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Breakfasts with different fiber and macronutrient contents do not differentially affect timing, size or microstructure of the subsequent lunch

Frühstücke mit unterschiedlichem Faser- und Makronährstoffgehalt haben keinen unterschiedlichen Einfluß auf Zeitpunkt, Größe oder Mikrostruktur des darauffolgenden Mittagessens

Summary The effects of four equienergetic breakfasts with varying fiber and macronutrient contents on hunger and satiety ratings, on subsequent lunch intake, and on postprandial carbohydrate and fat metabolism were investigated in normal weight male subjects in two experiments, in which lunch was offered at a predetermined time (Experiment 1) or in which the subjects were free to choose when to eat lunch (Experiment 2). Consumption of either a commercially available high fiber cereal (HFC, 10 % fiber), a medium fiber cereal (MFC, 7 % fiber), a low fiber cereal (LFC, 3 % fiber), or a standard continental breakfast (0 % fiber) on nonconsecutive days did not differentially affect hunger and satiety ratings, the size or microstructure of the subsequent lunch, and the breakfast to lunch intermeal interval (in Experiment 2). Plasma concentrations of glucose, lactate, and insulin increased more after the LFC breakfast than after the other breakfast varieties. A reactive postprandial hypoglycaemia occurred after the LFC breakfast, shortly before lunch. The plasma concentrations of fat metabolites (triglycerides, free fatty acids, β-hydroxybutyrate) and of glucagon were not differentially affected by the breakfast varieties. The results are consistent with the assumption that energy content of a meal is the major determinant of subsequent energy intake in man and that fiber content and macronutrient composition have only a modulating effect.

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Zusammenfassung Der Einfluss von 4 isoenergetischen Frühstücken mit unterschiedlichem Nahrungsfaser- und Makronährstoffgehalt auf Hunger und Sättigung, auf das nachfolgende Mittagessen sowie auf den postprandialen Kohlenhydrat- und Fettstoffwechsel wurde an normalgewichtigen, männlichen Probanden in 2 Experimenten untersucht, in denen das Mittagessen entweder zu einem vorbestimmten Zeitpunkt angeboten wurde (Experiment 1), oder in dem die Probanden selbst den Zeitpunkt des Mittagessens bestimmen konnten (Experiment 2). Der Verzehr eines handelsüblichen Müslis mit hohem (10 %), mittlerem (7 %) und niedrigem (3 %) Fasergehalt (HFC, MFC und LFC) oder ein Standard-Frühstück (0 % Fasern) hatten keinen unterschiedlichen Einfluß auf Hunger und Sättigung, Grösse und Mikrostruktur des folgenden Mittagessens und auf die Zeitspanne zwischen Frühstück und Mittagessen (in Experiment 2). Die Plasmakonzentrationen von Glucose, Lactat und Insulin stiegen nach dem LFC-Frühstück stärker an als nach den anderen Frühstücksvarianten. Eine reaktive postprandiale Hypoglykämie trat nach dem LFC-Frühstück kurz vor dem Mittagessen auf. Die Plasmakonzentrationen von Metaboliten des Fettstoffwechsels (Triglyceride, freie Fettsäuren, β-Hydroxybutyrate) und von Glucagon wurden durch die Frühstücksvarianten nicht unterschiedlich beeinflusst. Die Resultate stehen im Einklang mit der Annahme, daß der Energiegehalt einer Mahlzeit die wichtigste Determinante für die

nachfolgende Energieaufnahme ist. Der Faser- und Makronährstoffgehalt scheinen diesbezüglich nur einen modulierenden Effekt zu besitzen.

Key words Microstructure of eating – dietary fiber – macronutrients – mechanisms of satiety – cereals – metabolites

Schlüsselwörter Mikrostruktur des Essens – Nahrungsfasern – Makronährstoffe – Mechanismen der Sättigung – Müslis – Metabolite

Introduction

Dietary fibers have repeatedly been reported to reduce hunger or increase satiety ratings (e.g., 9, 17, 21), in particular in people on low calorie diets (1), and to affect both satiation (the process that terminates eating) and satiety (the subsequent state that prevents eating) (see (3)). In one study the ingestion of a high fiber breakfast decreased subsequent lunch intake (18). In another study, however, moderate differences in the fiber content of a test breakfast did not influence hunger ratings or subsequent energy intake at lunch (4). These discrepancies are presumably due to procedural differences and the use of different forms of fiber. Thus, the generality of an effect of dietary fiber on energy intake is open to discussion. The possible mechanisms of such an effect are also unclear. Gastrointestinal factors such as a retardation of gastric emptying by dietary fiber (9, 17, 18), or delayed absorption of glucose from the small intestinal lumen (11, 24, 25, 26), as well as metabolic factors related to differences in postprandial glycaemia or insulinaemia may be involved (8, 17, 20, 24, 25).

There are also disparate findings with respect to the influence of macronutrient content on subsequent energy intake. When compared with a high carbohydrate supplemented meal, an equienergetic high fat supplementation diminshed the satiating efficiency of the meal as evidenced by differences in energy intake in a test meal 90 min later (2). In another study, the macronutrient composition of a liquid breakfast had no effect on the subsequent lunch or on total energy intake for the rest of the day (7). Moreover, covert manipulations of macronutrient or energy contents of meals apparently lead to subsequent caloric but not macronutrient compensation (10).

The present study investigated the effects of equienergetic, real breakfasts with varying fiber and macronutrient contents on subsequent energy intake and on postprandial carbohydrate and fat metabolism. The effects of four breakfast varieties were tested. A short-term influence of the breakfasts on hunger and satiety might be reflected by changes in the size or timing of the subsequent lunch. Therefore, in a first experiment lunch was offered at a predetermined time after breakfast, whereas in a second experiment subjects were isolated from time cues and allowed to decide individually when to have lunch. To assess the metabolic consequences of the test breakfasts, plasma carbohydrate and fat metabolites, insulin and glucagon were measured before and at various times after the test breakfasts, as well as before and after the subsequent target lunch (only in the first experiment). In addition to the amount eaten at lunch, the microstructure of eating was recorded using the universal eating monitor (UEM; described in (13)). Information about subjective hunger ratings and postprandial feelings were obtained by questionnaires.

Subjects and methods

Subjects

Eighteen male normal weight subjects, age 21 to 32 years, participated in the study (nine in each experiment). Two subjects were later excluded because one was unable to participate in all four test trials of Experiment 1, and because blood could not be obtained from one subject in Experiment 2. The subjects weighed 60.2 to 81.2 kg, and their height was 168 to 190 cm. All subjects usually ate breakfast between 06:30 hours and 09:30 hours, lunch between 11:30 hours and 14:00 hours, and dinner between 18:00 hours and 21:30 hours before going to bed between 22:30 hours to 01:30 hours. Only a few subjects consumed snacks between meals. Subjects estimated drinking 10 to 25 dl of fluids a day. Regular physical activity was reported by nine subjects (between 4 and 10 h/week). Four subjects were smokers with an average of 2, 15, 17, and 20 cigarettes a day. The study was approved by the ethics committee of the University Hospital Zurich, and all subjects gave their written consent after the experimental procedure had been explained to them.

