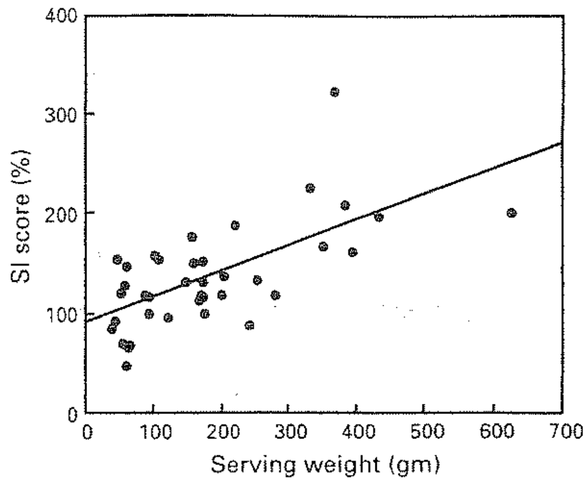

Figure 5 Relationship between the serving size of the test foods and the mean SI scores. $r = 0.66$, $P < 0.001$, $n = 38$.

6). Similarly, SI scores were related to both prospective consumption 1 ratings (how much more of this food would you like to eat?) ($r = -0.74$, $P < 0.001$, $n = 38$) and prospective consumption 2 ratings at 120 min (how much would you like to eat now?) ($r = -0.80$, $P < 0.001$, $n = 38$). A significant correlation was found between prospective consumption 1 and 2 ratings ($r = 0.70$, $P < 0.001$, $n = 38$), indicating that the magnitude of the initial satiating capacity of the food was maintained over 120 min and also predicted later food intake. Prospective consumption ratings were strongly associated with the foods' serving size.

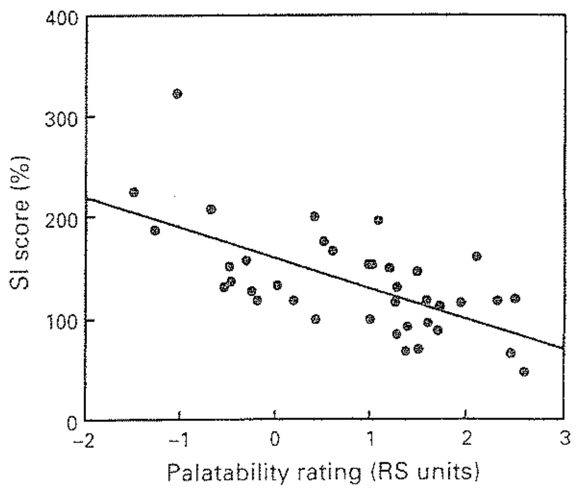

Figure 6 The relationship between the mean palatability ratings and SI scores of the test foods. $r = -0.64$, $P < 0.001$, $n = 38$.

Sensory specific satiety was also apparent. Significant inverse correlations were found between: (a) the sugar content of the test food and the subjects' desire for sweetness ($r = -0.75$, $P < 0.001$, $n = 38$); and (b) the protein content of the food and the subjects' desire for something savoury ($r = -0.41$, $P < 0.001$, $n = 38$).

Relationships with the nutritional composition of the foods

Figure 7 shows the relationships between the macronutrient composition of the test foods and the mean SI scores. Increasing fat content was associated with a lower SI score whereas increasing protein, fibre and water contents were associated with higher SI scores. Sugar, starch and total carbohydrate contents were not significantly related to the SI scores although the direction of the relationship with starch was positive.

Palatability ratings correlated positively with the fat ($r = 0.47$, $P < 0.01$, $n = 43$) and sugar ($r = 0.35$, $P < 0.05$, $n = 43$) contents of the foods and inversely associated with the starch ($r = -0.46$, $P < 0.01$, $n = 43$) and protein ($r = -0.38$, $P < 0.01$, $n = 43$) contents. Serving size and water content of the test foods were negatively but not significantly associated with palatability ratings.

Stepwise multiple regression using every individual test's responses ($n = 503$) indicated that the SI scores were most strongly associated with the serving size of the test foods ($P < 0.001$) and inversely associated with the sugar content of the foods ($P < 0.001$). Regression analysis of the mean SI scores only ($n = 38$) showed that the SI scores were most strongly associated positively with the foods' serving size ($P < 0.001$) and negatively with the foods' palatability ratings ($P < 0.009$) and sugar contents (not significant, $P < 0.149$).

