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PAPER

The effects of yoghurt containing a novel fat emulsion on energy and macronutrient intakes in non-overweight, overweight and obese subjects

AA Burns[1], MBE Livingstone[1]*, RW Welch[1], A Dunne[2], CA Reid[3] and IR Rowland[1]

[1]*Northern Ireland Centre for Diet and Health, University of Ulster, Coleraine, Co Londonderry, Northern Ireland, UK;* [2]*Department of Statistics, University College Dublin, Dublin, Ireland; and* [3]*Biomathematics and Statistics Scotland, The Rowett Research Institute, Bucksburn, Aberdeen, Scotland, UK*

OBJECTIVE: To investigate the effects of a yoghurt containing a novel fat emulsion on energy and macronutrient intakes up to 8 h post-consumption in non-overweight, overweight and obese subjects, and to assess energy compensation over the following 24 h.
DESIGN: A double-blind, placebo-controlled, within-subject crossover design was used. Twenty (10 female, 10 male) non-overweight (body mass index (BMI) 20–24.9 kg/m^2), 20 (10 female, 10 male) overweight (BMI 25–29.9 kg/m^2) and 20 (13 female, 7 male) obese (BMI > 30 kg/m^2) subjects participated in the study. Subjects were given in random order, 7 days apart, either a 200 g portion of a test (5 g of a novel fat emulsion + 1 g milk fat) or control (6 g milk fat) yoghurt at 09:00 h. At 4 and 8 h post-consumption subjects were given *ad libitum* access to a range of foods. Amounts of food consumed were determined by pre and post-covert weighing of individual serving dishes. Over the following 24 h subjects weighed and recorded all food intakes.
RESULTS: Mean energy intakes were significantly lower after the test yoghurt compared with the control yoghurt in non-overweight (3.79 *vs* 5.43 MJ; $P < 0.01$) and overweight (4.43 *vs* 6.12 MJ; $P < 0.001$) subjects 4 h post-consumption and in non-overweight (3.82 *vs* 5.38 MJ; $P < 0.001$), overweight (3.94 *vs* 5.80 MJ; $P < 0.001$) and obese (4.91 *vs* 6.26 MJ; $P < 0.01$) subjects 8 h post-consumption. The corresponding macronutrient intakes were also significantly reduced in non-overweight and overweight subjects ($P < 0.01$) at 4 h post-consumption and in all subjects 8 h post-consumption ($P < 0.01$). In the total group, energy intakes over the following 24 h were also significantly reduced (6.35 *vs* 7.70 MJ; $P < 0.01$) after the test yoghurt relative to the control yoghurt.
CONCLUSIONS: These results suggest that the effects of this novel fat emulsion are maintained at least up to 8 h and are evident in non-overweight, overweight and obese subjects.
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Keywords: fat; emulsion; prolonged satiety

Introduction

The hypothesis that fat is the least satiating of the macronutrients remains controversial.[1–7] The limited studies that have examined the potential effects of the physicochemical composition of fat on satiety and satiation have found that structural differences, such as chain length and degree of saturation, influence satiating efficiency.[8] Furthermore, the route of fat administration,[9,10] and the time interval between a preload and a test meal[11] have been shown to influence its satiating ability.

Previously our research group have shown that, in comparison with a yoghurt containing dairy fat, consumption of a yoghurt containing a novel fat emulsion (Olibra™) significantly decreased energy and macronutrient intakes in non-obese subjects at a meal 4 h later; and that the decreased intakes persisted for the rest of the day.[12] It is not known if this suppression of food intake would persist into the following day, or alternately if subjects would compensate by increasing consumption. It was speculated that overweight

*Correspondence: MBE Livingstone, Northern Ireland Centre for Diet and Health, University of Ulster, Coleraine, Co Londonderry, Northern Ireland BT52 1SA, UK.
E-mail: MBE.Livingstone@ulst.ac.uk
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and obese subjects may not respond in a similar way to non-overweight subjects after the test yoghurt because of the observation that individuals who are obese or who have a tendency to become obese may differ from non-overweight individuals, not only in their preference for high-fat foods,[13] but also in their ability to adjust subsequent intake to compensate for consumption of high-fat, high-energy foods.