Test breakfasts

The four breakfast varieties were: 1) A commercially available high fiber Swiss breakfast cereal with raisins (HFC) (Bio-Huus-Müesli, Bio-Familia AG, Sachseln), 2) a medium fiber breakfast cereal (MFC) with dried strawberry chunks (Frutta Crunch, Bio-Familia AG, Sachseln), 3) a low fiber high sucrose cereal (LFC) consisting of sweetened puffed rice (Smacks, Kellogg Company, USA), and 4) a standard continental breakfast consisting of two white rolls, butter, strawberry jam, and apricot yoghurt (Table 1). The HFC cereal consisted of oat flakes, corn flakes, sultanas, barley flakes, sun flower seeds, honey-wheat bits, almonds, hazelnuts, apple pieces, and wheat

Table 1 Energy and macronutrient composition of meals

Breakfast		Energy	Carbohydrates	Fat	Fiber	Protein
High fiber cereal	125 g	2 038 kJ	86.3 g*[1]	8.8 g	12.5 g	13.8 g
250 ml milk	3.7 % fat	700 kJ	12.0 g	9.2 g	–	8.0 g
20 ml cream	35 % fat	28 kJ	6.4 g	0.7 g	–	4.2 g
	Total	**2 766 kJ**	**104.7 g**	**18.7 g**	**12.5**	**26.0 g**
Medium fiber cereal	125 g	2 236 kJ	75.0 g*[2]	20.6 g	8.75 g	12.5 g
220 ml milk	2.8 % fat	528 kJ	11.0 g	6.2 g	–	7.0 g
	Total	**2 764 kJ**	**86.0 g**	**26.8 g**	**8.75 g**	**19.5 g**
Low fiber cereal	125 g	2 033 kJ	105.0 g*[3]	1.9 g	3.75 g	10.4 g
250 ml milk	3.7 % fat	700 kJ	12.0 g	9.3 g	–	8.0 g
30 ml cream	25 % fat	31 kJ	10.5 g	0.7 g	–	7.2 g
	Total	**2 764 kJ**	**127.5 g**	**11.9 g**	**3.75 g**	**25.6 g**
Standard breakfast						
2 white bread buns	90 g	1 206 kJ	46.8 g	7.2 g		8.0 g
butter	20 g	634 kJ	0.1 g	16.6 g		0.1 g
jam	50 g	560 kJ	33.0 g	–		0.3 g
joghurt,	180 g	0.1 % fat	369 kJ	14.4 g	0.2 g	7.2 g
	Total	**2 769 kJ**	**94.3 g**	**24.0 g**	–	**15.6 g**
Lunch						total amount offered
Risotto					–	
tomato risotto	250 g	3 750 kJ	185.0 g	5.0 g		22.5 g
butter	20 g	634 kJ	0.1 g	16.6 g		0.1 g
Parmesan cheese	25 g	400 kJ	0.0 g	7.0 g		8.0 g
minced porc	250 g	1 825 kJ	0.0 g	25.0 g		50.0 g
	Total	**6 609 kJ**	**185.1 g**	**53.6 g**		**80.6 g**

declarations according to the manufacturers
(*[1] sugar content not available, *[2] 22.0 g sugars, *[3] 61.0 g sugars)

flakes. The MFC cereal was made of whole oat flakes, wheat flakes, unrefined sugar, peanut oil, coconut, hazelnuts, honey, freeze-dried strawberries, raspberries, wheatgerm, glucose, pectin, and salt. The LFC cereal was produced from wheat, sugar, glucose syrup, honey, plant fats, lecithin, vitamins, and iron.

Design and procedure

Experiment 1

A fully repeated-measures design was employed. Independent variables were the composition of the test breakfasts (see above) and the timing of blood sampling (12 time points). Dependent variables were plasma metabolite and hormone levels, parameters of meal microstructure, and questionnaire data. The experiment was performed on 12 test days over a period of 20 working days. Each subject participated on 4 days with a minimum intermittent period of 1 day. Smoking, strenuous exercise, and alcohol consumption were prohibited after 17:00 hours the day before tests. Between 18:00 and 21:00 hours, subjects consumed a pre-packaged dinner consisting of fresh meat tortellonis (250 g), canned tomato sauce (190 g), grated parmesan cheese (50 g), fresh carrot salad (160 g), and canned fruit cocktail (227 g including syrup). The dinner provided 5 029 kJ (161.6 g carbohydrates, 46.7 g fat and 44.2 g protein). The dessert fruit cocktail could be eaten until 23:00 hours. Subjects were instructed to drink 330 ml mineral water at dinner. Additional bottles of mineral water were provided for individual fluid demands.

Three subjects were tested daily, beginning at 07:00, 07:30 and 08:00 hours. Upon arrival at the laboratory on the morning of the test day, each subject had fasted for at least 8 to 9 h. Figure 1 (top) shows the daily proceedings for each subject. After weight and height measure-

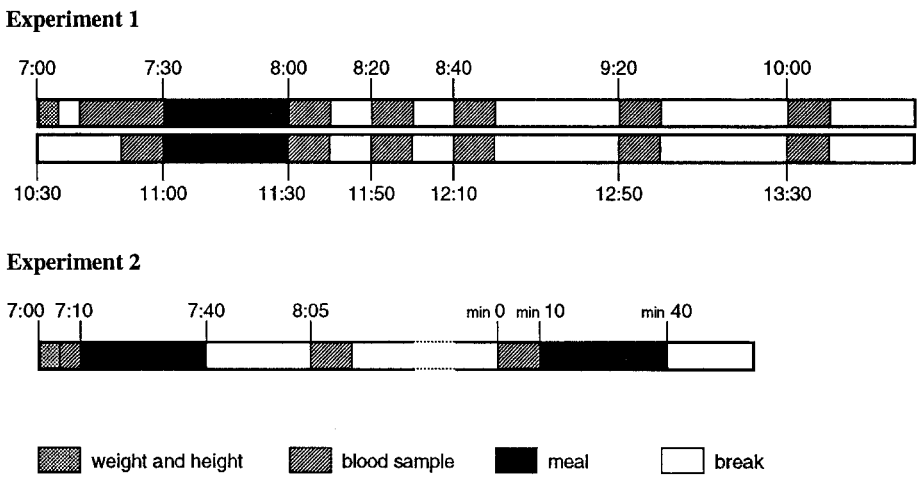


Fig. 1 Schedule of experimental proceedings for the first subject on each test day. Experiment 1: Second and third subject with delay of 30 min and 60 min, respectively. Experiment 2: Second, third and fourth subject with delay of 25 min, 50 min, and 75 min, respectively.

ments, a 20-gauge Vialon catheter (Becton, Dickinson, Switzerland) was placed into the antecubital vein and a fasting blood sample was drawn for baseline measurements. Eleven more blood samples were taken at various times, starting immediately after breakfast (see Fig. 1). Breakfast lasted 30 min, including completion of the two questionnaires given before and after the meal. Subjects were allowed to drink bottled mineral water with the meals and throughout the test period at their discretion. Between breakfast and lunch, subjects engaged in sedentary activities such as reading and watching TV.

A hot lunch was served 3.5 hours after the onset of breakfast. The lunch consisted of risotto (tomato flavoured rice stew; Knorr-Nährmittel AG, Thayngen) with bite-size pieces of meat. Subjects were instructed to eat as much of the oversized serving (6 609 kJ, carbohydrates 185.1 g, fat 53.6 g, protein 80.6 g) and to drink as much of the provided mineral water as they wanted. Lunch lasted 30 min, including answering the questionnaires before and after the meal. Subjects remained in the laboratory after lunch, engaging only in sedentary activities, until all blood samples were drawn.

