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Effects of increasing increments of fat- and sugar-rich snacks in the diet on energy and macronutrient intake in lean and overweight men

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Two studies have examined the effect on energy intake and macronutrient selection of increasing increments of mandatory high-fat or high-sugar snacks into the diet in men. The present study used a within-subject, repeated-measures design. In each experiment, six lean and six overweight, unrestrained men were each studied over three 7 d treatment periods, during which they were given mandatory snacks of the same energy density (550 kJ/100 g) comprising the following (in terms of percentage energy as fat–carbohydrate–protein): high-fat, 80:10:10; high-sugar, 10:80:10, of which 65 % was sugar, and 15 % starch. Subjects were given 0, 1·5 or 3·0 MJ/d snacks, in a randomised counterbalanced design, to be consumed mid-morning and mid-afternoon. Throughout each day, subjects had access *ad libitum* to fifteen high-protein, fifteen high-fat and fifteen high-carbohydrate foods, rotated on a 3 d menu. Mandatory high-fat snacks significantly elevated energy intake and fat intake, whereas high-sugar snacks elevated energy intake and carbohydrate intake (all $P < 0{\cdot}02$). Mandatory increases in sugar intake did not displace fat from the diet or vice versa. It was concluded that the ingestion of up to 3 MJ/d high-fat and high-sugar foods promoted weak compensation (18 % and 30 %, respectively) and therefore elevated daily energy intake by approximately 2·0–2·5 MJ.

Snack: Sugar: Fat: Energy intake

The rising secular trend in the prevalence of obesity in industrialised countries has been attended by an increase in the proportion of fat energy in the diet (Danforth, 1985; Ministry of Agriculture, Fisheries and Food, 1991), an increase in sugar consumption (Miller *et al.* 1994), an increase in dietary energy density (Poppitt & Prentice, 1996; Stubbs *et al.* 2000) and a decrease in the intake of less digestible forms of carbohydrates (Miller *et al.* 1994). Fat intake in particular appears to be a risk factor for a higher BMI (Lissner & Heitmann, 1995; Blundell & Macdiarmid, 1997).

Some cross-sectional studies have reported an inverse relationship between BMI and the percentage of energy intake derived from carbohydrates (Dreon *et al.* 1988; Tucker & Kano, 1992; Bolton-Smith & Woodward, 1994; Nelson & Tucker, 1996), especially sugar (Tucker & Kano, 1992; Bolton-Smith & Woodward, 1994; Gibney *et al.* 1995; Prentice, 1995). In one large study, the prevalence of obesity increased from the lowest to the highest fifth of fat:sugar intake and declined from the lowest to the highest fifth of total extrinsic sugar intake (Bolton-Smith & Woodward, 1994). These relationships have been termed the ‘fat:sugar seesaw’. Taken together, these observations suggest that high levels of carbohydrate *per se* are protective against obesity because an increasing intake of sugars may displace fat energy from the diet (Bolton-Smith & Woodward, 1994; Gibney *et al.* 1995; Hill & Prentice, 1995; Prentice, 1995).

There are a number of limitations, however, to these arguments. First, epidemiological studies rely heavily on self-reported energy intake, and the fat:sugar seesaw apparently disappears when misreporters are excluded from the dataset (Macdiarmid *et al.* 1998). Second, the above relationships ostensibly seem to be supported by data from laboratory studies. Most studies have shown that high-fat diets are more likely to promote higher energy intake and obesity than high-carbohydrate diets (Warwick & Schiffman, 1992). However, the evidence relating to the effect of sugars and rapidly hydrolysed starches on energy intake is far more controversial (Raben *et al.* 1997; DiMeglio & Mattes, 2000; Stubbs *et al.* 2001). This is partly because there is a large bias in the literature when considering how adding specific nutrients to the diet affects appetite and energy intake. In most studies, high-fat, energy-dense foods have been compared with low-fat, less energy-dense foods. Few studies have examined the effects of increasing the energy density of the diet using readily hydrolysed or short-chained carbohydrates (e.g. Stubbs *et al.* 1998). It is therefore unclear to what extent adding sugars and fats into the diet will affect the intake of energy or macronutrients. Given the widescale changes in the composition of food products currently available to consumers (Holland *et al.* 1991; Willett, 1998), these are important issues. Many health professionals have now adopted forms of positive advice that encourage people to

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actively increase their consumption of low-fat foods, in the hope that this will displace fat-rich foods (and hence energy-dense foods) from the diet (King & Gibney, 1999). The appropriateness of such advice has, however, been questioned (Astrup, 1998; Willett, 1998).

This paper describes two studies with the following objectives: to investigate the effect of adding increasing increments of 0, 1·5 and 3·0 MJ/d mandatory snacks comprising 80 % fat (study 1) or an 80 % sugar–starch mix (65 % sugar; study 2) by energy into the diet on appetite, energy intake and food selection; to determine whether fat intake reciprocally affects the intake of carbohydrate and vice versa; to compare the above effects in both lean and overweight subjects.

Materials and methods

Subjects

Six healthy lean and six healthy overweight men were recruited to take part in each study. Their characteristics are given in Table 1. Subjects were not informed that the true purpose of the study was to measure changes in food selection as a main outcome variable. The mean ages for the lean and overweight groups in study 1 were not significantly different when compared by student's *t* test. For study 2, however, the overweight group were significantly older than the lean group ($P=0·014$).

All subjects were categorised as non-restrained eaters by the Dutch Eating Behaviour Questionnaire (van Strien *et al.* 1986). None of the parameters on the Dutch Eating Behaviour Questionnaire was significantly different between lean and overweight subjects as shown by a Mann–Whitney U test.

