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The effects of high-carbohydrate vs high-fat breakfasts on feelings of fullness and alertness, and subsequent food intake

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Fourteen subjects consumed four realistic isoenergetic (2035 kJ) breakfasts, varying in macronutrient content (two fat-rich, two carbohydrate-rich (low- and high-fibre)), in random order on separate mornings. After breakfast, subjects left the laboratory and completed appetite and alertness ratings at specific times and recorded all subsequent fluid and food intake for the rest of the day. The high-fibre, carbohydrate-rich breakfast was the least palatable but most filling meal and was associated with less food intake during the morning and at lunch. Hunger returned at a slower rate after this meal than after the low-fibre, carbohydrate-rich meal. Both fat-rich breakfasts were more palatable but less satiating than the carbohydrate-rich meals and were followed by greater food intake during the morning, which may be a compensatory response to ingest a sufficient amount of food and/or carbohydrate to match the level of fullness produced by the subjects' habitual breakfasts. By the end of the day, the average total energy intake was significantly greater after the fat-rich EB meal than after the high-fibre, carbohydrate-rich meal ($P < 0.05$). Total day fat intakes were also significantly greater when the high-fat breakfasts were eaten. For every individual test, alertness ratings increased immediately after breakfast was consumed. On average, the high-fibre carbohydrate-rich meal was associated with the highest post-breakfast alertness ratings and with the greatest cumulative amount of alertness during the period between breakfast and lunch (AUC). Alertness AUC values up until lunch correlated positively with fullness AUC values ($r = 0.36$, $P < 0.01$, $n = 56$). The results confirm the relatively weak satiating power of fat-rich meals observed in controlled laboratory-based studies and indicate that a high-fibre, carbohydrate-rich breakfast may assist weight control efforts by maintaining fullness. Further research is required to determine whether satiety directly enhances alertness and whether low-GI carbohydrate-rich meals enhance alertness to a greater degree than high-GI meals.

Introduction

For many people, the period between dinner and breakfast is the longest fast of the day, often lasting more than 8 hours. Therefore, upon waking in the morning, the liver's glycogen stores can be substantially depleted and blood glucose levels can be relatively low (Pollitt *et al.*, 1981; Anderson, 1988). Consequently, breakfast is widely regarded as the most important meal of the day, essential for replenishing the body's fuel stores. Although the

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health benefits of breakfast have been widely promoted, the habit of skipping breakfast continues to be a popular weight-control strategy among normal- and over-weight people (Bellisle *et al.*, 1995; Rossner, 1995). However, this method of dietary restriction may be largely counterproductive. As the period of fasting continues, the sensation of hunger will become more intense and difficult to ignore and can result in subsequent overeating (de Castro & Elmore, 1988). This tendency has been observed in a number of large dietary surveys which have found that people who skip breakfast do not generally consume any less energy by the end of the day, because they tend to eat more calories during the morning and/or at lunch than regular breakfast-eaters (Morgan *et al.*, 1986; Bellisle *et al.*, 1988; Fricker *et al.*, 1990; Schlundt *et al.*, 1990; Spyckerelle *et al.*, 1990, Silverstein *et al.*, 1995; Ruxton *et al.*, 1996). This subsequent overeating can overcompensate for the caloric deficit incurred by skipping breakfast, particularly if it occurs in a typical work environment where energy-dense convenience foods are readily available.

The results of a breakfast intervention study confirmed that the habit of regularly consuming a nutritious breakfast can assist, rather than hinder, weight control efforts, by alleviating hunger and feelings of deprivation resulting from food restriction (Schlundt *et al.*, 1992). Obese women who regularly skipped breakfast were randomly assigned to a weight-loss programme which either included or omitted breakfast. After 12 weeks, the breakfast-eating group had fewer problems with impulsive eating, were consuming less fat, and had lost more weight than the breakfast-skipping group, despite consuming a similar amount of calories each day. The consumption of a satiating breakfast prevented hunger from reaching an intense level in the morning which reduced the urge to snack and enabled the subjects to maintain a moderate restriction in calorie intake over the rest of the day.

Although the health importance of breakfast has been a topic of considerable debate, most studies have focused on the differences between eating and missing breakfast on cognitive performance and nutritional status. The extent to which different types of breakfast meals affect appetite or alertness has not been well researched. Although breakfast consumption reduces hunger, not all breakfasts are equally satisfying. The sensory, nutritional and physical characteristics of the meal will determine, first, how much food is consumed before appetite is sufficiently sated and eating ceases (satiation), and second, the length of time during which the feeling of fullness is maintained (satiety). These characteristics also determine the rate at which the meal is digested and the rate at which glucose enters the bloodstream, brain and tissues. Subsequent changes in glucose metabolism may influence a range of brain functions involved in the regulation of appetite control (Campfield *et al.*, 1996) and memory and learning (Gold, 1995; Mathews, 1996).