Consequently the aim of the present study was to investigate if the effects of this novel fat emulsion on energy and macronutrient intakes would be sustained up to 8 h in non-overweight, overweight and obese subjects and to assess energy and macronutrient intakes for the following 24 h.

Subjects and methods

Subjects

Sixty subjects were recruited in this study: 20 subjects (10 females, 10 males) were non-overweight (body mass index, BMI) 20–24.9 kg/m^2), 20 subjects (10 females, 10 males) were overweight (BMI 25–29.9 kg/m^2), and 20 subjects (13 females, seven males) were obese (BMI $>$ 30 kg/m^2). The subjects were recruited by poster advertisement from the student and staff population at the University of Ulster. The study protocol was explained in detail to each subject, and the subjects who met the eligibility criteria and agreed to take part gave their written informed consent. Exclusion criteria were: smokers, vegetarians, those taking any prescription medication and any subject who had participated in any previous study using Olibra™ fat emulsion. The weight, height and percentage body fat (bioelectrical impedance Bodystat 1500, Bodystat Ltd, Isle of Man, UK) of each subject were measured prior to breakfast on the first study day. The study was approved by the Research Ethical Committee of the University of Ulster.

Study design

This study was conducted over 4 months in the metabolic suite at the University of Ulster. The study design was a randomised double-blind, placebo-controlled, within-subject crossover. Each subject was studied on two occasions, on the same day of each week, and with a one-week interval between crossover. Within the study, subjects were randomly assigned into two groups: group 1 received the test yoghurt on the first study day; and group 2 received the test yoghurt on the second study day. Each subject was requested to fast from 20:00 h on the evening before each study day and to refrain from moderate-to-heavy exercise on the days preceding and succeeding the study and during each study day. At 09:00 h on each study day, each subject consumed a 200 g portion of either the test or control yoghurt, each of which were presented in identical unmarked white containers. After eating the yoghurt, subjects resumed their normal routine for the morning, during which time they were instructed not to consume anything other than uncarbonated water, and to take the latter only if required. At 13:00 h subjects returned to the metabolic suite and were given *ad libitum* access to a range of sweet and savoury foods, which, prior to the study, had been established as forming part of the subject's normal diet. After the lunch meal subjects followed their normal routine until 17:00 h but were only permitted to drink uncarbonated water, if required. At 17:00 h subjects returned to the metabolic suite and were again given *ad libitum* access to a wide range of familiar foods. Only uncarbonated water was available to drink at both meal occasions due to the evidence that sweet drinks may reduce hunger ratings.[14] All foods presented at 13:00 h and 17:00 h were covertly weighed prior to the meal, and all uneaten food was weighed after the meal and when the subjects had left the metabolic suite. Intakes were assessed by difference.

Subjects rated their hunger, desire to eat, preoccupation with thoughts of food, perceived fullness and thirst, on visual analogue scales (VAS; in mm) by the pen and paper method. For example, hunger was rated on a 100 mm line preceded by the question 'How hungry do you feel?' and anchored on the left by 'not at all hungry' and on the right by 'as hungry as I have ever felt'. The other anchors for the questions on desire to eat, preoccupation with thoughts of food and perceived fullness consisted of the phases 'very weak…' against 'very strong…', 'no thoughts…' against 'very preoccupied…' and 'not at all…' against 'extremely full…', for each of the questions respectively. Subjects were instructed to make a single vertical mark at the appropriate point between the two anchors on each scale to indicate their subjective feelings of hunger, desire to eat, preoccupation with thoughts of food and perceived fullness respectively at defined time points (immediately before and after eating the yoghurt and thereafter at hourly intervals until 21:00 h on both study days. Yoghurts were rated for pleasantness by the subjects using of a VAS form 15 min post-consumption of both test and control yoghurts. Subjects were asked to report hourly on the VAS any ill effects or discomfort.

For the remainder of the day and up until 21:00 h the following day, subjects were permitted to eat and drink as they wished, but were instructed to keep a weighed record of all food and beverages consumed during this period using a set of weighing scales (Digital Scale, model 308, Ravencourt Ltd, UK) and a food diary.