Procedures

Figure 1 outlines the experimental protocol for both studies. The designs of the two studies were identical except for the composition of the snacks. The high-fat and high-sugar snacks were also matched as far as possible for taste, texture and appearance. Subjects did not have the opportunity to compare snacks of different compositions.

The subjects were each studied over three 7 d treatment periods using a randomised, counterbalanced design. There was at least a 5 d 'washout' interval between treatment periods. Throughout the treatment, subjects were resident in, but not confined to, the metabolic suite of the Human Nutrition Unit.

On days −1 and −2, subjects were fed a fixed diet designed to maintain energy balance, estimated at 1·6 times RMR (Black *et al.* 1996). On days 1–7, subjects received zero, one (1·5 MJ/d) or two (3·0 MJ/d) high-fat (study 1) or high-sugar (study 2) mandatory snacks, which were consumed at 10.30 hours and 15.30 hours. When only one snack was given it was consumed at 10.30 hours. In addition, subjects had access *ad libitum* to a diet that had been specifically designed to detect changes in both energy and macronutrient intake in response to dietary manipulations. The design and validation of this model have been detailed elsewhere (Stubbs *et al.* 1999; Mazlan, 2001). With the exception of the mandatory snacks, subjects entirely determined their own meal and snack times, sizes and compositions. From the

Table 1. Physical characteristics, energy requirements and Dutch Eating Behaviour Questionnaire scores for the subjects who took part in study 1 (fat increments) and study 2 (sugar increments)

(Mean values and standard errors of the mean)

Subject	Age (years)		Height (m)		Weight (kg)		BMI (kg/m^2)		RMR (MJ/d)		RMR 1·6 (MJ/d)		Restraint		Emotionality		Externality	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Study 1																		
Lean (*n* 6)	28·67	9·91	1·78	0·04	72·18	5·48	22·85	1·58	7·32	0·61	11·67	1·03	1·95	0·67	1·73	0·67	2·48	0·34
Overweight (*n* 6)	39·33	12·48	1·83	0·07	95·77	6·37	28·74	1·44	8·39	0·87	13·42	1·32	2·02	0·69	2·13	0·87	2·30	0·59
Study 2																		
Lean (*n* 6)	29·50	10·60	1·73	0·10	67·98	8·57	22·79	1·05	6·68	0·83	10·75	1·21	1·95	0·67	1·73	0·67	2·48	0·34
Overweight (*n* 6)	46·67	10·76	1·76	0·05	85·37	6·78	27·66	1·64	7·51	0·54	12·17	0·98	2·02	0·69	2·13	0·87	2·30	0·59

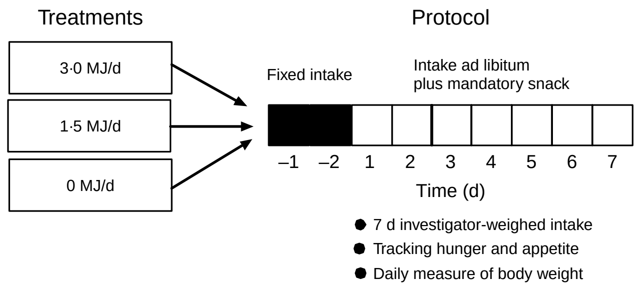

Fig. 1. Protocol followed by each of the subjects for the high-fat and high-sugar interventions. Each subject was studied three times as part of the high-fat or high-sugar intervention, but not both. To standardise energy and nutrient intakes prior to each intervention, subjects were fed to approximate energy balance at 1·6 × BMR for 2 d. During each of the three treatments, subjects received 0, 1·5 or 3·0 MJ/d of mandatory snacks. The order of treatment was randomised across subjects.

menu, subjects could consume as many servings of each food item or parts thereof, or forego items, as they wished. Subjects were required to maintain their normal activity routine and to refrain from consuming alcohol throughout the study period.

Formulation and preparation of mandatory snacks

The mandatory high-fat snacks were designed to contain approximately 80 % energy from fat and the remaining 20 % energy evenly split between carbohydrate and protein. The high-sugar snacks comprised 80 % sugar and rapidly assimilated starch, the remaining 20 % of energy being evenly split between fat and protein. Sugar comprised 65 % of total energy in the high-sugar snacks. The energy density was fixed at 550 kJ/100 g. The snacks took the form of a 275 g tub of raspberry flavoured parfait, which contained 1·5 MJ each. Thus, subjects were given 0, 1·5 or 3·0 MJ/d as zero, one or two mandatory snacks, during the respective treatment periods.

The nutritional manipulation was achieved by altering the type and amount of specific ingredients in an original recipe. The main sources of fat were double cream, vegetable oil and fromage frais. Very low-fat fromage frais and single cream were used as the low-fat alternatives to the similar ingredients in the high-fat version. Intense sweeteners and lemon juice were used to achieve similar sweetness levels. The amount of water was altered accordingly to obtain the required energy density. The detailed ingredients and compositions are given in Appendix 1. Prior to the study, both high-fat and high-sugar snacks were tasted and rated for preference by a separate panel of nineteen subjects. There was no significant difference in the mean preference for the two snacks ($P=0{\cdot}311$).

Presentation of freely selected diets

The selection diet was presented as a 3 d rotating menu. The menu contained forty-five food items per day, consisting of fifteen high-protein, fifteen high-fat and fifteen high-carbohydrate foods (see Stubbs *et al.* 1999; or contact the authors for a detailed composition of the diet). These foods took the form of fifteen breakfast items, fifteen meals and fifteen snacks, a third of which were high-protein, high-fat and high-carbohydrate, respectively, in each meal or snack category. Each food was given in an individually constant portion size. These were offered as freshly prepared, ready to eat or frozen depending on the specific food (see Stubbs *et al.* 1999). All frozen foods were microwaveable, so subjects could defrost and cook their meals or snacks in a short time.