Experiment 2

Basically the same design and procedure as in Experiment 1 were employed, with the following alterations (see Fig. 1, bottom): 1) Only three blood samples (baseline, after breakfast, just prior to lunch) were drawn by venapuncture. 2) Four subjects were tested daily, beginning at 07:00, 07:25, 07:50, and 08:15 hours. 3) The subjects themselves could determine when they wanted to consume the target lunch. Watches were taken from the subjects upon arrival at the laboratory, and other potential time cues were not available. After breakfast subjects engaged in sedentary activities, e.g. listening to music, in separate rooms. As soon as the subjects felt hungry enough to consume a warm meal, they came to the blood sampling room. After the third and last blood sample was drawn and the questionnaire was filled out, the same hot target lunch as in Experiment 1 was served.

Questionnaires

Subjects filled out a questionnaire before and after breakfast and lunch in each experiment. The questions addressed the subjects' degree of hunger and thirst and their perception of the meal. Some questions (not reported here) were posed to obscure the major purpose of the study. Answers were given through visual analogue scales ranging from 0–107 mm (e.g. from "not at all" (0 mm) to "extremely" (107 mm)). Other questions were answered by marking the appropriate expression on a five-point scale. Example: "no desire to eat" (1 point), "strong desire to eat immediately" (5 points). The questionnaire before each meal focused on the subjects' current hunger and thirst state, and the questionnaire after each meal inquired about the satisfaction of postprandial sensations.

Universal Eating Monitor (UEM)

The amount eaten at lunch and the microstructure of the meal (i.e. the cumulative food intake curve) was recorded with a scale integrated in the table underneath the plate (13). Subjects were not aware of the scale but were informed that they were supervised through a video camera during the meal. The weight of the plate was constantly monitored by the built-in scale, and recorded online by a computer in an adjacent room. By graphing the cumulative weight of the food eaten against time, a curve results that can be best described by a quadratic equation ($y = a + bx + cx^2$) (14). A non-linear regression analysis

Experiment 1

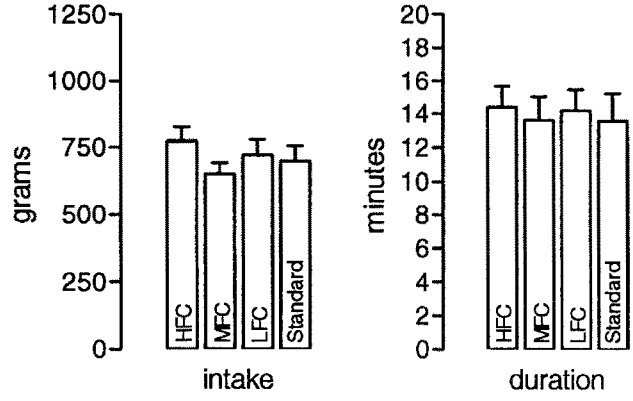


Fig. 2A Experiment 1: Size and duration of the fixed time lunch after the HFC, MFC, LFC, and standard breakfast. Bars represent means ± SEM of eight subjects.

determines the coefficients of the *cumulative intake curve*, where "b" describes the initial rate of eating, and "c" reflects the deceleration of eating and is, therefore, considered to be an expression of internal mechanisms of satiation (14, 22).

Blood analyses

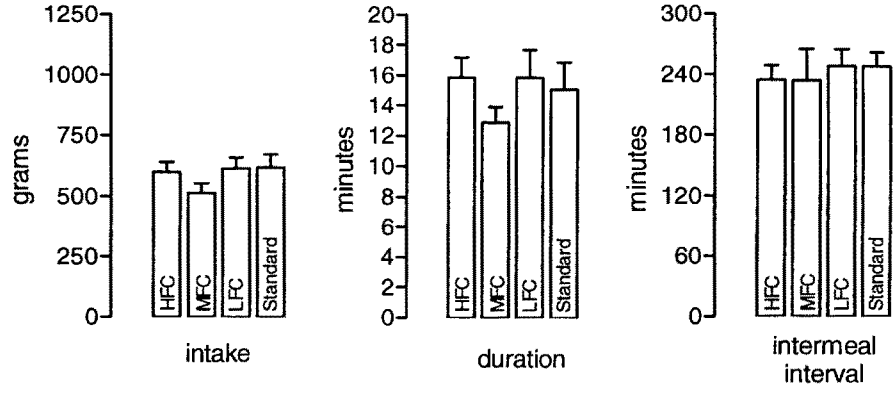
Each blood sample (the first 2 ml discarded) was drawn into a 2.7 ml sodium-fluoride tube and a 4 ml EDTA-tube of which 1 ml was transferred into a glass tube containing 50 ml Aprotinin (500 KIU, Boehringer, Mannheim) for later analysis of glucagon. All tubes were centrifuged at 3 800 rpm (≅ 1 900 G) for 10 min at 4 °C, and the plasma was removed and stored at -20 °C for analysis of metabolites and hormones. Insulin and glucagon were determined by commercially available radioimmunoassays (Insulin RIA 100; Pharmacia Diagnostics AB, Uppsala, Sweden; Glucagon Double Antibody, Diagnostic Products Corporation, Los Angeles, CA). Glucose, lactate, triglycerides (TG), free fatty acids (FFA), and β-hydroxybutyrate (BHB) were determined by standard colorimetric and enzymatic methods adapted for the Cobas Mira autoanalyzer (Hoffman LaRoche, Switzerland) (16, 23).

Statistics

One-way repeated measure analyses of variance (ANOVA) were used to detect differences between breakfast varieties in energy intake at lunch, cumulative intake curve coefficients, questionnaire ratings, plasma levels of metabolites and hormones, and time between breakfast and lunch in Experiment 2. Changes in plasma metabolite and hormone levels with time were also analyzed by ANOVA. When appropriate, additional comparisons of means were done with Student-Newman-Keuls post-hoc tests. Pearson product moment correlations were used to correlate energy intake, plasma levels of metabolites and ratings. To compare overall glucose, lactate and insulin responses to the test breakfasts and to the target lunch, the integrated areas under the curves' main peaks around breakfast and lunch (= net response; see results for exact time points) were calculated for each subject in Experiment 1. p values < 0.05 were considered significant. *SigmaStat* software version 1.0 (Jandel Corporation, San Rafael, CA) was used for statistical calculations.

Fig. 2B Experiment 2: Size and duration of the self-timed lunch and duration of the intermeal interval (breakfast to lunch) after the HFC, MFC, LFC, and standard breakfast. Bars represent means ± SEM of eight subjects.