Test foods

Test yoghurt

The composition of both yoghurts was matched for energy and macronutrient content (800 kJ, 6.8 g protein, 6.0 g fat, 28.8 g carbohydrate per 200 g portion). However the control yoghurt contained only milk fat, while in the test yoghurt 5 g of milk fat was replaced by 5 g of fat as Olibra™ emulsion (Scotia LipidTeknik, Stockholm, Sweden). Olibra™ is a food ingredient containing fractionated palm oil and fractionated oat oil in the proportions 95:5, dispersed in water to give a total fat content of 42% (w/w). The percentage fatty acid composition of Olibra™ compared to milk fat is as follows: palmitic (16:0), 42.1 *vs* 26.8; stearic (18:0), 4.3 *vs* 11.5; other saturates, 2.1 *vs* 25.8; oleic (18:1), 40.1 *vs* 28.7; linoleic (18:2), 10.4 *vs* 1.4; and other unsaturates, 1.0 *vs* 5.8. The test and control yoghurts were supplied by Skane Mejerier, Lunnarp, Sweden.

Lunch and evening meals

The lunch and evening meals were buffet-style, self-selection meals that allowed *ad libitum* consumption of a variety of foods that varied in macronutrient composition (Tables 1 and 2). All foods were served in larger than estimated average portions so that choice was not restricted by quantity. Different types of food were served in separate serving dishes so as not to influence food combination choices. Unlimited eating time was given to each subject. Uncarbonated water was available to drink at both meals.

Statistical analysis

Energy (MJ), macronutrient intakes (g), and the weight (g) of the food consumed at the *ad libitum* lunch and evening meals, subsequent evening snacks and intakes for the following 24 h were analysed using Wisp 1.25 C (Tinuviel Software, Warrington, UK). The data using individual BMI groups were analysed using analysis of variance with a mixed effect model. Subjects were treated as random and the fixed effects were treatment, treatment order, and 'carry-over', with sex, bodyweight, BMI, age and percentage body fat as covariates.

Table 1 Nutrient composition (per 100 g) of foods offered to subjects at the lunch meal (4 h post-consumption of yoghurt)

Menu items	*Amount provided*	*kJ (kcal)*	*Protein (g)*	*CHO (g)*	*Fat (g)*
Pizza	200 g	995 (237)	9.1	25.2	11.8
Sausage rolls	60 g	1596 (383)	9.9	25.4	27.6
Egg and onion sandwich	245 g	1112 (267)	7.9	17.0	19.0
Ham salad sandwich	190 g	903 (215)	10.7	21.7	10.1
Salad sandwich	205 g	733 (175)	6.3	20.3	8.1
Coleslaw	100 g	939 (258)	1.2	4.2	26.4
Cream crackers	28 g	1857 (440)	9.5	68.3	16.3
Stilton cheese	15 g	1701 (411)	22.7	0.1	35.5
Cream cheese	25 g	1807 (439)	3.1	0.0	47.4
Smoked cheese	25 g	1258 (303)	20.5	0.2	24.5
Emmental cheese	20 g	1587 (382)	28.7	0.0	29.7
Edam cheese	18 g	1382 (333)	26.0	0.0	25.4
Processed cheese	25 g	1367 (330)	20.8	0.9	27.0
Crisps	50 g	2215 (530)	5.7	53.3	34.2
Peanuts	200 g	2441 (589)	25.5	10.3	49.8
Apple	120 g	185 (43)	0.3	10.8	0.2
Satsumas	150 g	155 (36)	0.9	8.5	0.1
Banana	150 g	403 (95)	1.2	23.2	0.3
Fruit yoghurt	150 g	382 (90)	4.1	17.9	0.7
Iced sponge cake	180 g	1717 (407)	3.8	68.8	14.9
Chocolate biscuits	125 g	2197 (524)	5.7	67.4	27.6
Semi-sweet biscuits	125 g	1925 (457)	6.7	74.8	16.6
Sandwich biscuits	48 g	2151 (513)	5.0	69.2	25.9