In addition to these foods, subjects were also offered two out of three choices of garnish daily. Each of the garnishes contained 100 g salad vegetables. Subjects also had access *ad libitum* to water, decaffeinated tea or coffee with non-nutritive sweetener (Canderel; Merisant UK Ltd, High Wycombe, Bucks, UK), and were given a 200 g semi-skimmed milk allowance each day.

Each subject was allocated a fridge and freezer within the dining area of the Human Nutrition Unit, which were filled every morning with all the foods on the menu, after the previous day's left-overs had been removed for weighing. All foods were given in excess, with a similar amount offered every day. Additional frozen foods were available in a large freezer. Fresh foods were continually available to order from 06.00–21.00 hours each day. A staff member was always available in the unit during this period for this purpose.

Subjects' tasting sessions

Prior to the two studies, subjects were required to taste all 105 foods to be eaten *ad libitum* and the specific mandatory snack they were to receive. For study 1, the mean preference score for the high-fat mandatory snack was 80 mm (range 59–90 mm) on a scale of 100 mm. The mean preference score for the foods eaten *ad libitum* was 57 mm (range 27–85 mm). Over 73 % of the foods were given a preference score above 50 mm. For study 2, the average preference score for the high-sugar mandatory snack was 70 mm (range 43–96 mm) on the 100 mm scale. Over 88 % of the foods to be consumed *ad libitum* were given a preference score above 50 mm. The mean score for the foods consumed *ad libitum* was 62 mm (range 34–80 mm).

Data collection

Food intake. Subjects were given a food-intake diary to record the food or drink taken and the time of consumption. This allowed investigators to track the time and frequency of food intake. Subjects were also instructed to leave all left-overs and packaging in their fridge compartment. Every morning, a member of staff removed the left-overs for weighing and recorded the food intake in a food record that was kept in the kitchen.

Energy and macronutrient intakes were calculated using the British Food Composition Tables (Holland *et al.* 1991). A spreadsheet template was prepared for calculation of food intake using Microsoft Excel (Microsoft corporation, Redmond, WA, USA). Energy and nutrient intake were calculated from the weight of each food consumed.

Mealtimes reported in the food diary were cross-checked with the data entries on the Apple Newton MessagePad (Apple Computer Inc., Cupertino, CA, USA). Reported food intakes were cross-checked with food records kept in the kitchen. Food consumption was calculated to the nearest gram.

Questionnaires. A number of questionnaires were administered to subjects at various points in the protocol. These are detailed below.

First, restraint, emotionality and externality were assessed. Before the study, subjects were required to complete a Dutch Eating Behaviour Questionnaire, which attempts to assess restraint, externality and emotionality (van Strien *et al.* 1986).

Second, psychometric assessments of hunger and appetite were made. Visual analogue scales were completed every waking hour throughout days 1–7 on hand-held computers with a pen-based graphical interface (Apple Newton MessagePad; Apple Computer Inc.), as previously described (Stratton *et al.* 1998). These assessed changes in subjective appetite, hunger and satiety based on the methodology of Hill & Blundell (1982). The computer also contained a diary facility in which subjects recorded what they ate and when they ate it. Once the diary had been completed (after each meal or snack), another two questions appeared on the screen in the form of visual analogue scales asking subjects to rate how pleasant and how satisfying the food was.

Anthropometry. Height and RMR were recorded as previously described (Stubbs *et al.* 1999). Body weight (corrected to nude) was recorded for subjects each morning after voiding and before eating. Subjects were requested not to see their weight measurements during the course of the study. Changes in body weight were calculated from the slope of the trend line over each 7 d period using simple linear regression.

Statistical analysis

Analysis was performed using Genstat 5 release 4.1 statistical package (Genstat 5 Committee, Numerical Algorithms Group, Oxford, UK).

Food intakes were analysed by ANOVA, with subject group and treatment as treatment factors, and subject, run and day as blocking factors. Data from foods selected were sparsely distributed so foods were grouped into food type and meals (e.g. high-protein breakfast, high-protein meal, high-protein snack, high-fat breakfast, etc.). Food selection in relation to preference was analysed using χ^2 tests of independence.

The hourly subjective hunger and appetite scores were analysed by ANOVA of the scores, with subject group and treatment as factors, and subject, run and day as blocking factors. Data from hourly subjective hunger and appetite scores were not normally distributed, and a square-root transformation was applied before they were analysed.

Changes in body weight were analysed by ANOVA of the changes, with subject group and treatment as factors, and subject and run as blocking factors. Time trends for mean energy intake, subjective hunger and changes in body weight over each treatment were examined by simple linear regression. The ages of lean and overweight subject groups were compared by Student's *t* test. Lean–overweight comparisons for the Dutch Eating Behaviour Questionnaire were made using the Mann–Whitney U test.

Caloric compensation can be expressed as the difference in energy intake between the 0, 1·5 and 3·0 MJ/d treatments, which is reduced by changes in feeding *ad libitum*. This can be expressed relative to the zero control. Thus, if total intakes (inclusive of mandatory intakes) were 1·5 and 3·0 MJ/d greater on the medium and higher levels of snack intake, compensation would be 0 %. A lack of difference in total intake would represent 100 % compensation.

In the tables, statistics are represented as *F*-ratios, probability statistics and the associated standard error of the difference between the means. In this analysis, it is possible to use the estimate that differences between any of the two means exceeding twice the standard error of the difference will be significant at $P<0·05$.

Results

Study 1, fat increments

Food intake. First, less us consider intake inclusive of mandatory snacks. Table 2 shows that daily food, energy and fat intake were all substantially and significantly elevated on going from the 0 to the 3·0 MJ/d treatment. Carbohydrate and protein intakes were not influenced by dietary treatment. ANOVA showed no significant interaction between subject group (lean or overweight) for energy or macronutrient intake.