Recent research indicates that meals which facilitate moderate, sustained elevations in blood glucose may enhance alertness and satiety. For example, fat-rich meals have been found to be less satiating (van Amelsvoort *et al.*, 1989; Johnson & Vickers, 1993; Holt *et al.*, 1995; Stubbs *et al.*, 1996), and less effective in improving mood and alertness (Wells & Read, 1994, Lloyd *et al.*, 1996; Wells *et al.*, 1997) than isoenergetic carbohydrate-rich meals. Similarly, slowly digested carbohydrate-rich meals have been found to be more satiating than rapidly digested meals (van Amelsvoort & Westrate, 1992; Holt & Brand-Miller, 1994; Holt *et al.*, 1996). However, to date, no research has examined whether breakfasts which induce low vs high blood glucose responses have different effects on perceived alertness or cognitive performance. Therefore, the aim of this study was to compare the effects of four realistic breakfasts of equal energy content but varying macronutrient content (two high-fat and two high-carbohydrate) on feelings of alertness and fullness, and subsequent food intake. Comparing the meals on an isoenergetic basis highlights the relative effects of different macronutrient combinations. Most previous studies have compared the satiating effects of different foods by measuring changes in appetite ratings and the amount of food consumed at a meal served after a fixed time interval. However, presenting people with a meal before they are actually hungry may not provide a realistic indication of the test meal's effects on subsequent food intake. Eating may be stimulated by the presence of free palatable food, rather than in response to true hunger. Conversely, if subjects are not able to eat when they are actually hungry and are forced to wait, hunger ratings and food intake may be reduced at the next meal and would not reflect the behavioural responses that would most likely occur under free-living conditions. Therefore, a useful way of comparing the satiating effects of foods is to examine both the amount of time elapsing before eating next commences and the amount of food consumed (Himaya *et al.*, 1997). In this study, subjects were served fixed isoenergetic portions of the test meals, rather than being allowed to consume each meal *ad libitum*, in order to prevent the subjects from overeating beyond normal constraints because they were provided with free, palatable foods. After finishing breakfast and leaving the laboratory, subjects were free to eat as they pleased and recorded the time of day and the amount of fluid and food consumed in a diary over the rest of the day. Appetite ratings were collected at specific timepoints throughout the day.

Methods

Subjects

Fourteen healthy, non-smoking subjects (seven female, seven male) were recruited from the student population of Leeds University. All subjects were of a similar age (mean ± SD, 22 ± 2 yr) and were within the healthy weight range for their height (mean BMI ± SD, 21 ± 2 kg/m^2). None of the subjects were dieters, had irregular eating habits, suffered from premenstrual tension, or were taking prescription medication. All of the subjects scored <10 on both the restraint and disinhibition sub-scales (mean ± SD scores: 3.6 ± 2.8 and 5.1 ± 2.2 respectively) of the Three Factor Eating Questionnaire (Stunkard & Messick, 1985). All of the subjects ate breakfast daily (breakfast cereal and/or toast and a beverage) and said that they found the test foods acceptable before commencing the study.

Test meals

Four isoenergetic breakfasts, with different sensory and nutritional characteristics, were assembled using realistic combinations of common breakfast foods. Table 1 lists the nutritional composition of the breakfasts, as calculated from British food tables (Holland *et al.*, 1994) and manufacturers' data. The components of each breakfast are listed in Table 2. Two of the test meals were high in carbohydrate and low in fat and were based on ready-to-eat breakfast cereals and toast. These meals differed in their fibre content, rate of carbohydrate digestion, and predicted glycaemic impact. The Cornflakes (CF) breakfast was low in fibre and rich in rapidly-digested carbohydrate, whereas the All-Bran (AB) meal was relatively high in fibre, protein, and slowly digested carbohydrate. The CF meal had a higher predicted glycaemic index (GI) value (66%) than the AB meal (53%), as calculated by the method of Wolever and Jenkins (1986) using published GI values for the individual food components (glucose is the reference food with a GI of 100%) (Foster-Powell & Brand-Miller, 1995). Thus, blood glucose levels would be expected to rise and fall more rapidly after the CF meal. The other two test meals were both high in fat and low in fibre. The 'traditional' cooked eggs and bacon (EB) meal was high in fat and protein, whereas the

Table 1. The nutritional composition of the test meals and the average composition of the subjects' habitual breakfast (including macronutrients expressed as a percentage of energy). The data is for food components only and excludes the composition of beverages

	Croissants	*Eggs & bacon*	*Cornflakes*	*All-Bran*	*Habitual*
Total weight (g)	135	213	360	425	248
Energy (kJ)	2034	2035	2035	2035	1735
Energy density (g/kJ)	16	10	6	5	7
Protein [g (%)]	8.1 (7)	22.5 (19)	15.3 (13)	21.9 (18)	13.6 (13)
Fat [g (%)]	27.4 (50)	28.9 (52)	8.9 (16)	11.4 (21)	12.0 (26)
Total carbohydrate [g (%)]	55.1 (43)	36.4 (29)	90.2 (71)	77.5 (61)	66.3 (61)
Sugars [g (%)]	19.7 (15)	7.8 (6)	32.0 (25)	40.9 (32)	23.7 (22)
Starch [g (%)]	35.4 (28)	28.6 (23)	58.2 (46)	36.6 (29)	42.6 (39)
Fibre (g)	1.5	2.9	1.0	19.1	4.1

Table 2. The serving weights and energy content of the components of the four test meals as calculated from food tables or manufacturer's data*

Components	*Quantity (g)*	*Energy (kJ)*
Croissants meal		
Sainsbury's croissants (before reheating)	98	1468
Flora polyunsaturated margarine*	10	261
Sainsbury's strawberry jam*	27	305
Total	135	2034
Eggs and bacon meal		
Hen's egg fried in vegetable oil (cooled)	55	410
Sainsbury's rindless back bacon rashers (grilled and cooled)	43	819
Fresh tomato (grilled and cooled)	62	129
Sainsbury's medium-sliced white bread (before toasting)*	44	442
Flora polyunsaturated margarine*	9	235
Total	213	2035
Cornflakes meal		
Kellogg's Cornflakes™*	57	884
Fresh semi-skimmed milk	250	488
White sugar	6	96
Sainsbury's medium-sliced white bread (before toasting)*	31	306
Flora polyunsaturated margarine*	5	131
Sainsbury's strawberry jam*	11	130
Total	360	2035
All-Bran meal		
Kellogg's All-Bran™*	74	851
Fresh semi-skimmed milk	250	488
Raw sliced banana	66	264
Sainsbury's medium-sliced white bread (before toasting)*	30	301
Flora polyunsaturated margarine*	5	131
Total	425	2035

'continental' breakfast of croissants spread with margarine and jam (CR) was high in fat and refined carbohydrate. Predicted GI values for the EB and CR meals were 45% and 58% respectively.