Table 2 Nutrient composition (per 100 g) of foods offered to subjects at the evening meal (8 h post-consumption of yoghurt)

Menu items	*Amount provided*	*kJ (kcal)*	*Protein (g)*	*CHO (g)*	*Fat (g)*
Vegetable soup	205 g	89 (45)	1.6	6.3	1.7
Bread rolls	90 g	1139 (268)	10.0	51.8	3.8
Butter	30 g	3031 (737)	0.5	0.0	81.7
Tortilla chips	60 g	1927 (459)	7.6	60.1	22.6
Salsa	60 g	144 (34)	1.0	7.5	0.2
Cheddar cheese	200 g	1679 (405)	25.1	0.1	33.8
Chicken curry	400 g	635 (151)	20.0	4.4	6.1
Beef stew	400 g	331 (80)	5.2	3.4	4.8
Bolognaise sauce	400 g	407 (97)	6.6	4.0	6.2
Fish in breadcrumbs	150 g	983 (235)	12.4	15.2	14.3
Lettuce	20 g	53 (13)	0.7	1.9	0.3
Tomatoes	60 g	73 (17)	0.7	3.1	0.3
Cucumber	30 g	40 (10)	0.7	1.5	0.1
Spring onion	12 g	98 (23)	2.0	3.0	0.5
Coleslaw	90 g	939 (258)	1.2	4.2	26.4
Savoury rice	100 g	599 (142)	2.9	26.3	3.5
Potato salad	120 g	553 (132)	1.8	14.7	7.8
Tuna salad	90 g	614 (147)	7.2	8.3	9.8
Carrots	60 g	93 (22)	0.6	4.4	0.4
Peas	60 g	291 (69)	6.0	9.7	0.9
Sweetcorn	60 g	470 (111)	4.2	19.6	2.3
Oven potato chips	200 g	687 (162)	3.2	29.8	4.2
Creamed potato	200 g	463 (110)	1.8	14.0	5.7
Boiled rice	140 g	587 (138)	2.6	30.9	1.3
Pasta	180 g	442 (104)	3.6	22.2	0.7
Lemon cheesecake	120 g	1139 (274)	2.6	21.2	20.4
Fruit salad	200 g	237 (55)	0.7	13.8	0.1
Ice-cream	120 g	751 (179)	3.5	24.7	8.0
Cream	60 g	1539 (373)	2.0	3.1	39.3
Fruit yoghurt	150 g	382 (90)	4.1	17.9	0.7
Iced sponge cake	180 g	1717 (407)	3.8	68.8	14.9
Chocolate biscuits	125 g	2197 (524)	5.7	67.4	27.6
Swiss rolls, chocolate	48 g	1421 (337)	4.3	58.1	11.3
Semi-sweet biscuits	125 g	1925 (457)	6.7	74.8	16.6
Chocolate digestive	80 g	2071 (493)	6.8	66.5	24.1
Sandwich biscuits	48 g	2151 (513)	5.0	69.2	25.9

The treatment effect refers to the energy and macronutrient intakes after the test yoghurt relative to their intake after the control yoghurt. The treatment order effect compared the intakes of the subjects who received the test yoghurt on the first study day (group 1) with those who received the test yoghurt on the second study day (group 2). The 'carry-over' term represents the effects of treatment-order (group 1 *vs* group 2), differences in 'carry-over', and treatment × treatment-order interaction, all of which were analysed in this crossover design. The possibility of an interaction between the treatment effect, and sex, body weight or BMI was considered by including the appropriate interaction terms in the model and testing them for statistical significance. Non-significant ($P > 0.05$) interaction terms were omitted from the model when testing treatment and treatment-order effects. The percentage difference in energy and macronutrient intakes after the test and control yoghurts was calculated as: test energy intake − control energy intake/control energy intake × 100. The energy and macronutrient intakes for the remainder of the evening and the following 24 h were analysed by non-parametric analyses in order to reduce the influence of outliers in the data. Analysis of energy and macronutrient intakes were performed using the SAS statistical program (SAS Institute Inc. Cary, NC, USA). The visual analogue ratings were analysed using analysis of variance (ANOVA) by calculating a mean rating for each 14 h (pre- and post-yoghurt, 10:00–21:00 h) period with treatment and sex as factors, and subject as a blocking factor. Under conditions where data were not normally distributed a square root transformation was used for the analysis. Real mean values were used for reporting hunger ratings. VAS were analysed using the GENSTAT 5 statistical program (Genstat Rothamsted Experimental Station, Harpenden, UK). Results were considered significant at the $P<0.05$ level.