Experiment 2



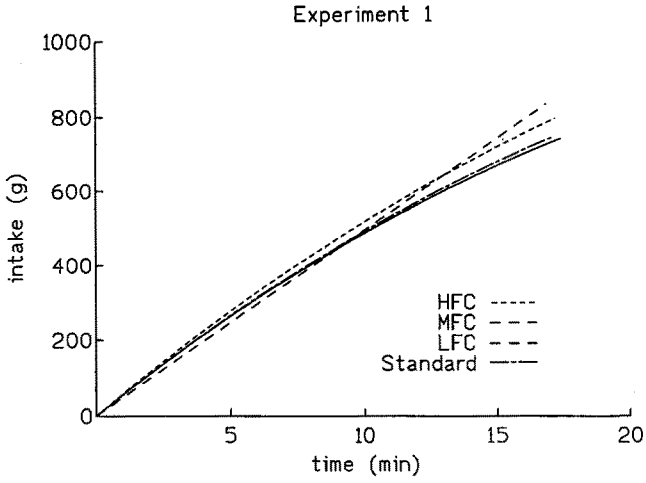


Fig. 3A Experiment 1: Fitted cumulative intake curves at the fixed time lunch plotted with the mean coefficients for each breakfast variety. See text for further details.

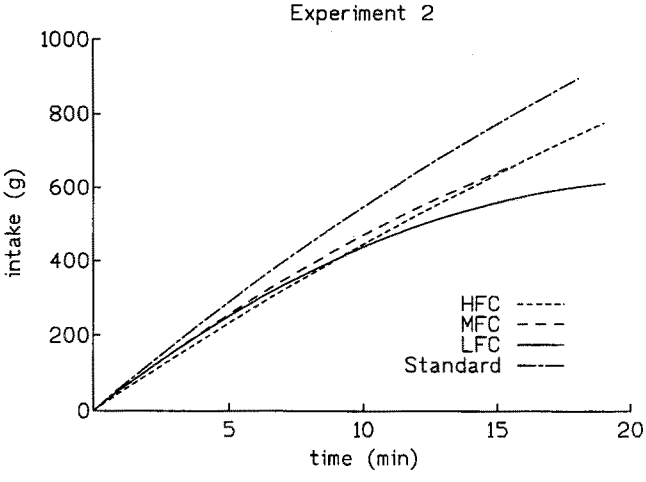


Fig. 3B Experiment 2: Fitted cumulative intake curves at the self-timed lunch plotted with the mean coefficients for each breakfast variety. See text for further details.

Results

Lunch intake

The amount of food consumed during the fixed time lunch (Experiment 1) or the self-timed lunch (Experiment 2) did not differ significantly after the HFC, MFC, LFC or standard breakfasts (Figs. 2A and 2B) (Experiment 1: $F(3,7) = 2.77$, $p > 0.07$), Experiment 2: $F(3,7) = 1.01$, $p > 0.40$). Lunch duration did also not differ significantly after the four breakfast varieties in both experiments (Experiment 1: $F(3,7) = 0.16$, $p > 0.92$, Experiment 2: $F(3,7) = 1.84$, $p > 0.18$). In Experiment 2, the breakfast-lunch intermeal interval ranged from 172 to 345 min and was not influenced by the breakfast variety ($F(3,7) = 0.94$, $p > 0.43$) (Fig. 2B). Water intake during lunch was around 300 ml for all breakfast varieties in both experiments and was also not significantly different (Experiment 1: $F(3,7) = 0.54$, $p > 0.66$; Experiment 2: $F(3,7) = 1.27$, $p > 0.31$).

Microstructure of lunch

As indicated by the mean cumulative food intake curves for the breakfast varieties (Figs. 3A and 3B), the microstructure of eating during the fixed time lunch (Fig. 3A) and the self-timed lunch (Fig. 3B) was also not affected significantly by the four breakfast varieties. The plots presented in Figs. 3A and 3B were obtained by performing a non-linear regression analysis on the microstructure data recorded by the UEM, fitting a quadratic equation to the cumulative intake curve (14, 21), plotting intake as a function of time, and extending the average curves for the mean meal duration. There was no significant difference in the rate (b) or deceleration (c) coefficients between HFC, MFC, LFC, and the standard breakfast in either experiment. In both experiments lunch duration was negatively correlated with the rate of intake (Experiment 1: $r = -0.55$, $p < 0.01$; Experiment 2: $r = -0.83$, $p < 0.01$). In Experiment 2 the duration of the intermeal interval was positively correlated with the intake rate (b: $r = 0.41$, $p < 0.03$), and negatively correlated with the deceleration of intake (c: $r = -0.43$, $p < 0.02$), but it was not significantly correlated with the amount eaten at lunch ($r = -0.09$, $p > 0.65$). Furthermore, there was a positive correlation of the deceleration of the cumulative intake curve with the amount eaten ($r = 0.59$, $p < 0.01$) and with lunch duration ($r = 0.71$, $p < 0.01$).

Although the results of the two experiments in this study cannot be directly compared (different subjects, different days), it is interesting to note some overall differences between the microstructure of lunch in both situations: 1) There was less variability in the cumulative intake curves between the breakfast varieties in Experiment 1 than in Experiment 2. 2) Despite the somewhat longer intermeal interval in the self-timing situation, subjects in Experiment 2 consumed generally less food during lunch than subjects in Experiment 1 ($F(1,15) = 20.8$, $p < 0.01$). As this was not associated with a reduced lunch duration ($F(1,15) = 0.19$, $p > 0.67$), the overall rate of intake (expressed by the coefficient b of the cumulative intake curve) was lower in Experiment 2 ($b = 0.80 \pm 0.05$, mean ± SEM) than in Experiment 1 ($b = 1.11 \pm 0.05$) ($F(1,15) = 17.6$, $p < 0.01$).

Questionnaires

The subjects liked all test breakfasts similarly in both experiments (Tables 2 and 3). Hunger ratings before and

Table 2 Experiment 1: Answers to questionnaires concerning hunger and satiety sensations before and after meals