All preparation and serving procedures were standardised. The day before serving, eggs were fried in vegetable oil and untrimmed bacon rashers and tomato halves were grilled for a standard time, and then stored overnight in fridge (4°C). The required portions of fried eggs, grilled bacon and tomatoes were weighed and plated on the morning of the test and were reheated in a microwave oven for 2 min immediately before serving. The croissants were purchased in bulk from the bakery section of a large supermarket and were stored frozen. Croissants were defrosted and then reheated for 2 min in a hot oven (180°C) before spreading with margarine and jam and serving immediately. The components of the two carbohydrate-rich meals were weighed and plated shortly before serving. The raw banana used for the AB meal was served at roughly the same stage of ripeness for each subject and was sliced and placed on top of the All-Bran just before serving. Toasted bread was prepared immediately before serving using the same commercial brand of sliced white bread which was purchased in bulk and stored frozen until required. Each test meal was served with an individually standardised drink which was the same as the subjects' regular breakfast beverage (tea, coffee, orange juice, milk or water). This ensured that the subjects who normally drank a hot, caffeine-containing drink would not feel

Table 3. Experimental schedule

Time	*Assessment*
Before breakfast	Pre-meal VAS ratings
Start eating breakfast (0 min)	
Immediately after breakfast	Record time taken to eat meal and complete post-breakfast hedonic and appetite ratings Leave laboratory and commence food diary
30, 45, 60, 120 min after starting breakfast	VAS ratings
Immediately before and after lunch	VAS ratings
15.30 h	Mid-afternoon VAS ratings
Immediately before and after dinner	VAS ratings
18.30 h	Mid-evening VAS ratings
Just before retiring at night	VAS ratings and end of day questionnaire

that an important part of their meal was missing, which could adversely affect mood, alertness and satisfaction.

Ratings of subjective sensations
Postprandial changes in feelings of alertness and motivation to eat (hunger, desire to eat, fullness, and prospective consumption) were assessed at specific times using 100-mm visual analogue rating scales (VAS), according to the schedule outlined in Table 3. Each sensation was assessed with a separate VAS anchored with the opposing extremes of the sensation (e.g. ‘Not at all full’ (0) to ‘Extremely full’ (100)). Immediately after breakfast, the subjects also rated the pleasantness of the meal on a 100-mm VAS, anchored from ‘Not at all pleasant’ (0) to ‘Extremely pleasant’ (100); and how much more they felt they needed to eat to be adequately satisfied on another 100-mm VAS (‘Nothing at all’ (0) to ‘A large amount’ (100)).

Protocol
A within-subjects, repeated-measures design was used. Each subject consumed all of the four breakfasts, in random order on separate mornings, on the same day of the week at the same time of day. Subjects were required to complete their test sessions on ‘normal’ week days without special social events and maintain regular exercise and eating patterns throughout their participation in the study. Subjects were asked to eat the same meal on the evening before each test and then fasted for a standard time overnight (10–12 h). The next morning, the subjects reported to the research unit at a standard time between 7.30–9.30 a.m., as close as possible to their usual breakfast time. The investigators checked that each subject was feeling well and that their activity and food intake had been normal the previous day. The subjects first completed fasting VAS ratings and were then given a test meal which they consumed while seated alone in a small room free from distractions. Immediately after breakfast, subjects recorded the time taken to finish the meal and completed another set of VAS ratings. The subjects were then given a portable digital scale and a diary in which they recorded the weight of all food and fluid consumed during the rest of the day. They were also given 11 VAS booklets, each of which was to be completed at a specific time (Table 3). Subjects then left the laboratory to resume their normal activities and were free to eat and drink as they pleased. At the end of the day just before going to bed, subjects completed a questionnaire which assessed activity and eating patterns, illness and the overall extent of alertness, hunger, and thirst experienced over the day.

After completing all four test meals, the subjects completed a weighed food diary for one normal week day. On this day, subjects ate their usual week day breakfast and then completed the post-breakfast hedonic and appetite VAS ratings. Thus, we were able to compare the nutritional composition, immediate satiating power and hedonic qualities of the test meals with those of the subjects’ habitual breakfasts.

Statistical analysis
Energy and macronutrient intakes were calculated from the food diaries using manufacturer's data and Comp-eat™ computer software based on the British food tables (Lifeline Nutrition Services Ltd, London). Repeated-measures analysis of variance (ANOVA) was used to examine the relationships between VAS ratings and *ad libitum* food intake using SAS software (Statistical Analysis Systems, SAS Institute Inc, Cary, NC, USA). Incremental areas under the alertness and fullness response curves up until lunch were calculated using the trapezoidal rule with fasting levels as the baseline and truncated at zero. The AUC calculation allows comparison of the integrated effects of the test meals over a fixed time period (Matthews *et al.*, 1990). Significant differences in the mean responses among the meals were detected using the Fisher PLSD test for multiple comparisons (Statview student™ software, Abacus concepts Inc, Berkley, USA), which was a more appropriate *post hoc* test of significance than multiple *t*-tests (Godfrey, 1985).

Results

End of day questionnaire
One-way ANOVA indicated that food intake and activity patterns over each test day were not significantly different from normal or among the test meals. In addition, lecture and work schedules, and perceptions of the overall degree of thirst, hunger, contentedness and alertness experienced over each test day were not significantly different from normal or among the test meals. Thus, the subjects appear to have begun each test meal in a similar state and experienced similar environmental conditions each test day.