The percentage of total daily energy intake (including the mandatory snacks) derived from each macronutrient was significantly affected by the increments in fat. Percentage energy intake from protein and carbohydrate decreased, whereas percentage energy from fat increased.

As far as intake exclusive of mandatory snacks was concerned, examination of just the intakes *ad libitum* (minus the mandatory snacks) revealed no significant treatment effects for amount of food, energy or any of the macronutrients. There was no significant group × treatment interaction for any dietary parameter in absolute or percentage terms.

Regression analysis showed that food and energy intake did not change over time either within or between treatments. A separate analysis of the lean and overweight groups revealed a similar pattern of results.

Food selection. The χ^2 tests showed that there was no significant difference in the type of food selected over the three treatment periods ($\chi^2_{(16)} = 8·18$, $P=0·943$) or over the three runs ($\chi^2_{(16)} = 8·54$, $P=0·931$). Subjects tended to select the foods they liked. However, lean and overweight subjects selected different types of food ($\chi^2_{(8)} = 45·85$, $P<0·001$). Overweight subjects selected high-carbohydrate meals and high-fat snacks more frequently than did lean subjects.

Questionnaires. For all subjects, there were no significant effects of dietary treatment on hunger, fullness, thirst, prospective consumption and desire for sweet or savoury foods. There was no significant subject group (lean or overweight) × treatment interaction for any of these outcomes. Regression analysis showed no significant increase or decrease in any aspect of motivation to eat over the 7 d of each treatment. Similar patterns were seen in both the lean and overweight groups. The high-fat snacks did not affect the perceived pleasantness of food or the satisfaction upon ingestion of meals *ad libitum*.

Changes in body weight. ANOVA of the regression slopes showed a significant effect of dietary treatment on change in body weight ($F_{(2,20)} = 6·52$, $P=0·007$). On average, over a 7 d period, subjects lost 0·34 kg on the control diet but gained 0·55 and 0·39 kg body weight on the 1·5 and 3·0 MJ treatments, respectively (SED 0·26 kg).

Study 2, sugar increments

Food intake. When intake inclusive of mandatory snacks is considered, Table 3 shows that total daily food, energy and carbohydrate intakes were significantly elevated on moving

Table 2. Mean daily food, energy and macronutrient intake, together with standard error of the difference, *F*-ratios and probability statistics for the main effects, for the six lean and six overweight subjects during each treatment period in study 1 (fat increments)

	Treatment					
	0 MJ	1·5 MJ	3·0 MJ			
	Mean	Mean	Mean	SED	$F_{(2,10)}$	*P* value
Lean subjects						
Inclusive of mandatory snacks						
Weight (kg)	**1·81**	**2·17**	**2·43**	0·12	14·29	**<0·001**
Energy (MJ)	**11·2**	**12·3**	**14·0**	0·69	7·34	**0·011**
Protein (MJ)	2·1	2·2	2·4	0·17	0·94	0·421
Fat (MJ)	**4·2**	**5·3**	**6·6**	0·31	28·75	**0·001**
Carbohydrate (MJ)	4·9	4·8	5·0	0·32	0·16	0·852
Protein (%Energy)	**19·1**	**18·0**	**17·1**	0·53	7·64	**0·01**
Fat (%Energy)	**37·0**	**42·6**	**47·1**	0·99	51·99	**< 0·001**
CHO (%Energy)	**43·7**	**38·7**	**35·7**	0·99	33·26	**< 0·001**
Exclusive of mandatory snacks						
Weight (kg)	1·81	1·89	1·88	0·12	0·31	0·743
Energy (MJ)	11·2	10·8	10·9	0·69	0·27	0·772
Protein (MJ)	2·1	2·1	2·1	0·17	0·15	0·859
Fat (MJ)	4·2	4·1	4·2	0·31	0·09	0·918
Carbohydrate (MJ)	4·9	4·6	4·6	0·32	0·63	0·551
Protein (%Energy)	19·1	19·2	19·2	0·65	0·01	0·993
Fat (%Energy)	37·0	37·2	37·7	*1·46*	0·11	0·896
CHO (%Energy)	43·7	42·9	43·0	*1·32*	0·23	0·799
Overweight subjects						
Inclusive of mandatory snacks						
Weight (kg)	**2·07**	**2·38**	**2·56**	0·14	6·64	**0·015**
Energy (MJ)	**12·6**	**14·3**	**14·9**	0·55	9·43	**0·005**
Protein (MJ)	2·3	2·5	2·5	0·13	0·70	0·520
Fat (MJ)	**4·8**	**6·3**	**7·0**	0·23	48·82	**< 0·001**
Carbohydrate (MJ)	*5·5*	*5·5*	*5·4*	0·24	0·06	0·942
Protein (%Energy)	**19·0**	**17·5**	**16·6**	0·56	9·3	**0·005**
Fat (%Energy)	**36·8**	**43·0**	**46·8**	0·91	61·8	**< 0·001**
CHO (%Energy)	**44·0**	**38·7**	**36·3**	0·89	39·07	**< 0·001**
Exclusive of mandatory snacks						
Weight (kg)	2·07	2·10	2·01	0·14	0·22	0·804
Energy (MJ)	12·6	12·7	11·9	0·55	1·63	0·244
Protein (MJ)	2·3	2·3	2·2	0·13	1·32	0·310
Fat (MJ)	4·8	5·1	4·6	0·23	1·98	0·189
Carbohydrate (MJ)	5·5	5·3	5·1	0·24	1·42	0·286
Protein (%Energy)	19·0	18·6	18·5	0·63	0·29	0·757
Fat (%Energy)	36·8	38·1	37·3	0·97	1·00	0·403
CHO (%Energy)	44·0	42·5	43·9	1·01	1·26	0·325

Differences between any two means exceeding twice the SED are significant at $P<0·05$.

between the 0, 1·5 and 3·0 MJ/d treatments. Protein and fat intakes were unaffected by the intervention. There was a significant group × treatment interaction for food intake ($P=0·020$) but not for energy or macronutrient intake.