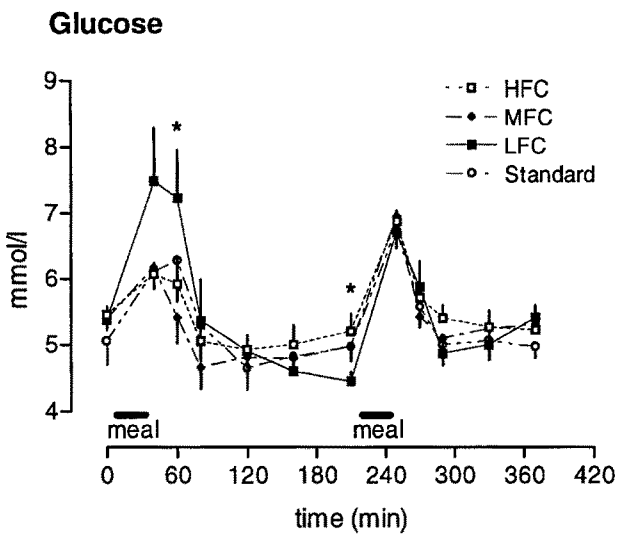
Breakfast		questions	HFC	MFC	LFC	Standard	P-value
before breakfast		How strong is your desire to eat? (answers 1–5)	3.1 ± 0.2	3.2 ± 0.2	3.1 ± 0.2	3.3 ± 0.5	NS
		How full do you feel?	20.5 ± 7.0	14.4 ± 4.9	18.6 ± 8.5	18.4 ± 7.8	NS
	A	How hungry are you right now?	58.3 ± 5.8	63.1 ± 6.3	55.0 ± 6.0	58.9 ± 6.5	NS
after breakfast		How did the meal taste?	62.1 ± 7.2	74.2 ± 7.5	60.3 ± 9.4	85.3 ± 5.9	NS
		How full do you feel after this meal?	69.8 ± 8.3	53.5 ± 10.4	70.6 ± 9.5	63.3 ± 8.3	NS
	B	How hungry are you after this meal?	27.0 ± 7.9	43.9 ± 10.4	30.4 ± 10.7	27.4 ± 10.3	NS
	Δ^1	Prandial decrease of hunger (= A–B)	31.3 ± 8.8	19.3 ± 12.2	24.6 ± 12.7	31.5 ± 12.6	NS
		How thirsty are you after this meal?	17.4 ± 5.1	13.6 ± 4.3	27.3 ± 10.1	12.0 ± 3.7	NS
		How long do you think you will be satiated after this meal?	61.5 ± 9.3	46.6 ± 10.2	25.0 ± 6.0	55.3 ± 10.2	0.025[1]
Lunch							
before lunch		How strong is your desire to eat? (answers 1–5)	3.0 ± 0.2	3.3 ± 0.3	3.5 ± 0.3	3.3 ± 0.4	NS
		How full do you feel?	28.1 ± 8.5	24.3 ± 10.4	12.6 ± 4.5	21.1 ± 6.6	NS
	C	How hungry are you right now?	59.9 ± 8.2	56.8 ± 10.2	65.5 ± 6.2	61.4 ± 6.6	NS
	Δ^2	Postprandial increase in hunger (= C–B)	32.9 ± 10.8	12.9 ± 14.9	35.1 ± 13.1	34.0 ± 12.5	NS
after lunch		How did the meal taste?	63.9 ± 4.9	60.4 ± 6.0	67.3 ± 7.1	65.0 ± 5.3	NS
		How full do you feel after this meal?	93.0 ± 3.4	88.1 ± 3.8	86.1 ± 5.7	92.8 ± 3.1	NS
		How hungry are you after this meal?	6.5 ± 2.4	8.4 ± 3.4	10.3 ± 4.3	4.8 ± 2.1	NS
		How thirsty are you after this meal?	27.9 ± 8.0	15.5 ± 5.1	37.9 ± 11.6	18.3 ± 6.57	NS
		How long do you think you will be satiated after this meal	65.5 ± 10.7	67.3 ± 8.4	59.3 ± 11.9	64.0 ± 6.9	NS

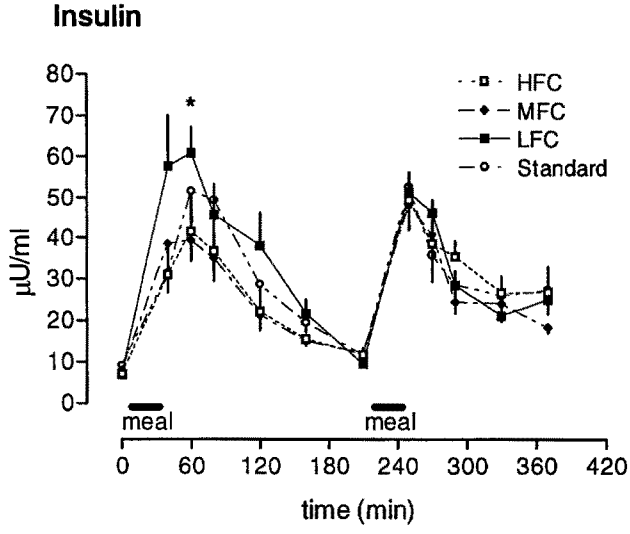
Values are means ± SEM of 8 subjects; 0 = weakest and 107 (in mm of visual analogue scale or 5 respectively) = strongest sensation of the feeling.
HFC = High fiber cereal, MFC = Medium fiber cereal, LFC = Low fiber cereal.
[1] Student-Newman-Keuls test: F(3,21) = 3.82; HFC different from LFC, LFC different from standard breakfast.

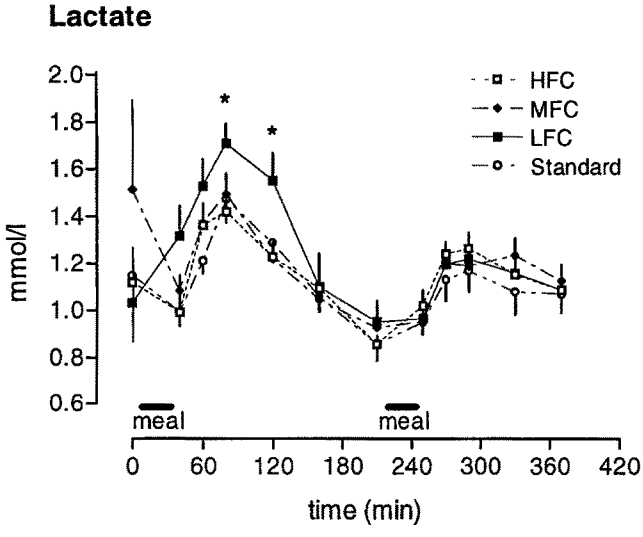
Table 3 Experiment 2: Answers to questionnaires concerning hunger and satiety sensations before and after meals

Breakfast		questions	HFC	MFC	LFC	Standard	P-value
before breakfast		How strong is your desire to eat? (answers 1–5)	3.3 ± 0.3	3.0 ± 0.3	3.3 ± 0.2	3.3 ± 0.3	NS
		How full do you feel?	14.0 ± 2.7	22.7 ± 4.6	17.3 ± 4.4	17.4 ± 4.3	NS
	A	How hungry are you right now?	74.1 ± 4.8	64.9 ± 5.8	68.6 ± 3.0	70.9 ± 6.6	NS
after breakfast		How did the meal taste?	61.1 ± 9.66	71.9 ± 7.7	48.9 ± 10.3	64.6 ± 9.26	NS
		How full do you feel after this meal?	81.4 ± 4.4	82.9 ± 3.4	79.3 ± 7.5	75.9 ± 3.7	NS
	B	How hungry are you after this meal?	34.6 ± 12.1	14.6 ± 3.4	21.4 ± 6.1	23.3 ± 5.8	NS
	Δ^1	Prandial decrease of hunger (= A–B)	39.6 ± 13.7	50.3 ± 6.5	47.3 ± 6.6	47.6 ± 7.8	NS
		How thirsty are you after this meal?	48.4 ± 11.9	62.9 ± 8.3	52.6 ± 11.3	42.5 ± 12.6	NS
		How long do you think you will be satiated after this meal	51.6 ± 9.5	66.0 ± 6.7	39.1 ± 5.54	33.4 ± 6.0	0.02[1]
Lunch							
before lunch		How strong is your desire to eat? (answers 1–5)	3.3 ± 0.2	3.1 ± 0.1	3.5 ± 0.3	3.6 ± 0.3	NS
		How full do you feel?	13.0 ± 3.4	19.8 ± 3.3	14.6 ± 4.2	13.8 ± 4.2	NS
	C	How hungry are you right now?	76.3 ± 4.8	72.5 ± 4.8	78.1 ± 5.6	76.9 ± 5.5	NS
	Δ^2	Postprandial increase in hunger (= C–B)	41.7 ± 12.0	57.9 ± 6.1	56.8 ± 8.6	53.6 ± 6.7	NS
after lunch		How did the meal taste?	69.5 ± 6.7	74.0 ± 5.3	79.5 ± 5.9	73.5 ± 5.9	NS
		How full do you feel after this meal?	78.1 ± 10.0	81.3 ± 5.6	89.1 ± 3.7	89.4 ± 3.6	NS
		How hungry are you after this meal?	6.6 ± 1.3	11.3 ± 2.7	6.3 ± 1.6	7.9 ± 1.8	NS
		How thirsty are you after this meal?	28.0 ± 11.6	42.1 ± 11.0	33.3 ± 13.1	24.9 ± 10.2	NS
		How long do you think you will be satiated after this meal?	71.7 ± 11.5	80.0 ± 5.9	64.5 ± 11.5	77.5 ± 6.9	NS

Values are means ± SEM of 8 subjects; 0 = weakest and 107 (in mm of visual analogue scale or 5 respectively) = strongest sensation of the feeling.
HFC = High fiber cereal, MFC = Medium fiber cereal, LFC = Low fiber cereal.
[1] Student-Newman-Keuls test: F(3,20) = 4.12; MFC different from LFC and standard breakfast.