Postprandial changes in alertness
For each individual subject, baseline alertness ratings were not significantly different among the four test meals. Figure 1 illustrates the average alertness response curves from the end of breakfast until immediately before lunch. On average, there were no significant differences in alertness ratings among the test meals at any timepoint during the day. For each individual test session, alertness ratings were at a low level before breakfast and increased immediately after eating. The AB meal was associated with the greatest increase in alertness immediately after breakfast (+10.4 ± 4.3 mm), followed by CF (7.6 ± 3.8 mm), CR (6.9 ± 4.0 mm) and EB (6.2 ± 3.9 mm). Stepwise multiple regression analysis indicated that the post-breakfast alertness ratings were most strongly associated, in a positive manner, with the serving weight ($P < 0.001$, $n = 56$) and fibre content of the test meals ($P < 0.007$, $n = 56$).

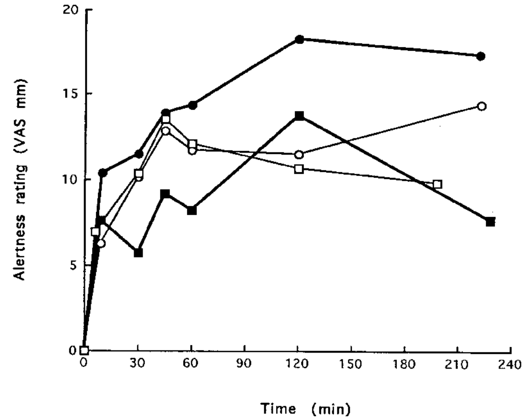

Figure 1. Changes in perceived alertness after breakfast until lunch (mean VAS ratings, $n = 14$). ● All-Bran, ■ Cornflakes, ○ Eggs and Bacon, □ Croissants.

Potential differences in alertness may have been obscured by the food intake during the morning, since alertness ratings for the CR and EB meals rose slightly as additional food was consumed. However, the AB meal was associated with the least amount of food intake, but the highest alertness ratings at every timepoint up until lunch. Alertness ratings after the high-GI CF meal dropped slightly within the first 30 min, when there was no additional food intake, but did not rise again with subsequent food intake. On average, the total amount of alertness experienced during the period after breakfast up until lunch (area under the cumulative alertness response curve: AUC) was not significantly different among the four meals. However, the AB meal had the highest average alertness AUC value (meal ± SEM: 4556 ± 1392 mm.min) followed by CF (3164 ± 831 mm.min), EB (3102 ± 961 mm.min), and CR (3045 ± 821 mm.min). Alertness AUC values (up until lunch) correlated positively with the fullness AUC values ($r = 0.36$, $P < 0.01$, $n = 56$), and correlated negatively with the hunger AUC values ($r = -0.40$, $P < 0.01$, $n = 56$). Stepwise multiple regression analysis indicated that the amount of carbohydrate, protein and energy consumed during the morning (including breakfast) were positively associated with the alertness AUC values, whereas fat consumption was negatively related, but these associations were just below significance.

Hedonic and appetite responses immediately after breakfast

The fat-rich CR breakfast took the shortest time to eat and was significantly more pleasant but less filling and satisfying than the AB ($P < 0.001$), CF ($P < 0.01$), EB and habitual meals ($P < 0.05$). The fat-rich EB meal was also significantly less filling than the AB meal ($P < 0.05$). The subjects felt they needed to consume significantly more of the fat-rich meals than the carbohydrate-rich meals in order to feel adequately satisfied ($P < 0.01$) and would have liked larger servings. The average increase in fullness immediately after breakfast was greatest after the AB meal (66.4 ± 4.5 VAS mm), followed by CF (59.0 ± 5.6 mm), EB (45.5 ± 7.4 mm) and CR (42.7 ± 7.2 mm). Thus, on average, the high-fibre, carbohydrate-rich AB meal took the longest time to eat and was the most filling and satisfying meal. Although this meal was considered to be relatively less palatable (mainly by those subjects with low habitual fibre intakes), it was not unacceptable.

Both the palatability and prospective consumption ratings correlated negatively with the serving weight, protein, carbohydrate, sugar, and fibre contents of the breakfasts, but positively with the meals' fat content. Stepwise regression analysis indicated that the serving weight of breakfast was the strongest predictor of the palatability ratings ($P < 0.001$), and was related in a negative manner.

Changes in appetite during the morning

Figures 2 and 3 illustrate the average changes in the fullness and hunger ratings up until lunch. Desire to eat and prospective consumption ratings followed a similar pattern to the hunger ratings. The high-fibre AB meal produced the greatest suppression of appetite up until lunch, followed by CF, EB, and CR. Fullness reached a significantly higher peak after the AB meal than after the fat-rich CR ($P < 0.001$) and EB meals ($P < 0.01$). As shown in Figure 4, the total

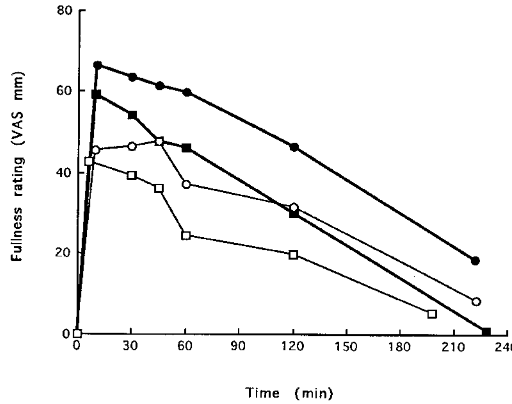

Figure 2. Changes in perceived fullness after breakfast until lunch (mean VAS ratings, $n = 14$). ● All-Bran, ■ Cornflakes, ○ Eggs and Bacon, □ Croissants.