The percentage of total daily energy intake derived from each macronutrient (inclusive of mandatory snacks) was significantly affected by the increments in the high-sugar snacks. Percentage energy intake from protein and fat decreased, and percentage energy intake from carbohydrate increased, on going from the 0 to the 3·0 MJ/d treatment. There was a significant group × treatment interaction for the percentage of energy intake derived from carbohydrate ($P=0·022$). In the lean group, the percentage energy intake from carbohydrate increased by 7 % from the 0 to the 3·0 MJ treatment, whereas in the overweight group the increase was higher, at 10 %.

For intake exclusive of mandatory snacks, the intakes of food, energy, fat and protein (but not carbohydrate; excluding mandatory snacks) all decreased slightly and significantly on going from the 0 to the 3·0 MJ/d treatment. There was a significant subject × treatment interaction for food intake *ad libitum* (i.e. weight of food eaten) but not for intake of energy or macronutrients. Examination of the intakes *ad libitum* alone (minus the mandatory snacks) revealed that percentage energy intake derived from protein, fat or carbohydrate did not differ between treatments.

Regression analysis was conducted on food, energy and nutrient intake (inclusive of mandatory snacks) over the 7 d of each treatment period. Food intake did not change over time during the 0 and 1·5 MJ/d treatment periods. However, the mean daily amount of energy consumed *ad libitum* (exclusive of mandatory snacks) was consistently lower during the 3·0 MJ/d treatment ($t=-2·533$, $P=0·028$).

Food selection. There was no significant difference in the type of food selected over the three treatment periods ($\chi^2_{(16)}=8·20$; $P=0·943$) or the three runs of treatment period ($\chi^2_{(16)}=8·70$; $P=0·925$). Subjects also tended to select the foods they liked. Throughout the study, lean

Table 3. Mean daily energy and macronutrient intake, together with standard error of the difference, *F*-ratios and probability statistics for the main effects, during each treatment period, for the six lean and six overweight subjects for study 2 (sugar increments)

	Treatment					
	0 MJ	1·5 MJ	3·0 MJ			
	Mean	Mean	Mean	SED	$F_{(2,10)}$	*P* value
Lean subjects						
Inclusive of mandatory snacks						
Weight (kg)	**1·79**	**1·81**	**2·12**	0·07	13·07	**0·020**
Energy (MJ)	**11·3**	**11·9**	**13·4**	0·59	6·45	**0·016**
Protein (MJ)	1·9	1·9	2·1	0·09	2·63	0·121
Fat (MJ)	4·0	4·0	4·1	0·22	0·06	0·944
Carbohydrate (MJ)	**5·4**	**6·0**	**7·3**	0·33	16·61	**<0·001**
Protein (%Energy)	**17·0**	**15·8**	**15·4**	0·30	16·6	**< 0·001**
Fat (%Energy)	**35·0**	**33·1**	**29·9**	0·82	20·1	**< 0·001**
Carbohydrate (%Energy)	**47·9**	**51·1**	**54·7**	0·67	50·4	**< 0·001**
Exclusive of mandatory snacks						
Weight (kg)	**1·79**	**1·53**	**1·57**	0·07	6·66	**0·014**
Energy (MJ)	11·3	10·4	10·4	0·59	1·62	0·246
Protein (MJ)	1·9	1·7	1·8	0·09	2·94	0·099
Fat (MJ)	4·0	3·9	3·8	0·22	0·67	0·532
Carbohydrate (MJ)	5·4	4·8	4·8	0·33	1·73	0·227
Protein (%Energy)	17·0	16·7	17·1	0·35	1·14	0·358
Fat (%Energy)	35·0	36·6	36·2	0·90	1·66	0·238
Carbohydrate (%Energy)	47·9	46·7	46·6	0·83	1·58	0·253
Overweight subjects						
Inclusive of mandatory snacks						
Weight (kg)	**2·01**	**2·34**	**2·47**	0·07	24·56	**< 0·001**
Energy (MJ)	**11·6**	**13·1**	**13·7**	0·35	18·14	**< 0·001**
Protein (MJ)	2·3	2·4	2·4	0·08	0·59	0·573
Fat (MJ)	4·6	4·6	4·3	0·17	1·78	0·218
Carbohydrate (MJ)	**4·7**	**6·1**	**7·0**	0·26	38·8	**< 0·001**
Protein (%Energy)	**20·2**	**18·6**	**17·7**	0·65	7·86	**0·009**
Fat (%Energy)	**38·1**	**34·5**	**30·4**	0·90	37·75	**< 0·001**
CHO (%Energy)	**41·5**	**46·6**	**51·6**	0·90	64·6	**< 0·001**
Exclusive of mandatory snacks						
Weight (kg)	2·01	2·07	1·92	0·07	2·25	0·156
Energy (MJ)	**11·6**	**11·7**	**10·6**	0·35	5·08	**0·030**
Protein (MJ)	**2·3**	**2·3**	**2·1**	0·08	5·59	**0·023**
Fat (MJ)	**4·6**	**4·5**	**4·0**	0·17	6·05	**0·019**
Carbohydrate (MJ)	4·7	4·9	4·5	0·26	1·00	0·402
Protein (%Energy)	20·2	19·7	20·1	0·85	0·18	0·835
Fat (%Energy)	38·1	37·8	36·3	0·92	2·4	0·141
CHO (%Energy)	41·5	42·1	43·1	0·94	1·63	0·243

Differences between any two means exceeding twice the SED are significant at $P<0·05$.

and overweight subjects selected different types of food ($\chi^2_{(8)} = 201·20$; $P<0·001$). The main differences were that overweight subjects selected high-fat meals more frequently than did the lean subjects, whereas lean subjects consumed high-carbohydrate snacks more frequently.