Prospective consumption 1 ratings correlated positively with the fat content of the foods ($r = 0.38$, $P < 0.05$, $n = 43$), so that larger serves of the foods with a higher fat content were desired. Sugar, starch and total carbohydrate contents were not significantly associated with prospective consumption 1 ratings. However, inverse associations were found with serve size ($r = -0.51$, $P < 0.001$, $n = 43$), protein and fibre contents ($r = -0.32$ and $r = -0.31$, $P < 0.05$, respectively).

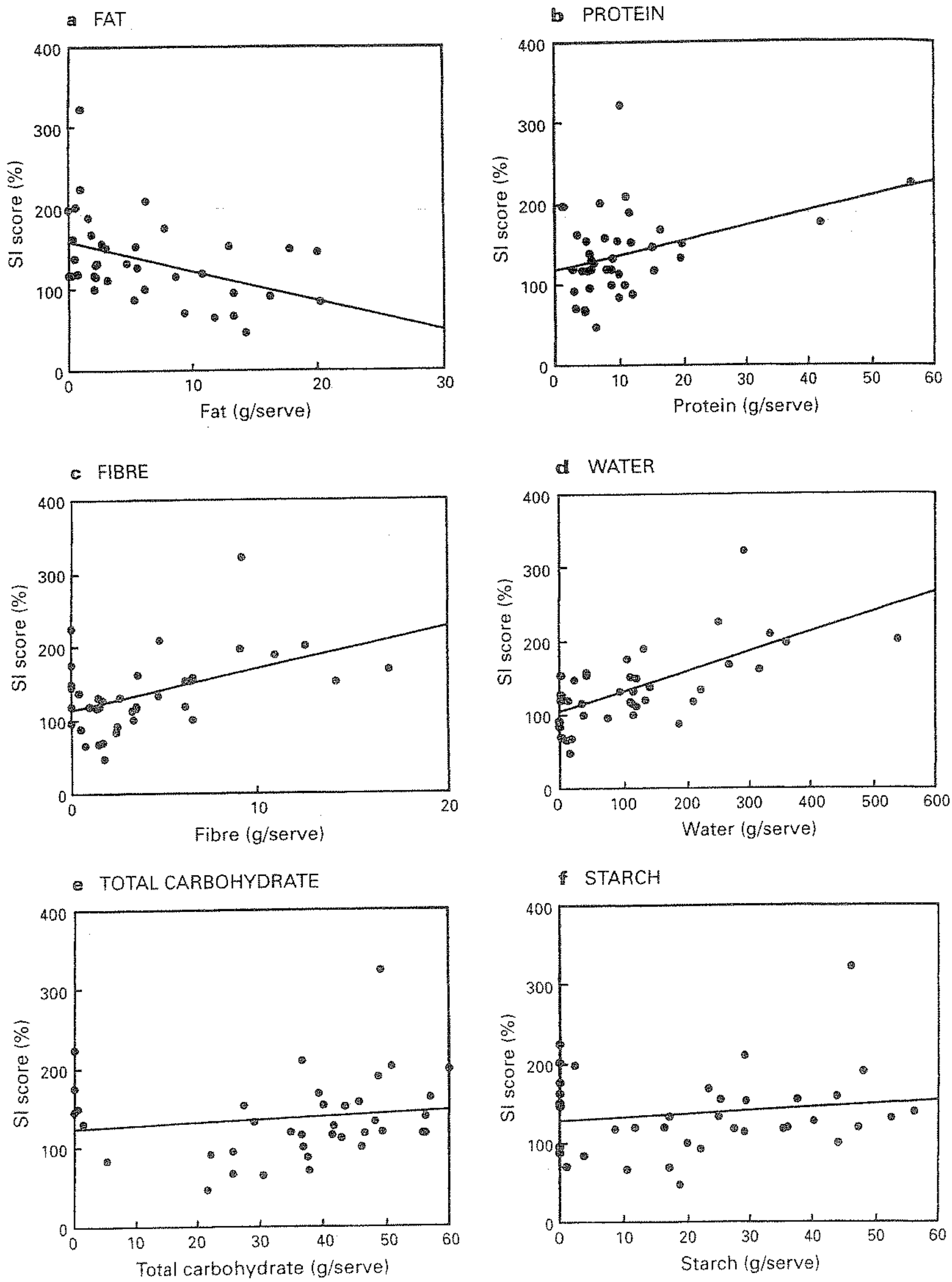

Figure 7 Relationships between the nutrient contents of the test foods and the mean SI scores. (**a**) Fat: $r = 0.43$, $P < 0.01$, $n = 38$. (**b**) Protein: $r = 0.37$, $P < 0.05$, $n = 38$. (**c**) Fibre: $r = 0.46$, $P < 0.01$, $n = 38$. (**d**) Water: $r = 0.64$, $P < 0.001$, $n = 38$. (**e**) Total carbohydrate: $r = 0.12$, n.s., $n = 38$. (**f**) Starch: $r = 0.14$, n.s., $n = 38$.