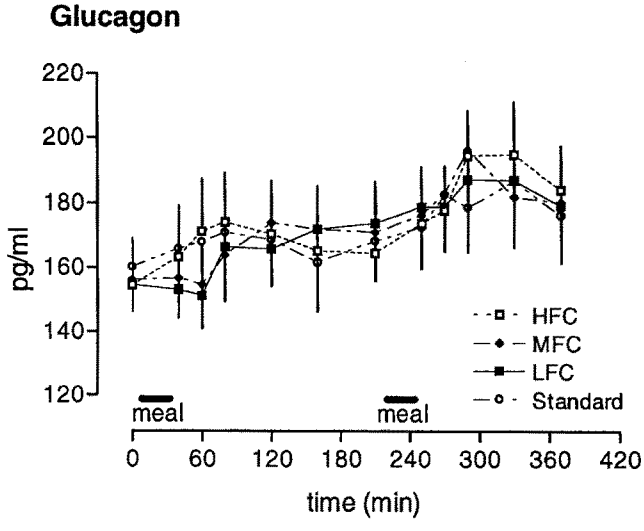


Fig. 4 Effect of HFC, MFC, LFC, and standard breakfast on plasma glucose (top) and plasma lactate (bottom) concentrations. Values are means ± SEM of eight subjects. * Indicates significant treatment differences, $p < 0.05$ in post-hoc tests after significant ANOVA (glucose: 60 min, $F(3,7) = 3.27$, 210 min, $F(3,7) = 5.59$; lactate: 80 min $F(3,7) = 3.63$, 120 min $F(3,7) = 6.29$).

Fig. 5 Effect of HFC, MFC, LFC, and standard breakfast on plasma insulin (top) and plasma glucagon (bottom) concentrations. Values are means ± SEM of eight subjects. * Indicates significant treatment differences, $p < 0.05$ in post-hoc tests after significant ANOVA ($F(3,7) = 3.53$).

after the meals as well as the prandial declines and post-breakfast increases in hunger ratings (Δ^1, Δ^2 in Tables 2 and 3) were also not affected significantly by the different test breakfasts. The HFC and standard breakfasts (Experiment 1; $F(3,7) = 3.82$, $p < 0.05$) and the MFC breakfast (Experiment 2; $F(3,7) = 4.12$, $p < 0.02$) were estimated to have a longer lasting satiety effect than the LFC breakfast. After lunch, postprandial fullness ($r = 0.40$, $p < 0.05$), but not remaining hunger sensations ($r = 0.11$, $p > 0.5$), was positively correlated with the amount eaten at lunch.

Plasma metabolites and hormones

Experiment 1

The plasma glucose concentration changed significantly with time ($F(11,31) = 19,2$, $p < 0.001$) and varied between breakfasts (Fig. 4). With the LFC breakfast, it was higher than with the other breakfasts at 60 min and lower at 210 min. The overall glucose response to the breakfasts (area under the curve between 0 and 80 min) was also greater after the LFC than after the other breakfasts ($p < 0.05$ in

post-hoc test after significant ANOVA, $F(3,7) = 4.01$). The breakfasts did not affect the plasma glucose level or overall glucose response after lunch (area under the curve between 210 and 290 min; $F(3,7) = 0.45$, $p > 0.7$), nor did the glucose response after breakfast differ from the response after lunch ($F(1,31) = 0.49$, $p > 0.5$). Only with the LFC breakfast, plasma glucose level was lower before lunch (210 min) than at baseline (0 min) ($F(1,7) = 32.9$, $p < 0.001$). After the HFC and MFC breakfasts, the plasma glucose level was significantly lower than after the subsequent lunch (40 min vs. 250 min) (HFC: $F(1,7) = 11.9$, $p < 0.01$; MFC: $F(1,7) = 10.4$, $p < 0.01$). Finally, there was no significant correlation between the glucose level before lunch and hunger ratings at the corresponding time ($r = 0.07$, $p > 0.16$).

The plasma lactate concentration (Fig. 4) also changed with time ($F(11,31) = 14.1$, $p < 0.001$) and differed between breakfasts, i.e., it was higher after the LFC breakfast than after the other breakfasts at 80 and 120 min (Fig. 4). The overall lactate response (area under the curve between 40 and 160 min) to the LFC breakfast was also greater than the response to the other breakfasts ($p < 0.05$ in post-hoc test after significant ANOVA, $F(3,7) = 6.33$). The lactate response was generally greater after breakfast than after lunch ($F(1,31) = 23.6$, $p < 0.001$). After the MFC, LFC, and standard breakfasts, plasma lactate concentration was higher than after lunch (ps < 0.05 for 80 vs. 290 min).

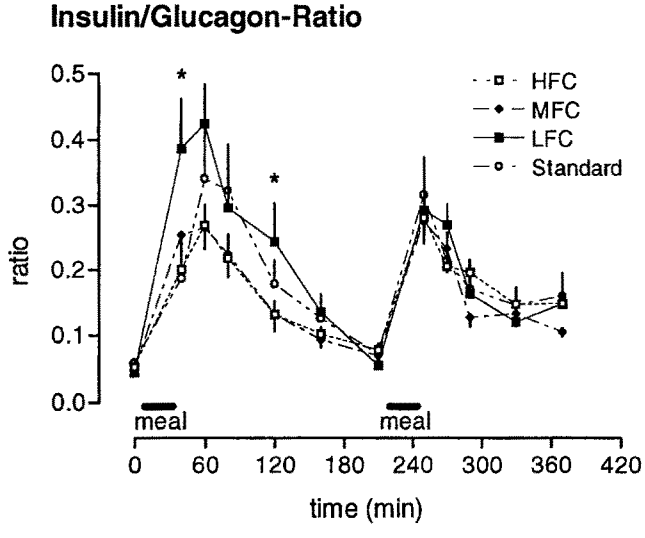


Fig. 6 Effect of HFC, MFC, LFC, and standard breakfast on insulin/glucagon ratio. Values are ratio means ± SEM of eight subjects. * Indicates significant treatment differences, $p < 0.05$ in post-hoc tests after significant ANOVA (40 min $F(3,7) = 4.22$, 120 min $F(3,7) = 3.66$).