Questionnaires. No aspect of motivation to eat was affected by dietary treatment. There were no interactions between subjects groups and treatment for any of the parameters measured. There was no time trend from days 1–7 within or between treatments for any aspect of motivation to eat. There was no significant difference in perceived pleasantness of the food and the satisfaction subsequent to ingesting meals or snacks between the dietary treatments. There was no group × treatment interaction for the two measurements.

Changes in body weight. On average, subjects lost 0·32 kg on the control diet and 0·17 kg on 1·5 MJ/d but gained 0·11 kg on the 3·0 MJ/d (SED 0·18 kg) treatment. ANOVA of the regression slopes showed that these differences were not significant ($P=0·086$). There was no group × treatment interaction for weight change. Both lean and overweight subjects followed a similar trend. A student's *t* test analysis of the regression slopes showed no consistent trend in weight change during all the treatment periods. Similar patterns were seen when both the lean and overweight groups were analysed separately.

Combined analysis of studies 1 and 2

Considering the intake inclusive of mandatory snacks, when food intake data from studies 1 and 2 were combined and analysed together, there were no significant study × treatment interactions between subject groups and treatments for total energy ($P=0·754$) and protein ($P=0·708$) intakes. There was, however, a significant study × treatment (i.e. dose) interaction between subject group and treatment for total fat ($P<0·001$) and carbohydrate ($P<0·001$) intake. Total fat intake increased with high-fat increments and total carbohydrate intakes increased with high-sugar increments. Thus, the two studies had similar effects on food, energy and protein intake, but a markedly different effect on fat and carbohydrate intake. These differences are highlighted in Fig. 2.

For intake exclusive of mandatory snacks, examination of intakes *ad libitum* alone (exclusive of mandatory snacks) revealed no significant study × treatment (i.e. dose) interaction on the energy ($P=0{\cdot}778$), protein ($P=0{\cdot}712$), fat ($P=0{\cdot}426$) or carbohydrate ($P=0{\cdot}957$) intake *ad libitum*. Similar findings were seen when protein, fat and carbohydrate intakes *ad libitum* were expressed as a percentage of energy intake.

Discussion

Part of the controversy surrounding the capacity of fats and sugars to elevate energy intake has occurred because many comparisons are epidemiological and often relate to data collected over previous decades. Diets have, however, recently changed. Consumers have been exposed to a large increase in the range of low-fat but energy-dense foods, rich in sugars or readily assimilated starches. Few if any studies have directly compared the effects of adding fat- and sugar-rich foods, of the same energy density, over several days into the diet of subjects feeding *ad libitum*. In the current intervention, adding increasing increments of mandatory high-fat snacks to the diet led to a progressively higher daily energy intake. The increase in daily energy intake was mainly caused by the increased fat intake incorporated into the mandatory snacks. There was virtually no compensation of energy intake on the 1·5 MJ/d treatment, and a compensation of only approximately 0·53 MJ (18 %) occurred with 3·0 MJ of snacks.

Subjects over-ate to a similar extent when high-sugar snacks were added incrementally into their diet. Caloric compensation was in the region of 0·42 MJ (28 %) and 0·93 MJ (31 %) for the 1·5 and 3·0 MJ/d treatments, respectively. The increased energy intake derived from the carbohydrate content of the high-sugar snacks.

A comparison of the two studies revealed that the subjects responded quite similarly to the high-fat and high-sugar snacks, as both markedly elevated energy intake. It has previously been suggested that sugar-rich foods and fat-rich foods may both elevate energy intake when compared with starchy foods of a lower energy density (Raben *et al.* 1997). Data from these two studies are in agreement with a number of now-established findings that high-fat foods promote a higher energy intake (Dreon *et al.* 1988; Tucker & Kano, 1992; Bolton-Smith & Woodward, 1994; Lissner & Heitmann, 1995; Nelson & Tucker, 1996; Blundell & Macdiarmid, 1997; Stubbs *et al.* 2000). This effect has been referred to as high-fat hyperphagia or passive overconsumption as there is little evidence of any active attempt of subjects to compensate (Blundell & Macdiarmid, 1997). High-fat hyperphagia can operate within 1 d (Blundell & Macdiarmid, 1997), up to 14 d (Stubbs *et al.* 2000) and even over months when the diet has been systematically manipulated (Kendall *et al.* 1991).

The effect of high-sugar foods on energy intake is far more controversial. This is because the majority of studies often compare high-fat, more energy-dense foods with lower-fat (often high-sugar) foods, which have a lower energy density. The present studies therefore compared high-sugar and high-fat snacks of the same energy density. Parenthetically, the energy density of the snacks used in the present studies was less than half that of many commercially available snack products (Holland *et al.* 1991). What is notable is the ease with which high-sugar snacks promoted overconsumption. These present findings, and other recent work (DiMeglio & Mattes, 2000; Raben *et al.* 2002), are providing important data that will enable us to define exactly when high-carbohydrate foods promote overconsumption. It has