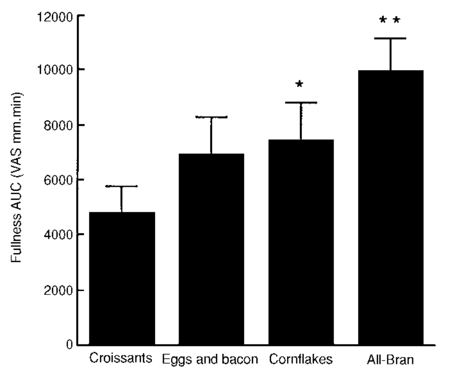

Figure 3. Changes in perceived hunger after breakfast until lunch (mean VAS ratings, $n = 14$). ● All-Bran, ■ Cornflakes, ○ Eggs and Bacon, □ Croissants.

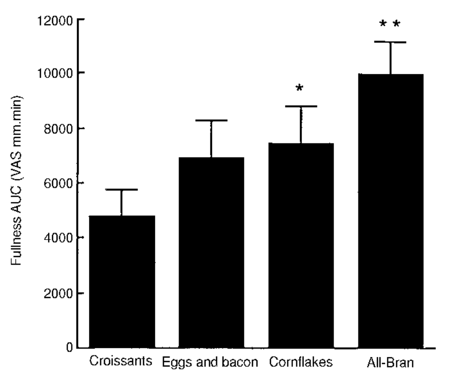

Figure 4. Fullness AUC values covering the time period between the end of breakfast until immediately before lunch (mean ± SEM, $n = 14$). *CF > CR ($P < 0.05$); **AB > CR ($P < 0.001$), EB, CF ($P < 0.05$).

amount of fullness experienced after breakfast up until immediately before lunch (AUC) was significantly greater after the AB meal (9986 ± 1211 mm.min) than after CF (7429 ± 1372 mm.min; $P < 0.05$), EB (6917 ± 1380; $P < 0.05$) and CR (4769 ± 977 mm.min; $P < 0.01$). The fullness AUC value for CF was also significantly greater than CR's ($P < 0.05$).

Relationships between fullness and the nutrient content of the test meals

Linear regression analysis showed that the individual fullness AUC values up until lunch correlated negatively with the breakfasts' fat content ($r = -0.26$, $P < 0.05$, $n = 56$) and correlated positively with the serving weight ($r = 0.36$, $P < 0.01$, $n = 56$), fibre ($r = 0.32$, $P < 0.05$), protein ($r = 0.29$, $P < 0.05$), and sugar ($r = 0.26$, $P < 0.05$) contents. Total carbohydrate and starch contents were positively associated with fullness AUC values (just below significance). Stepwise multiple regression indicated that, among the nutritional variables, the test meal serving weight was the strongest predictor of both the post-breakfast fullness ratings ($P < 0.001$, $n = 70$ – including the habitual breakfast) and the fullness AUC values up until lunch ($P < 0.007$, $n = 56$).

Food intake during the morning

On average, the subjects waited a significantly shorter amount of time before they next ate after the EB meal (122 ± 22 min) than after the AB (178 ± 21 min, $P < 0.05$), habitual (187 ± 20 min, $P < 0.05$) and CF meals (192 ± 21 min, $P < 0.01$). As shown in Table 4, the subjects consumed more energy during the morning before lunch after EB ($n = 9$, 612 ± 201 kJ) and CR meals ($n = 6$, 314 ± 141 kJ), than after the CF ($n = 3$, 172 ± 131 kJ), AB ($n = 4$, 154 ± 127), and habitual breakfasts ($n = 3$, 124 ± 116). Despite the greater food intake, hunger ratings immediately before lunch were still higher after the high-fat breakfasts than after the high-carbohydrate meals (CR > AB, $P < 0.05$).

Energy intake at lunch

Individual fullness AUC values up until lunch correlated significantly with the amount of energy consumed at lunch ($r = -0.34$, $P < 0.01$, $n = 56$), and also with the amount of energy consumed during the morning and at lunch ($r = -0.28$, $P < 0.01$, $n = 56$). Pre-lunch fullness ratings also correlated negatively with the amount of energy consumed at lunch ($r = -0.39$, $P < 0.01$, $n = 56$). These correlations confirm that the appetite ratings were a valid measure of subjective satiety sensations and predicted subsequent food intake.

Figure 5 illustrates the amount of energy consumed at different times of the day. On average, lunch was consumed half an hour earlier after the CR meal than after the other breakfasts. Despite consuming more food during the morning, the subjects ate significantly more energy at lunch after the CR ($P < 0.001$), EB and CF meals (both $P < 0.01$) than after the AB meal (Table 4). Subjects also consumed more energy at lunch after the CR breakfast than after the EB meal ($P < 0.05$).

The influence of the serving weight of breakfast on subsequent food intake

The serving weights of the high-carbohydrate and habitual breakfasts were much greater than the high-fat meals (Table 1). Thus, the subjects were accustomed to eating a greater weight of food for breakfast than provided by the high-fat test meals. As shown in Figure 6, on average, the subjects consumed a greater weight of food and fluid after the fat-rich meals than after the habitual ($P < 0.01$) and carbohydrate-rich breakfasts (Table 4). However, the total weight of food and fluid consumed by the beginning of lunch was still less after the high-fat breakfasts than after the habitual and high-carbohydrate meals (CR < AB: $P < 0.01$; CR < H: $P < 0.05$). Subsequent food intake began much sooner after the high-fat breakfasts and appears to have been necessary for the subjects to reach the level of fullness they usually experience after breakfast, since hunger ratings after the high-fat meals were not suppressed by the additional food intake and remained at a higher level before lunch. In line with the higher pre-lunch hunger ratings, the subjects consumed a greater amount of food and fluid at lunch on the high-fat breakfast days. By the end of lunch, there were no significant differences among the test meals in the total weight of food and fluid consumed from the start of the day, but total energy intakes for this period were slightly higher on the high-fat breakfast days.