Results

There were no significant differences in height between the female groups, but the obese females were significantly older, and both the overweight and obese females had significantly higher BMIs and higher percentage body fat than the non-overweight subjects (Table 3). In the males there were no significant differences between groups in age and height, but the overweight and obese had significantly higher BMIs and percentage body fat than the non-overweight subjects (Table 3). Within BMI groups there were no significant differences between the females and males in age or BMI, but the males were significantly taller and had lower percentage body fat. No subjects reported any ill effects or discomfort after consumption of either test or control yoghurts.

Energy and macronutrient intakes at the lunch and evening meal

The mean energy, macronutrient intakes and total weight of food eaten 4 and 8 h post-consumption of the test and control yoghurts for the all subjects tested are presented in Table 4, while data for the three separate BMI categories are presented in Table 5. For all subjects, energy, fat, protein and carbohydrate intakes and the total weight of food consumed were significantly reduced at 4 and at 8 h post-consumption of the test yoghurt, relative to the control yoghurt (Table 4). Within the individual BMI groups energy and macronutrient intakes were significantly reduced at 4 h post-consumption of the test yoghurt in the non-overweight and overweight groups (Table 5). Although the obese group also reduced their food intake under the test yoghurt conditions, the reduction was not significant at 4 h but by 8 h post-consumption of the test yoghurt all BMI groups significantly reduced their energy and macronutrient intakes (Table 5).

The treatment effect 4 h post-consumption was found to be dependent on gender in that the male subjects consumed more ($P<0.001$) after both test and control yoghurts relative to the female subjects. Furthermore, a treatment-order effect was observed 4 h post-consumption. Subjects who had received the test yoghurt on the second study day (group 2) consumed significantly more energy, fat, protein,

Table 4 Energy and macronutrient intakes 4 and 8 h post-consumption of the test and control yoghurts for all subjects

	4 h post-consumption (n = 60)	*8 h post-consumption (n = 60)*
Energy intake (MJ)[A]		
Test	4.26 ± 0.21[d]	4.23 ± 0.18[d]
Control	5.60 ± 0.28	5.81 ± 0.21
Percentage difference	− 23.9	− 27.2
Fat (g)[B]		
Test	54.1 ± 3.20[c] (46.9%)	45.3 ± 2.39[c] (39.3%)
Control	74.8 ± 4.19 (48.8%)	66.6 ± 2.83 (42.0%)
Percentage difference	− 27.7	− 32.0
Protein (g)[B]		
Test	36.7 ± 2.03[d] (14.0%)	37.7 ± 1.78[d] (14.5%)
Control	46.6 ± 2.52 (13.6%)	52.1 ± 2.28 (14.6%)
Percentage difference	− 21.2	− 27.6
Carbohydrate (g)[B]		
Test	101.9 ± 4.41[d] (39.1%)	119.5 ± 4.84[d] (46.2%)
Control	128.7 ± 6.30 (37.6%)	154.8 ± 4.83 (43.4%)
Percentage difference	− 20.8	− 22.8
Weight of food eaten (g)[A]		
Test	477.8 ± 22.60[c]	865.5 ± 35.78[d]
Control	592.4 ± 28.71	1111.0 ± 38.92
Percentage difference	− 19.3	− 22.1

[a]$\bar{x}$ ± s.e.
[b]$\bar{x}$ ± s.e. (percentage of energy).
[c]Significantly different from control, $P<0.01$.
[d]Significantly different from control, $P<0.001$.