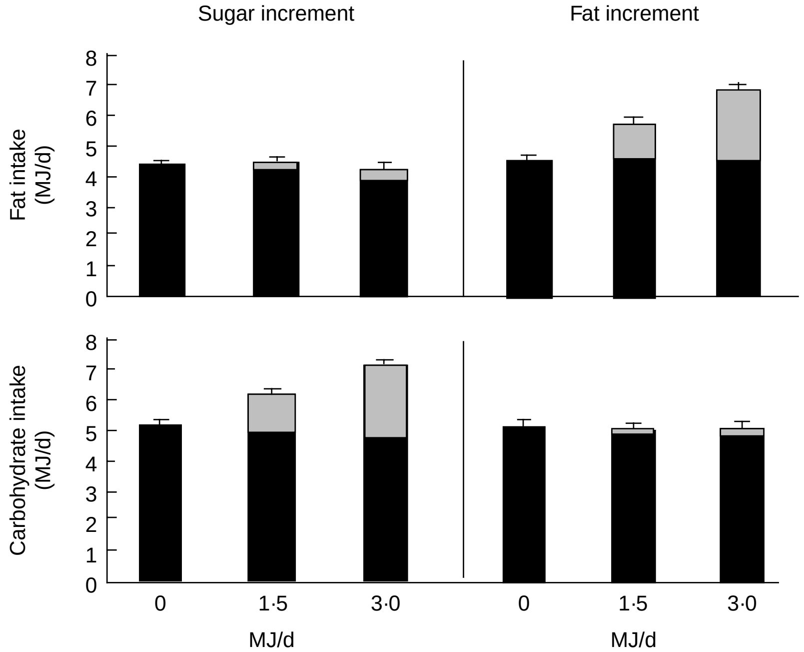

Fig. 2. The effect of 0, 1·5 and 3·0 MJ of sugar-rich or fat-rich mandatory snacks of identical energy density on energy intake *ad libitum* (■) in six lean and six overweight men over 7 d intervention periods. ▨, Energy from mandatory snacks. Total daily energy intake increased significantly with increasing energy from mandatory snacks There were no statistically significant differences between the increments in fat and sugar intake.

already been shown that sugar-rich drinks can elevate intake when compared with either acaloric drinks (Raben *et al.* 2002) or even solid foods of the same composition (DiMeglio & Mattes, 2000). We previously found that high-carbohydrate foods are significantly, but slightly, more satiating than high-fat foods of the same energy density, owing to a consistent but modest effect (see Stubbs *et al.* 2000). Subjects readily overconsume and gain weight when the energy density of a high-carbohydrate diet is increased by the covert addition of maltodextrins (Stubbs *et al.* 1998).

In the present studies, adding sugar-rich snacks into the diet had a very similar effect in terms of elevating energy intake to that seen when high-fat snacks of the same energy density were added. It is also well documented that the sensory attribute of sweetness is an important stimulus for intake (see Stubbs *et al.* 2001). It thus appears that carbohydrates that are wet, sweet, hydrolysed or readily hydrolysed, and exist in a food matrix that does not slow digestion and/or absorption, may be conducive to an overconsumption of energy.

Many previous studies examining the effects of fat and carbohydrate on energy intake have not been specifically designed to detect changes in macronutrient selection. The present study used a model that has been shown to detect changes in both macronutrient (Stubbs *et al.* 1999; Mazlan, 2001) and energy (Johnstone *et al.* 2002) intake.

Evidence that fat influenced carbohydrate intake or that carbohydrate (sugar) influenced fat intake

Increments in fat intake had no significant leverage effect on carbohydrate intake or the intake of any other nutrient. As fat intake from the mandatory snacks increased, subjects did not alter their absolute intakes of protein, fat and carbohydrate from the diet selected *ad libitum*. The net effect of the high-fat snacks on macronutrient intake (inclusive of the snacks) was to increase the percentage energy derived from fat and decrease the percentage energy from protein and carbohydrate. This effect was due to the fact that the snacks simply added onto the *ad libitum* energy intake. Because the high-fat snacks did not affect the absolute intake of protein or carbohydrate, expressing macronutrient intakes as a percentage of total energy intake gives a false impression of a fat:sugar seesaw (Macdiarmid *et al.* 1998).

Similarly, there was little evidence that adding increasing increments of sugars to the diet had much effect in terms of displacing dietary fat. The small displacement that occurred was far from sufficient to offset the excess energy intake induced by consumption of the high-sugar snacks. There was evidence that the high-sugar snacks produced a compensatory reduction in energy intake of approximately 1 MJ/d between the 0 and 3·0 MJ/d treatment. The energy parameters of this effect should be emphasised. The intake of 3·0 MJ/d of high-sugar food decreased fat intake *ad libitum* by a maximum of 0·5 MJ/d and energy intake *ad libitum* by no more than 1 MJ/d. The net effect was a positive energy balance of +2 MJ/d. There was slightly greater compensation for the high-sugar snacks than the high-fat snacks. However, this study found no evidence that increased sugar intake prevented overconsumption. The results of these studies suggest that an increased mandatory intake of fat and of sugar both helped to promote an excess energy intake.

These two studies provide no evidence of a fat:sugar seesaw (Prentice, 1995). The data suggest that adding sugars into the diet incrementally will lower fat intake or lower energy intake very little. This study does not support epidemiological studies, which have suggested that an elevated sugar intake protects against a positive energy balance (Bolton-Smith & Woodward, 1994; Gibney *et al.* 1995; Hill & Prentice, 1995; Prentice, 1995; Nelson & Tucker, 1996). The fat:sugar seesaw is primarily an artifact of expressing nutrient intakes as a percentage of energy intake, which is itself elevated by the snacks. These studies suggest that both high-fat and high-sugar snacks can promote excess energy intake. Although commercially available snacks that are high in fat are more energy dense than those which are high in sugar, both tend to be foods of a high energy density (Holland *et al.* 1991). It has also been suggested that sugar may act as a vehicle for fat intake. The design of the present study does not address this issue.