Table 4 Energy and nutrient intakes during the morning and over the whole day (mean ± SEM, n = 14). Total day intakes include breakfast

	Croissants	*Eggs & bacon*	*Cornflakes*	*All-Bran*	*Habitual*	*Significant differences*
Energy						
Energy consumed after breakfast until before lunch (kJ)	314 ± 141	612 ± 201	172 ± 131	154 ± 127	124 ± 116	H < EB ($P < 0.01$) CF, AB < EB ($P < 0.05$)
Energy consumed at lunch (kJ)	3776 ± 348	3010 ± 276	3430 ± 363	2481 ± 254	3171 ± 321	AB < CR ($P < 0.001$), CF ($P < 0.01$) EB < CR ($P < 0.05$)
Energy intake morning + lunch, excluding breakfast (kJ)	4090 ± 346	3622 ± 409	3735 ± 364	2635 ± 262	3295 ± 306	AB < CR ($P < 0.001$), H ($P < 0.05$) CF, EB ($P < 0.01$)
Total day energy intake (MJ)	11.4 ± 0.4	12.0 ± 1.0	11.7 ± 0.9	10.1 ± 0.8	10.1 ± 0.7	AB, H < EB ($P < 0.05$)
Weight						
Total weight of food and fluid consumed after breakfast until before lunch (g)	284 ± 112	249 ± 77	141 ± 81	146 ± 76	47 ± 32	H < CR, EB ($P < 0.01$) CF < CR ($P < 0.05$)
Total weight of food and fluid consumed at breakfast and during the morning until just before lunch (g)	333 ± 89	469 ± 78	501 ± 81	571 ± 76	514 ± 49	CR < AB ($P < 0.01$), H ($P < 0.05$)
Total weight of food and fluid consumed at lunch (g)	703 ± 84	600 ± 63	670 ± 97	593 ± 60	606 ± 65	None
Total weight of food and fluid consumed over the whole day including breakfast (g)	2383 ± 285	2830 ± 352	2803 ± 357	2516 ± 242	2685 ± 356	None

Table 4 Continued

	Croissants	*Eggs & bacon*	*Cornflakes*	*All-Bran*	*Habitual*	*Significant differences*
Fat						
Fat intake during the morning and at lunch, excluding breakfast (g)	48 ± 5	38 ± 5	43 ± 6	26 ± 3	37 ± 5	AB < CF, CR ($P < 0.01$)
Total day fat intake (% of total energy intake)	40 ± 2	39 ± 1	35 ± 2	34 ± 1	35 ± 2	AB < CR ($P < 0.01$), H < CR ($P < 0.01$) CF < CR ($P < 0.05$)
Carbohydrate						
Carbohydrate intake during the morning and at lunch, excluding breakfast (g)	120 ± 10	109 ± 13	123 ± 17	78 ± 9	94 ± 7	AB < CR, CF ($P < 0.01$) AB < EB ($P < 0.05$) H < CF ($P < 0.05$)
Total day carbohydrate intake (% of total energy intake)	44 ± 2	44 ± 2	53 ± 2	51 ± 1	48 ± 2	CR < CF ($P < 0.01$), AB ($P < 0.05$) EB < CF ($P < 0.01$), AB ($P < 0.05$)
Protein						
Protein intake during the morning and at lunch, excluding breakfast (g)	31 ± 3	27 ± 3	25 ± 3	24 ± 3	29 ± 5	None
Total day protein intake (% of total energy intake)	12 ± 1	15 ± 1	13 ± 1	15 ± 1	15 ± 2	CR < AB ($P < 0.01$), EB, N ($P < 0.05$) CF < AB ($P < 0.01$), EB, N ($P < 0.05$)
Fibre						
Total day fibre intake (g)	12 ± 2	21 ± 3	14 ± 1	29 ± 1	16 ± 2	CR, CF, EB, H < AB ($P < 0.01$) CR < EB ($P < 0.01$); CF < EB ($P < 0.05$)

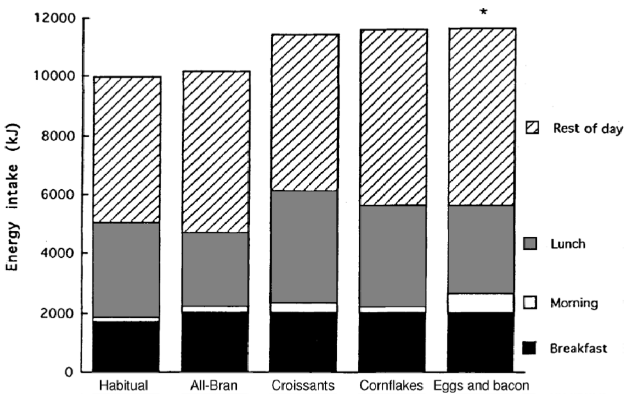

Figure 5. Total day energy intakes (mean ± SEM, n = 14). *EB > AB, H ($P < 0.05$).

Total energy and nutrient intakes by the end of the day

After lunch, there were no significant differences in subsequent energy intake (Figure 6). On average, the total day's energy intake was greater on the EB day than the AB day ($P < 0.05$) (Table 4). As shown in Figure 7, the subjects did not reduce their intake of fat after the high-fat breakfasts. Thus, both high-fat breakfasts were associated with significantly greater total day fat intakes than the AB and habitual breakfasts (min $P < 0.05$). Total fat intakes accounted for 40% of the total day's energy intake on the high-fat breakfast days and 35% of the total day's energy intake on the habitual, CF and AB days. Total day carbohydrate and fat intakes were negatively related. Total day carbohydrate intakes as a percentage of energy intake were greater on the high-carbohydrate (min $P < 0.05$) and habitual breakfast days than on the high-fat breakfast days. Total day protein intakes did not differ among the test meals (13–15% of total energy intake). The fibre content of breakfast had a significant impact on total day fibre intakes which varied from 14–29 g/d. The amount of fibre provided by the AB meal was not achieved with subsequent food intake after any of the other breakfasts.