Table 3 Physical characteristics of subjects[a]

	Females BMI (kg/m²)			*Males BMI (kg/m²)*		
	20–24.9 (n = 10)	*25–29.9 (n = 10)*	*> 30 (n = 13)*	*20–24.9 (n = 10)*	*25–29.9 (n = 10)*	*> 30 (n = 7)*
Age (y)	25.4 ± 6.04[A]	33.2 ± 15.8[A]	40.5 ± 10.9[B]	30.1 ± 7.17[A]	32.2 ± 8.41[A]	37.7 ± 13.7[A]
Height (m)	1.61 ± 0.06[A]	1.61 ± 0.04[A]	1.62 ± 0.05[A]	1.77 ± 0.06[B]	1.78 ± 0.06[B]	1.77 ± 0.06[B]
Weight (kg)	56.9 ± 5.97[A]	70.7 ± 4.42[B]	90.0 ± 14.6[C]	71.9 ± 6.65[D]	82.4 ± 6.05[C]	99.4 ± 10.6[F]
BMI (kg/m²)	21.9 ± 0.97[A]	27.2 ± 1.07[B]	34.0 ± 4.63[C]	22.8 ± 0.91[A]	26.1 ± 1.45[B]	32.1 ± 1.56[C]
Body fat (%)	26.1 ± 2.83[A]	33.7 ± 3.89[B]	41.3 ± 6.64[C]	13.1 ± 3.37[D]	17.1 ± 5.92[E]	28.3 ± 2.90[F]

[a]$\bar{x}$ ± s.d.
Within a row, numbers with the same superscript letters indicate no significant difference between BMI groups. Different superscript letters indicate significant difference between BMI groups.

Table 5 Energy and macronutrient intakes 4 and 8 h post-consumption of the test and control yoghurts for non-overweight, overweight and obese subjects

	4 h post-consumption BMI (kg/m²)			*8 h post-consumption BMI (kg/m²)*		
	20–24.9 (n = 20)	*25–29.9 (n = 20)*	*> 30 (n = 20)*	*20–24.9 (n = 20)*	*25–29.9 (n = 20)*	*> 30 (n = 20)*
Energy intake (MJ)[a]						
Test	3.79 ± 0.57[d]	4.43 ± 0.38[e]	4.56 ± 0.41[NS]	3.82 ± 0.29[e]	3.94 ± 0.24[e]	4.91 ± 0.34[d]
Control	5.43 ± 0.28	6.12 ± 0.47	5.25 ± 0.44	5.38 ± 0.34	5.80 ± 0.38	6.26 ± 0.38
Percentage difference	−30.2	−27.6	−13.1	−30.0	−32.1	−21.6
Fat (g)[b]						
Test	45.8 ± 3.8[d] (44.8%)	56.5 ± 6.1[e] (46.9%)	60.0 ± 6.2[NS] (48.2%)	41.3 ± 3.6[e] (39.7%)	39.7 ± 3.0[e] (36.9%)	54.9 ± 4.8[d] (41.1%)
Control	69.3 ± 7.5 (47.0%)	83.0 ± 7.6 (49.7%)	72.1 ± 6.7 (50.2%)	60.5 ± 4.3 (41.3%)	66.9 ± 5.3 (42.3%)	72.4 ± 4.9 (42.4%)
Percentage difference	−33.9	−31.9	−16.8	−31.7	−40.6	−24.2
Protein (g)[b]						
Test	31.3 ± 2.3[d] (13.6%)	39.7 ± 3.4[e] (14.6%)	39.2 ± 3.9[NS] (14.0%)	32.0 ± 2.3[e] (13.9%)	36.1 ± 2.8[e] (14.9%)	44.9 ± 3.4[c] (14.9%)
Control	45.1 ± 5.2 (13.5%)	51.5 ± 3.9 (13.7%)	43.2 ± 3.8 (13.3%)	49.7 ± 3.4 (15.1%)	52.9 ± 4.5 (14.8%)	53.4 ± 4.0 (13.9%)
Percentage difference	−30.6	−22.9	−9.2	−35.6	−31.7	−15.9
Carbohydrate (g)[b]						
Test	95.8 ± 7.3[d] (41.6%)	104.2 ± 7.2[e] (38.5%)	105.7 ± 8.5[NS] (37.8%)	109.3 ± 8.5[e] (46.4%)	116.7 ± 7.3[d] (48.2%)	132.4 ± 8.8[e] (44.0%)
Control	131.0 ± 13.3 (39.5%)	137.2 ± 9.7 (36.6%)	117.8 ± 9.4 (36.5%)	143.7 ± 9.7 (43.6%)	152.8 ± 9.0 (42.9%)	167.8 ± 9.2 (43.7%)
Percentage difference	−26.9	−24.0	−10.3	−23.9	−23.6	−21.1
Weight of food eaten (g)[a]						
Test	433.5 ± 34.5[d]	506.0 ± 45.9[e]	494.0 ± 36.2[NS]	769.1 ± 53.3[e]	886.1 ± 55.9[e]	941.3 ± 71.7[d]
Control	581.5 ± 59.4	645.4 ± 52.7	550.5 ± 33.6	1040.9 ± 59.7	1172.9 ± 70.4	1119.3 ± 71.6
Percentage difference	−25.4	−21.6	−10.3	−26.1	−24.4	−15.9