Discussion

To our knowledge this is the first validated satiety index of common foods. Our findings show that 1000 kJ (240 kcal) servings of different foods vary greatly in their satiating capacity. The SI score of boiled potatoes (323 ± 51), for example, was sevenfold higher than that of croissants (47 ± 17). Bread, our reference food (SI score = 100), was consistently one of the least satisfying foods tested. There were also wide differences in satiety within the same food group. Among the breakfast cereals, for example, muesli gave an SI score (100 ± 23) only half of that of porridge (209 ± 36). We found that on average bakery products containing fat and added sugars (cakes, cookies, etc) were the least satiating food while fruits containing fibre-entrapped natural sugars produced the highest satiety scores. Most importantly, we were able to show that subjective satiety predicted later food intake. A 100 unit difference in satiety index score resulted in a 225 kJ difference in the amount of food eaten at a meal 2 h later (Figure 4). This correlation provides an objective measure of the validity of the satiety index.

We found that the peak satiety response to a food was a good predictor of the total 2 h AUC satiety response (r= 0.96). In addition, there was a negative correlation between prospective consumption ratings at the end of the meal and SI scores (r = −0.74). Taken together, these results suggest that the early satiating capacity of a food strongly influences how much will be eaten at the meal or within the next few hours, if an opportunity to eat arises.

We believe that a satiety index of foods could serve as a useful tool in planning diets for weight reduction or weight gain. Tables of the satiety:energy ratio of foods could be consulted in order to devise a diet that would minimise hunger pangs and increase the likelihood of compliance with a prescribed low energy intake. In other situations, such as sport when very high carbohydrate intakes are desirable, tables of satiety could be used to determine the easiest way of ingesting large amounts of carbohydrate. It is currently assumed that similar foods will have the same satiating capacity, yet we have shown that foods within the same food group can have a twofold difference in their satiety index. Bananas, for example, were found to be much less satiating than apples or oranges.

The advantage of using a satiety index with a reference food, such as white bread, is that other researchers can not only confirm these findings but can also determine the satiety index scores of other foods using a different set of subjects. The use of a reference food controls for inherent differences between the subjects, such as body weight, which might be expected to affect the satiety response to a 1000 kJ portion of a food. We chose a 1000 kJ (240 kcal) portion as a practical serving size which might distinguish between the short-term satiating capacities of different foods. Larger portions of some foods such as apples and potatoes would have been unphysiological in terms of bulk. A smaller portion of other foods (eg peanuts) would have been completely unsatisfying thereby masking any potential realistic differences between the foods. However, it remains to be established whether the relative differences observed in this study can be reproduced with different energy loads and at different times of the day.

We strived to keep pre-conceived ideas about foods and their serving size from influencing our results. Where possible, pieces of the food were taken from under a perspex hood and we standardised the size of the pieces, the temperature, the plate size etc. Unfortunately, it was not feasible to take the liquid foods from under the hood. Eleven foods out of the 38 were fed without it, thereby adding a source of variation. However, seven of these liquid foods represented the breakfast cereal group, and comparisons *within* this group probably remain valid.