Discussion

The results of this study show that the carbohydrate : fat ratio and energy density (kJ/g) determined the degree of fullness after eating to a greater extent than the meal's total energy

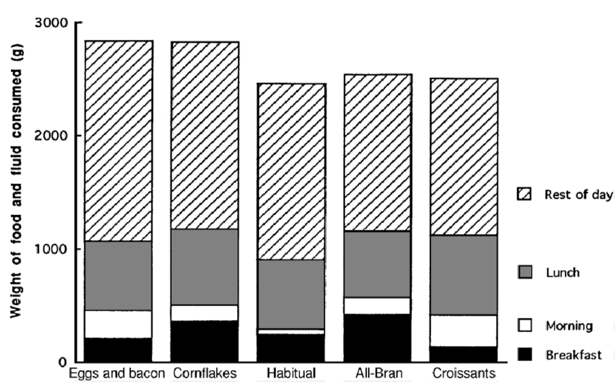

Figure 6. Total amount of food and fluid consumed during the day (mean ± SEM, n = 14).

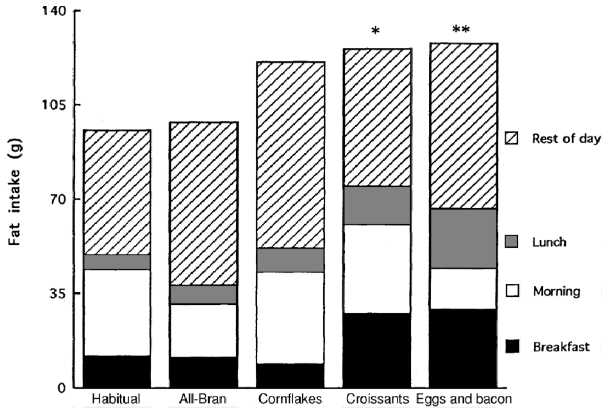

Figure 7. Total day fat intakes (mean ± SEM, n = 14). *CR > AB (P < 0.01), H (P < 0.05); **EB > AB, H (P < 0.01).

content. This is consistent with findings from previous studies showing that the strongest determinant of the satiating powers of iso-energetic meals is the portion size and energy density (kJ/g) of the meals (Haber *et al.*, 1977; Bolton *et al.*, 1981; Holt & Brand-Miller, 1994; Holt *et al.*, 1995; Poppitt & Prentice, 1996). In this study, the energy-dense high-fat breakfasts were only weakly satiating compared to the high-carbohydrate meals. Not only were the high-fat meals served in unsatisfyingly smaller amounts, but their greater palatability stimulated the subjects' desire to eat, leaving the subjects feeling inadequately satisfied after finishing the test portions. This is in agreement with results from previous studies which have shown that a greater amount of energy must be consumed from fat-rich meals than carbohydrate-rich meals before satiation is achieved, particularly at a high level of hunger (Lawton *et al.*, 1993; Cotton *et al.*, 1994; Green *et al.*, 1994; Green & Blundell, 1996).

In this study, the weak satiating power of the high-fat meals was illustrated by (1) the relatively low fullness ratings; (2) the faster onset of subsequent eating; and (3) greater energy consumption during the morning. The subjects habitually ate a greater amount of food and carbohydrate for breakfast than provided by the portions of high-fat test meals. Therefore, the marked increase in energy consumption during the morning after the high-fat breakfasts may have been necessary to replenish carbohydrate reserves to their usual levels and normalise satiety – i.e. achieve the levels of gastric fullness and satisfaction that the subjects normally experience after breakfast. This hypothesis is supported by the finding that fullness ratings failed to rise with the additional food intake after the high-fat meals. Similarly, by the end of lunch, the habitual level of carbohydrate intake had been achieved on all four test conditions. These findings agree with those from a number of dietary trials which have observed that subjects tend to eat a constant weight of food, regardless of dietary composition (Stubbs *et al.*, 1995; Bellisle *et al.*, 1996; Poppitt & Prentice, 1996; Saltzmann *et al.*, 1997). Thus, an increase in the energy density (fat content) of the diet results in a passive increase of energy intake. Similarly, recent dietary intervention trials have observed that subjects will adjust their food intake to maintain constant carbohydrate and protein intakes when dietary fat content is altered (Tremblay *et al.*, 1991; Lyon *et al.*, 1995). In the study by Tremblay *et al.*, (1991), lean males consuming high-fat diets felt adequately satiated only when they had consumed enough carbohydrate to maintain their usual level of carbohydrate oxidation. Further research is required to examine whether a high-fat meal is particularly less satiating than a high-carbohydrate meal when consumed at breakfast when glycogen reserves are relatively low, rather than at lunch or dinner. Differences in satiety could theoretically be even greater in children who tend to have lower liver glycogen levels than adults after an overnight fast due to their relatively smaller size and higher metabolic rate (Lechky, 1990).