The plasma insulin concentration also changed with time ($F(11,31) = 36.0$, $p < 0.001$) (Fig. 5) and significant treatment differences were observed after breakfast (60 min): The LFC breakfast increased plasma insulin concentration more and triggered a greater overall insulin response (area under the curve between 0 and 160 min) than the HFC and MFC breakfasts ($p < 0.05$ in post-hoc test after significant ANOVA, $F(3,7) = 6.10$). The overall insulin response to all breakfasts was not significantly different from the response to lunch ($F(1,31) = 0.23$, $p > 0.62$). Plasma insulin generally dropped to about baseline level before lunch. In general, postprandial hyperinsulinemia was also similar following breakfast and lunch, but with the HFC ($F(1,7) = 4.77$, $p < 0.05$) and the standard breakfast ($F(1,7) = 5.08$, $p < 0.05$), plasma insulin was higher after lunch than after breakfast (250 vs. 40 min). Insulin levels just before lunch (210 min) were negatively correlated with the reported satiety state at that time ($r = -0.47$, $p < 0.01$) and positively correlated with the amount eaten at lunch ($r = 0.43$, $p < 0.05$).

Plasma glucagon levels gradually increased with time ($F(11,31) = 19.2$, $p < 0.001$) (Fig. 5), but there was no significant difference between breakfast varieties at any time. The insulin/glucagon ratio (Fig. 6) was also calculated for all individual plasma samples and was significantly higher at 40 and 120 min after the LFC breakfast than after the other breakfast varieties.

Plasma β-hydroxybutyrate (BHB) decreased with time ($F(11,31) = 13.5$, $p < 0.001$) (Fig. 7). Basal plasma concentrations of BHB varied considerably between subjects. This was mainly due to one subject who's BHB value was always particularly high in the first four plasma samples. No significant treatment differences in plasma BHB level were observed between breakfast and lunch. After lunch, plasma BHB level was lower at 270 min with the LFC breakfast than with the MFC breakfast. At 290 and 330 min plasma BHB was lower with the standard breakfast than with the HFC or MFC breakfast.

The plasma free fatty acid (FFA) concentration changed with time ($F(11,31) = 25.1$, $p < 0.001$) (Fig. 7). More specifically, it decreased during breakfast and increased after lunch. Significant differences between test breakfasts were found at 160 min, when the plasma FFA level was higher after the HFC than after the LFC or the standard breakfasts, and higher after the MFC than after the LFC breakfast. Plasma FFA level was generally higher after lunch than after breakfast (290 vs. 80 min, $p < 0.05$ for MFC, LFC, and standard breakfast). With the standard breakfast the FFA level was significantly higher after the subsequent lunch (330 min) than with the other breakfasts (Fig. 7).

The plasma triglyceride level ($F(11,31) = 45.7$, $p < 0.01$) gradually increased, and total plasma protein level ($F(11,31) = 4.44$, $p < 0.01$) (Fig. 8) decreased with time, but there was no significant difference between breakfast varieties for these parameters at any time.

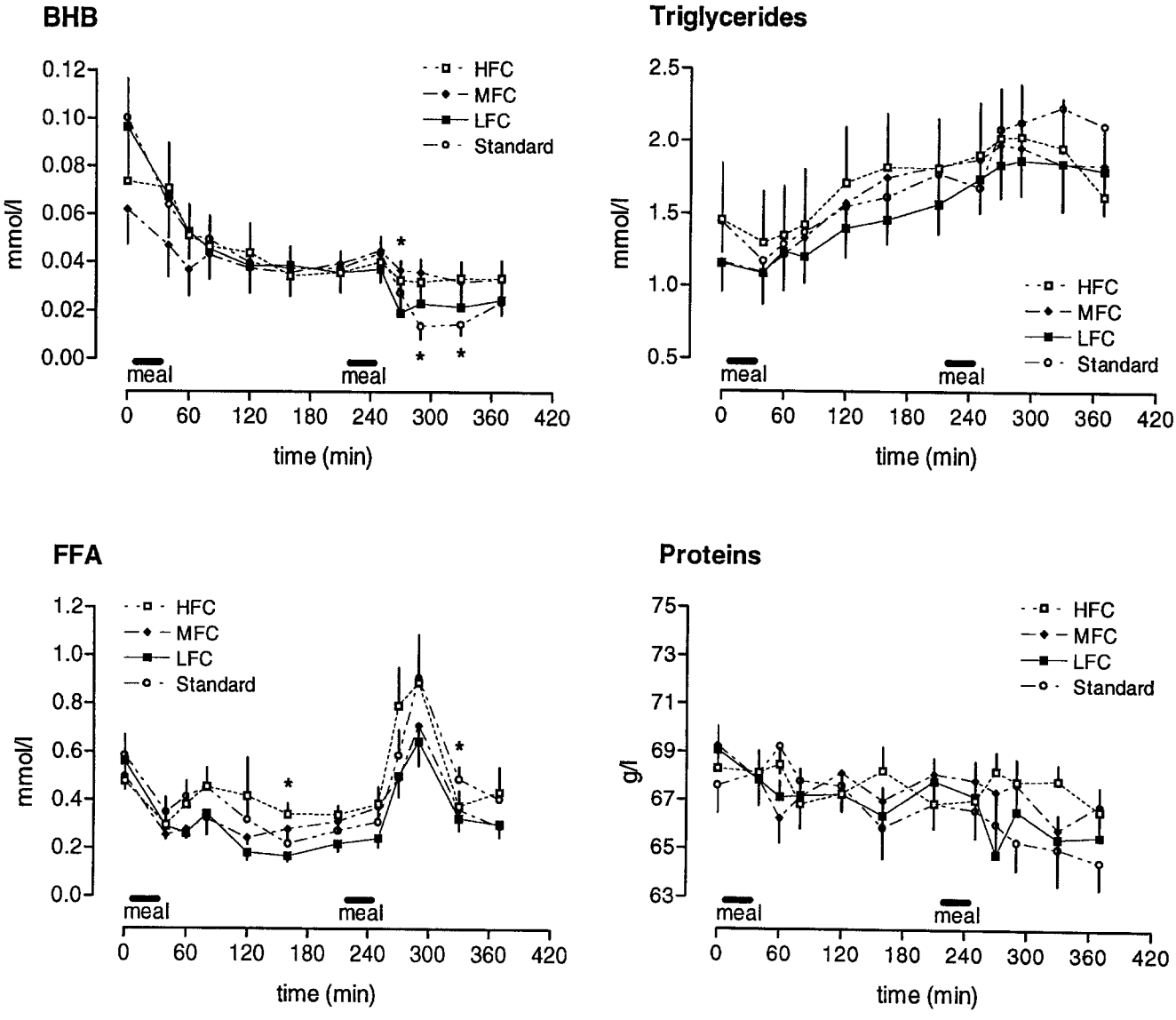


Fig. 7 Effect of HFC, MFC, LFC, and standard breakfast on plasma β-hydroxybutyrate (BHB, top) and free fatty acids (FFA, bottom) concentrations. Values are means ± SEM of eight subjects. * Indicates significant treatment differences in post-hoc tests after significant ANOVA (BHB: 270 min $F(3,7) = 3.17$, 290 min $F(3,7) = 6.42$, 330 min $F(3,7) = 5.15$; FFA: 160 min $F(3,7) = 7.24$, 330 min $F(3,7) = 4.78$).