Time trends

Evidence of time trends was completely lacking in terms of energy intake or subjective motivation to eat. The mandatory snacks were designed as readily ingested, digested and assimilated vehicles for fat and sugar intake. It is interesting in this context that there was no tendency for daily energy intake to decrease with time on any treatment. This is in contrast to diet- and exercise-induced energy deficits, for which compensatory trends of approximately 0·2 MJ/d for intake have been recorded (Johnstone *et al.* 2002). The absence of compensatory trends over time suggests that the effects induced by these snacks would be sustained for some time. This in turn is likely to lead to marked gains in weight over time of between 0·1 and 0·2 kg/week.

Although, in the present study, there was little compensation for the covert snacks, compensation may be greater under free-living conditions in which subjects are familiar with the energy content of foods through learned experience. Furthermore, there is some evidence that people who snack frequently exhibit a greater capacity to compensate for covert reductions in the energy content of specific meals, relative to subjects who derive most of their energy intake from fewer, larger meals (Westerterp-Plantenga *et al.* 1994). Habitual snacking patterns were not assessed in these studies, but the use of a within-subject, repeated-measures design would have reduced the impact of habitual feeding patterns on the effects of the snacks on energy intake.

Body weight and energy balance

It is important to note that considerable caution should be exercised in extrapolating changes in body weight over a period of 7 d to a change in energy balance. Thus, little more can be said about energy balance from body weight data except that it broadly confirmed the patterns of intake and the fact that subjects tended towards a positive energy balance on the 3·0 MJ/d treatments and a negative energy balance on the 0 MJ/d treatments. These patterns are supported by the fact that, on the 1·5 MJ high-sugar snacks, subjects actually lost a small amount of weight, whereas the subjects on the high-fat snack gained over 0·5 kg.

Sensitivity of the current experimental model and limitations of the study

The model used to detect changes in nutrient intake has been validated both statistically and mathematically (Stubbs *et al.* 1999; Mazlan, 2001). This model has been shown to be responsive to prior changes in nutrient intake at the same energy density (Stubbs *et al.* 1999; Mazlan, 2001), and to changes in the amount and energy density of foods, as well as to prior energy deficits (Stubbs *et al.* 2004). Indeed, in the present study, we were able to detect subtle differences in food selection between lean and overweight subjects and in fat intake in response to the high-sugar mandatory snacks. It therefore seems likely that the tendency for mandatory increments in sugar and fat intake not to lever each other (respectively) out of the diet is a real effect and not a consequence of a type 2 error.

The manipulation was covert, and subjects were naïve to the specific composition of the snacks. Some subjects will respond differently to overt manipulations. In addition, the timing of the snack could make a difference to subsequent food intake: there is some evidence that the timing of snack consumption can affect subsequent compensation. This was not addressed in the present study (Stubbs *et al.* 2004).

The study was conducted in relatively unrestrained lean and overweight men; women and more restrained eaters may differ in their responses. The subjects were also relatively sedentary, and it is possible that the effects seen in the present study could be altered by extreme differences in habitual activity. Finally, the duration of the present study was only 7 d, and the time course over which human subjects compensate for relatively acute interventions such as these is not yet clear. Initial evidence suggests that compensation is greater in longer-term studies (Kendall *et al.* 1991; Yates *et al.* 1997).

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Appendix 1. Composition of mandatory snacks used in the studies

1. High-fat raspberry parfait

Food	Weight (g)	Protein (g)	Fat (g)	Carbohydrate (g)	Sugar (g)	Starch (g)	Energy (kJ)
Gelatine	3	2·53	0	0	0	0	43·05
Raspberries	56	0·78	0·17	2·58	2·58	0	61·04
Lemon juice	5	0·02	0	0·08	0·08	0	1·55
Double cream	37	0·63	17·76	0·99	0·99	0	684·13
Single cream	34	0·88	6·49	1·39	1·39	0	277·78
Fromage frais	49	3·38	3·92	1·62	1·62	0	229·81
Oil	5	0	4·99	0	0	0	184·80
Sweetex*, granulated	3	0·04	0	2·79	0	2·79	48·15
Protifar†	1	0·89	0·02	0·01	0·01	0	15·70
Water	87	0	0	0	0	0	0
	280	9·15	33·36	9·47	6·68	2·79	
		Protein	Fat	Carbohydrate	Sugar	Starch	Total
Energy (kJ)		155·50	1234·21	151·50	106·82	44·69	1541·25
Energy (kJ/100 g)		55·55	440·79	54·11	38·15	15·96	550·45
% Energy		10·09	80·08	9·83	6·93	2·90	

*Crookes Health Care Ltd, Nottingham, UK.
†Nutricia NV, Zoetermeer, The Netherlands.

2. High-sugar raspberry parfait

Food	Weight (g)	Protein (g)	Fat (g)	Carbohydrate (g)	Sugar (g)	Starch (g)	Energy (kJ)
Gelatine	3	2·53	0	0	0	0	43·05
Raspberries	49	0·69	0·15	2·25	2·25	0	53·41
Lemon juice	12	0·04	0	0·19	0·19	0	3·72
Fromage frais	14	0·97	1·12	0·46	0·46	0	65·66
Single cream	14	0·36	2·67	0·57	0·57	0	114·38
Glucose powder	7	0	0	6·37	6·37	0	108·29
Sugar	48·5	0	0	50·93	50·93	0	814·80
VLF fromage frais	56	4·37	0·11	1·85	1·85	0	109·76
Potato flour	15·5	0·16	0·16	14·26	0	14·26	207·55
Water	61	0	0	0	0	0	0
	280	9·11	4·21	76·89	62·63	14·26	
		Protein	Fat	Carbohydrate	Sugar	Starch	Total
Energy (kJ)		154·82	155·70	1230·16	1002·00	228·16	1540·68
Energy (kJ/100 g)		55·29	55·61	439·34	357·86	81·49	550·24
% Energy		10·05	10·10	79·85	65·04	14·81	