[a] $\bar{x} \pm$ s.e.
[b] $\bar{x} \pm$ s.e. (percentage of energy).
[c] Significantly different from control, $P < 0.05$.
[d] Significantly different from control, $P < 0.01$.
[e] Significantly different from control, $P < 0.001$.
[NS] Not significantly different from control, $P > 0.05$.

carbohydrate and total weight of food relative to the subjects who received the test yoghurt on the first study day (group 1). This treatment-order effect was also apparent 8 h post-consumption for energy, fat, carbohydrate and for the weight of food eaten.

Energy and macronutrient intakes for the remainder of the evening and the following 24 h

Energy and macronutrient intakes for the remainder of the evening and the following 24 h are presented in Tables 6 and 7 respectively, and these show all subjects combined and the individual BMI groups. For the total group, energy and macronutrient intakes remained significantly lower during the evening following consumption of the test yoghurt (Table 6). Within the BMI groups energy and macronutrient intakes were reduced following test yoghurt conditions, but the reductions were only significant in the non-overweight subjects (Table 6). Over the following 24 h energy intakes were significantly lower for the total group, and for the non-overweight and obese groups. The corresponding macronutrient intakes, with the exception of fat intake in the obese group, were also significantly reduced. Although the overweight group reduced their energy and macronutrient intakes in the following 24 h after the test yoghurt, the reductions were not significant (Table 7). No alcohol consumption was reported over the following day as food diaries were only kept up until 21:00 h.

The cumulative energy intake for all subjects and individual BMI groups for the following 24 h are shown in Figures 1–4. With the exception of one time point (15:00 h) energy intakes were significantly lower throughout the day following the test yoghurt for the subjects as a group. After 13:00 h energy intake of the non-overweight subjects remained significantly lower after the test yoghurt (Figure 2). Energy intakes were lower at all time points following the test yoghurt in the overweight group but the differences were not significant (Figure 3). The cumulative energy intake for the obese subjects after the test yoghurt, was significantly reduced from 17:00 h (Figure 4).

Subjective hunger, desire to eat, thoughts of food and fullness

The mean ratings for hunger, desire to eat, preoccupation with thoughts of food and perceived fullness on both test and control study days are shown in Figures 5–8. Subjects had significantly reduced hunger, desire to eat and

Table 6 Energy and macronutrient intakes for the remainder of the study evening for all subjects combined and for individual BMI groups