In this study, the high-fibre, carbohydrate-rich breakfast had the lowest energy density and the most enduring effect on satiety. This meal contained a large amount of insoluble fibre, slowly-digested carbohydrate, and protein, and reduced food intake during the morning and at lunch. Several other studies have also found that high-carbohydrate meals containing a large amount of fibre (12–29 g) can effectively suppress hunger and/or food intake over the next 2–4 h, particularly when the fibre is relatively unrefined and intimately mixed within the food matrix (Levine *et al.*, 1989; Holt *et al.*, 1992; Burley *et al.*, 1993; Raben *et al.*, 1994; Delargy *et al.*, 1995; Holt *et al.*, 1995). Some studies which have not found increased fullness after high-fibre meals have used either relatively small amounts of fibre or energy-dense foods such as oats rather than extruded bran cereal (e.g. Silberbauer *et al.*, 1996). In this study, the high-fibre breakfast was initially more satiating than the other meals, because it was heavier, less palatable and more difficult to eat, and would increase gastric distension to a greater extent. During the next 2.5–3.5 h, the low-GI, high-fibre meal maintained the feeling of fullness at a much higher level than the other meals, reflecting its slower rate of carbohydrate digestion and the prolonged period of carbohydrate absorption in the small intestine (Benini *et al.*, 1995; Holt *et al.*, 1996; Lavin *et al.*, 1996). Fullness dissipated at a much faster rate after the low-fibre vs high-fibre carbohydrate-rich meal which contained more rapidly digestible carbohydrate. This result adds to the body of evidence showing that meals rich in slowly digested carbohydrate are more effective in maintaining blood sugar levels above fasting values and enhancing satiety than isoenergetic meals based on rapidly digested carbohydrate (van Amelsvoort & Westrate, 1992; Holt & Brand-Miller, 1994; Holt *et al.*, 1996; Raben *et al.*, 1997).

For every individual subject, breakfast consumption was immediately followed by an increase in alertness. The free-living protocol may have obscured potentially larger differences in feelings of alertness among the test meals. However, overall, the high-fibre carbohydrate-rich meal was followed by the greatest rise in post-breakfast alertness ratings and the greatest cumulative alertness response during the morning (AUC), which was approximately 1.5-fold higher than the alertness AUC values for the fat-rich breakfasts. Relationships between meal macronutrient composition and alertness have not been well examined, but recent studies have found that fat-rich meals depress mood and alertness to a greater extent than carbohydrate-rich meals (Lloyd *et al.*, 1994, 1996; Wells & Read, 1994). In this study, fullness and alertness ratings after the high-fibre meal remained significantly elevated in the late postprandial period while fullness and alertness ratings for the low-fibre, high-carbohydrate meal were declining. Alertness ratings increased 120–240 min after the high-fat EB meal, but are more likely to reflect the increased food and carbohydrate intake occuring during this period, rather than a late effect of the meal itself. Linear regression analysis indicated that the total amount of alertness experienced during the period between breakfast and lunch was significantly associated with the degree of fullness experienced. In addition, carbohydrate intake during the morning was positively, but not significantly, related to alertness AUC values, whereas fat intake was negatively associated. On the basis of these results, it is logical to speculate that high-carbohydrate meals may be able to enhance alertness by increasing blood glucose levels and feelings of fullness. In the absence of hunger, it may be easier for a person to focus on their work activities rather than their grumbling stomach. However, further research using tightly controlled methodology is necessary to determine whether changes in fullness can directly influence cognitive variables and mood states. A recent study found that breakfast consumption was associated with a marked improvement in children's cognitive test performance when consumed 30 minutes, rather than 2 hours, before testing when blood sugar levels would still be elevated (Vaisman *et al.*, 1996). Thus, it would be useful to examine whether low-GI carbohydrate-rich foods can enhance cognitive performance to a greater extent than rapidly digested high-GI foods.

The high-fibre meal was not sweet, but it contained more sugar than the other breakfasts. This indicates that the capacity of sugar to increase palatability or weaken satiation has obvious limits depending on the other components of the meal. The croissants meal was sweet, rich in fat, highly palatable and weakly satiating. In contrast, both low-fat breakfasts, either sweet or bland, were less pleasant but more satiating. This confirms that the high fat content of many sweet, palatable convenience foods (chocolate, cakes, biscuits, ice-cream) is a stronger determinant of excessive energy intake than the products' sugar content (Green *et al.*, 1994; Green & Blundell, 1996). As shown in this study, moderate amounts of sugar and jam can be used to improve the palatability of low-fat foods (bread, breakfast cereals) without greatly weakening satiety or stimulating food intake.

The results of this study clearly demonstrate that a breakfast rich in fibre and low in fat with an adequate amount of protein and carbohydrate may alleviate hunger throughout the morning and facilitate a lower total day's fat intake. This may be the optimal breakfast meal for people attempting to control their weight, and by maintaining moderate glycaemia and assuaging hunger it may also help people maintain concentration during the morning. However, further research is required to examine whether the relative differences in the acute satiating effects of the test meals observed in this study continue to be apparent when the meals are consumed on a regular basis. Consuming a high-fibre breakfast cereal is a relatively easy way to ingest a large amount of fibre and can greatly increase daily fibre intakes in accordance with dietary guidelines. In contrast, high-fat breakfasts increase the risk of an excessive daily fat intake, particularly since people tend not to reduce fat consumption during the rest of the day. The few subjects who regularly consumed high-fibre breakfast cereals considered the high-fibre meal to be much more pleasant than the subjects who consumed mainly low-fibre foods. Thus, fibre-rich foods, like low-fat products, may become more acceptable if eaten on a regular basis (Mattes, 1993). However, other carbohydrate-rich foods containing less fibre may also be sufficiently filling to prevent additional food intake during the morning. A wide variety of low-fat breakfast foods (breads, muffins, crumpets, ready-to-eat cereals) are now available, but further research is required to compare their effects on satiety. Ready-to-eat breakfast cereals which are fortified with vitamins and minerals may be a particularly valuable choice for female slimmers who should moderate their energy consumption without compromising their micronutrient intake. Similarly, substituting breakfast cereals for foods with a higher fat content can be palatable and easy method of reducing daily fat intakes to recommended levels (Kirk *et al.*, 1997).

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