Fig. 8 Effect of HFC, MFC, LFC, and standard breakfast on plasma triglyceride (top) and plasma protein (bottom) concentrations. Values are means ± SEM of eight subjects.

Experiment 2

As far as can be judged from the limited number of samples, the postprandial metabolic responses to the four breakfast varieties were similar to the responses in Experiment 1 and are therefore not presented. Again plasma glucose level just prior to lunch was lowest after the LFC breakfast ($F(3,7) = 7.68$, $p < 0.002$). None of the other metabolite and hormone levels at that time differed between the breakfast varieties. Hunger ratings prior to lunch and glucose level were again not correlated, but there was a significant positive correlation between the glucose level just before lunch and the duration of the intermeal interval ($r = 0.37$, $p < 0.05$).

Discussion

In the present study, equienergetic, "real" breakfasts with varying fiber content and nutrient composition did not

differentially affect hunger ratings, energy intake and microstructure of eating during the subsequent lunch, served at a predetermined or at a self-selected time. This is in line with and extends several previously reported failures of dietary fiber (2, 4, 7) or macronutrient content (7, 10) to affect energy intake. Yet, reduced hunger ratings or energy intake in response to dietary fiber ingestion have also been reported (1, 9, 18, 20, 21). These discrepancies are presumably due to procedural differences. In some studies in which dietary fiber did reduce hunger ratings or subsequent energy intake, higher amounts of fiber were used (1, 9, 18), the fiber was given over longer periods of time (1, 21), or the high and low fiber test meals were not equienergetic (18). Considering that the HFC (10 % fiber) and MFC (7 % fiber) breakfasts contained a fairly high amount of fiber, the present results also suggest that fiber content of a test meal must be above 10 % to influence subsequent energy intake under normal ecological conditions.

Unlike some other studies testing the effect of dietary fiber on energy intake, the macronutrient content of the breakfasts used in this experiment varied because the main goal was to compare "real" breakfasts, i.e., commercially available cereals prepared close to the suggestions of the manufacturer. Therefore, the breakfasts provided the same amount of energy but had a different macronutrient content. It is unlikely that an effect of dietary fiber on lunch intake was obscured by the varying macronutrient content because the target lunch was served about 3 h after completion of breakfast, at a time when an immediate effect of breakfast macronutrient composition on energy intake had presumably ceased (2). Furthermore, nutrient composition of liquid breakfasts used elsewhere had no effect on the energy intake of a lunch consumed 3.5 h later (7). On the other hand, fiber supplementation of breakfast has been reported to affect lunch intake 3.5 h later (18).

The fiber content and the nutrient composition of the breakfasts used in this study were apparently not able to change the timing of the subsequent lunch or the amount eaten. As meal size and the timing of meals may to be in part controlled by different factors (15), the present results indicate that fiber content and nutrient composition of breakfast do not influence the maintenance of satiety or the mechanism(s) that terminate food intake at lunch.

The shape of the cumulative intake curve is considered to reflect learning processes and internal mechanisms regulating food intake (14, 26). The mean cumulative intake curves of each test day in this study were remarkably similar to the curves described by Kissileff et al. (14). We did not see a pronounced deceleration of intake towards meal end in any of the experiments, as described for normal weight subjects by Westerterp-Plantenga et al. (26). However, non-decelerated cumulative intake curves are not unusual for normalweight, young males (12, 26). Although a direct comparison of the curves of both experiments is inappropriate, the smaller variability of the cumulative intake curves, the higher rate of intake and the greater lunch intake, despite the somewhat shorter intermeal interval in Experiment 1 compared to Experiment 2, seem to suggest that the normal physiological controls of eating were somehow weakened by the fixed timing of the lunch in Experiment 1. Further studies are necessary to clarify this interesting point, in particular as most short-term human eating studies employ fixed time target meals.

Although the breakfast varieties did not significantly affect post-breakfast hunger ratings and lunch intake, the subjects believed that the HFC and standard breakfast (Experiment 1) or the MFC breakfast (Experiment 2) would suppress hunger for a longer time than the LFC breakfast. This seems to reflect a judgement of the satiating efficiency of foods based on the perceived nutritional value: The sweet LFC may have been considered less nutritional than the HFC or MFC, two products that are advertised and conceived as healthy and very nutritional.

There were significant postprandial metabolic differences between treatments, particularly for glucose, insulin, and lactate. In earlier studies, a delayed postprandial increase in plasma glucose after the consumption of complex carbohydrates has been reported (8, 17, 24), presumably due to a slower glucose absorption from the intestine into the blood. The higher fiber content of the HFC and MFC may have resulted in the slower uptake of glucose into the blood stream, resulting in the attenuated increase in blood glucose. Glucose and insulin, except on LFC breakfast days, increased faster after lunch than after breakfast. Whether or not this reflects a delaying effect of the breakfast fiber content (in particular of the HFC and MFC breakfasts) on glucose absorption cannot be judged from the present data. On the other hand, the overall glucose, insulin, and lactate responses to breakfast were more pronounced after the LFC than after the other test breakfasts. The higher glycaemic response to the LFC might be a result of the higher sugar and lower fiber content of the breakfast. The fiber content of the breakfasts may have delayed glucose absorption somewhat. However, as carbohydrate and fiber content of the breakfasts varied, it cannot be judged from the present results to what extent the fiber content alone influenced the glycaemic response.

A reactive postprandial hypoglycaemia was detected after the LFC breakfast in both experiments, i.e., shortly before lunch, plasma glucose concentration was lower on days with the LFC breakfast than on the other experimental days. As indicated by the high plasma lactate concentration after the LFC breakfast, the reactive hypoglycaemia reflects an enhanced glucose utilization which can be attributed to the high insulin response. Considering presumably that a pre-meal decline in blood glucose may

provide a metabolic pattern that contributes to meal initiation (5, 19), which has recently been described also in man (6), it is interesting to note that the preprandial glucose level was correlated with the duration of the self-controlled intermeal interval in Experiment 2. This is compatible with the idea that blood glucose level is somehow involved in the maintenance of satiety. On the other hand, we found no significant correlation between the blood glucose concentration and the hunger ratings before lunch.

The rise in the plasma FFA level after lunch is presumably due to hydrolysis of ingested triglycerides by lipoprotein lipase. This rise appeared particularly pronounced on days when the HFC or the standard breakfast were served, but there is no clear explanation for this finding since no other blood parameter showed treatment differences. The increase in plasma FFA after lunch was not accompanied by an increase in plasma BHB, indicating that hepatic fatty acid oxidation was not enhanced. The reasons for this dissociation are unknown. Whether the higher plasma FFA concentration after the HFC breakfast reflects an inhibitory effect of dietary fiber on fatty acid oxidation (20), or whether it coincides with enhanced fatty acid oxidation, as might be possible considering the usual positive correlation between plasma FFA concentration and fatty acid oxidation and the low insulin/glucagon ratio for HFC, cannot be decided from the present results.

In summary, the present study demonstrates that "real" breakfasts with different fiber content and nutrient composition have some distinct effects on postprandial metabolic variables, but do not differentially affect the timing, the size, or the microstructure of the subsequent lunch. They also do not alter subsequent hunger and satiety ratings. The results are consistent with the assumption that energy content of a meal is the major determinant of subsequent food intake and that fiber content and nutrient composition have only a modulating effect on subsequent energy intake.

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