The serving size of the test foods was the strongest predictor of the SI scores and prospective consumption ratings suggesting that both satiation and satiety were highly dependent on the energy density of the foods. Foods of a low energy density (low kJ/g) are particularly satiating since they are inherently high in fibre or water (contributing bulk but no energy) and must be served in large amounts to provide 1000 kJ. They are more difficult to eat and quickly produce greater gastric distension which helps inhibit further intake. Conversely, fatty energy-dense foods (high kJ/g) are often highly palatable, easily consumed, are served in smaller amounts to provide 1000 kJ, and stimulate the desire to eat. Hence, these foods readily promote the passive overconsumption of energy (Blundell & Hill, 1978; Tordoff & Read, 1991). Several studies have shown that when human volunteers are offered fat-rich foods they consume significantly more energy than when they are presented with less energy-dense carbohydrate-rich foods (Lissner *et al.*, 1987; Blundell *et al.*, 1993; Cotton, Burley & Blundell, 1993; Lawton *et al.*, 1993; Cotton, Burley & Blundell, 1994; Green, Burley & Blundell, 1994). Subsequent food intake is also increased after high fat meals so that the total day's energy intake is greater. This high-fat hyperphagia appears to be largely due to an inability of the body to rapidly detect the high energy density of fatty foods. At least two studies have not demonstrated this relative hyperphagia if fat-rich or carbohydrate-rich formulas *of equal energy density* are compared (van Stratum *et al.*, 1978; Stubbs, 1992). This suggests that obesity is primarily maintained by an energy-dense diet *per se* (Porikos, Booth & van Itallie, 1977; Duncan, Bacon & Weinsier, 1983; Romieu *et al.*, 1988; Astrup & Raben, 1992; Astrup *et al.*, 1994; Thomas *et al.*, 1994; Miller *et al.*, 1994).

SI scores also correlated positively with the water, fibre and protein content of the foods but inversely with fat content. These correlations are in agreement with the findings of other studies which have shown that macronutrients vary in their satiating capacities. Protein-rich foods and amino acid formulas have consistently been found to produce stronger and more sustained feelings of fullness and decrease food intake later than foods high in fat or sucrose (Booth, Chase & Campbell, 1970; Butler *et al.*, 1981; Hill & Blundell, 1986; Rolls, Hetherington & Burley, 1988). However, different protein sources have been shown to produce different satiety responses. For example, white fish was found to produce greater satiety than equivalent protein loads as lean beef or chicken (Uhe, Collier & O'Dea, 1991).

Palatability is also an important influence on both satiation and satiety because it is a primary determinant of food choice and the amount of food eaten. When the palatability of a diet is enhanced, food intake is increased both during a meal and over longer periods (Rolls, 1981). In this study, we found that palatability ratings correlated positively with the fat ($r = 0.47$, $P < 0.01$, $n = 43$) and sugar ($r = 0.35$, $P < 0.05$) contents of the foods and negatively with SI scores ($r = -0.64$, $P < 0.001$, $n = 38$). Additionally, the subjects desired greater serving sizes of the highly palatable foods. Thus, the more palatable foods tended to be high in fat/sugar, were less satiating and resulted in greater food intake at the meal eaten 2 h later.

High fibre and fibre-supplemented foods have been shown to be highly satiating (Heaton, 1981; Blundell & Burley, 1987; Turconi *et al.*, 1993) whereas refined foods have been associated with increased insulin responses and decreased satiety (Haber *et al.*, 1977; Holt & Brand Miller, in press). In this study, brown pasta was more satiating than white pasta; wholemeal and grain bread were more satiating than white bread; and porridge and All-Bran were more satiating than the other breakfast cereals. In addition, simple 'whole' foods such as the fruits, potatoes, steak and fish were the most satiating of all foods tested. Interestingly, many traditional plant foods such as beans, lentils and potatoes also contain antinutrients which can delay or inhibit the absorption of nutrients or affect gastrointestinal hormone release. These factors could contribute to their greater satiating powers (Hill *et al.*, 1990; Truswell, 1992). The results therefore suggest that 'modern' Western diets which are based on highly palatable, low-fibre convenience foods are likely to be much less satiating than the diets of the past or those of less developed countries.

Many people find it easy to gain weight but much more difficult to lose weight by decreasing their food intake. The restrained eating required to deliberately restrict caloric intake often leads to disordered eating (Ruderman, 1986; Tuschl, 1990). This may partly explain why current dieting strategies are largely ineffective in producing lasting weight loss. Therefore, strategies which focus on making more satiating food choices would appear to be a logical measure in controlling energy intake. If the differences we report between the satiating properties of foods are reproducible and correlate with weight change then high satiety food choice tables could be devised. Based on this new knowledge, the food industry could formulate products designed specifically to enhance satiety. Further research is required to confirm the practical value of these findings and to examine other foods and food preparation techniques for their effects on satiety.

Acknowledgements—This study was supported by grants from Kellogg's Australia Pty Ltd, Pagewood, Australia, and the University of Sydney. The authors would also like to thank Natasha Porter, a Masters student, for her assistance with the experimental work for the carbohydrate-rich food group and Prof AS Truswell and Dr Philippa Wall for their assistance in the preparation of the manuscript.

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