	All subjects (n = 60)	*BMI 20–24.9 (kg/m²)* (n = 20)	*BMI 25–29.9 (kg/m²)* (n = 20)	*BMI > 30 (kg/m²)* (n = 20)
Energy intake (MJ)[a]				
Test	0.49±0.1[d]	0.50±0.1[d]	0.80±0.3[NS]	0.20±0.6[NS]
Control	0.96±0.2	1.40±0.3	0.80±0.2	0.66±0.2
Percentage difference	−17.0	−64.3	0.0	−69.7
Fat (g)[b]				
Test	2.8±0.6[c] (21.6%)	3.6±1.1[c] (27.2%)	3.4±1.4[NS] (16.1%)	1.5±0.8[NS] (28.3%)
Control	6.9±1.3 (27.2%)	10.9±3.0 (29.4%)	5.4±1.5 (25.5%)	4.3±1.5 (24.6%)
Percentage difference	−59.4	−66.9	−37.0	−65.1
Protein (g)[b]				
Test	1.4±0.3[d] (4.8%)	1.8±0.6[d] (6.0%)	1.8±0.7[NS] (3.8%)	0.7±0.3[NS] (5.9%)
Control	4.3±0.8 (7.5%)	5.2±1.3 (6.2%)	4.0±1.4 (8.4%)	3.7±1.6 (9.4%)
Percentage difference	−67.4	−65.4	−55.0	−81.1
Carbohydrate (g)[b]				
Test	11.4±2.3[c] (39.0%)	12.0±3.8[d] (40.3%)	16.6±5.4[NS] (34.9%)	5.7±2.3[NS] (47.9%)
Control	24.8±4.3 (43.4%)	33.1±8.2 (39.7%)	20.2±5.5 (42.4%)	21.1±8.3 (53.7%)
Percentage difference	−54.0	−63.7	−17.8	−73.0
Alcohol (g)[b]				
Test	5.7±1.2[NS] (34.5%)	4.5±1.3[c] (26.5%)	12.3±2.6[c] (45.2%)	1.2±0.2[NS] (17.9%)
Control	7.1±2.3 (21.9%)	11.7±3.1 (24.7%)	6.4±1.6 (23.7%)	2.7±1.1 (12.3%)
Percentage difference	−19.7	−61.5	+92.2	−55.5

[a] $\bar{x}\pm$s.e.
[b] $\bar{x}\pm$s.e. (Percentage of energy).
[c] Significantly different from control, $P<0.01$.
[d] Significantly different from control, $P<0.001$.
[NS] Not significantly different from control, $P>0.05$.

Table 7 Total energy and macronutrient intake over the following 24 h (post-study day) for all subjects combined and for individual BMI groups

	All subjects (n = 60)	*BMI 20–24.9 (kg/m²)* (n = 20)	*BMI 25–29.9 (kg/m²)* (n = 20)	*BMI > 30 (kg/m²)* (n = 20)
Energy intake (MJ)[a]				
Test	6.35±0.4[d]	7.85±0.9[c]	6.20±0.5[NS]	4.97±0.3[d]
Control	7.70±0.3	9.25±0.7	7.06±0.5	6.76±0.4
Percentage difference	−17.5	−15.1	−12.2	−25.8
Fat (g)[b]				
Test	58.1±5.6[c] (33.2%)	68.8±12.4[c] (32.4%)	55.2±7.3[NS] (32.5%)	50.3±8.8[NS] (35.1%)
Control	69.1±4.8 (33.8%)	82.7±9.9 (33.5%)	67.1±7.5 (35.2%)	57.4±6.3 (32.6%)
Percentage difference	−15.9	−16.8	−17.7	−12.4
Protein (g)[b]				
Test	60.5±3.9[d] (15.4%)	72.6±8.8[c] (15.2%)	61.9±5.8[c] (16.2%)	47.1±3.5[d] (14.6%)
Control	78.2±4.7 (17.1%)	92.6±8.5 (16.7%)	76.4±8.5 (17.9%)	65.5±6.6 (16.6%)
Percentage difference	−22.6	−21.6	−18.9	−28.1
Carbohydrate (g)[b]				
Test	202.6±10.5[c] (51.4%)	250.3±19.7[NS] (52.4%)	195.8±17.8[NS] (51.3%)	161.7±10.1[c] (50.2%)
Control	226.1±10.8 (49.1%)	276.5±23.3 (49.8%)	201.1±14.0 (46.9%)	200.9±12.5 (50.8%)
Percentage difference	−10.4	−9.5	−2.6	−19.5

[a] $\bar{x}\pm$s.e.
[b] $\bar{x}\pm$s.e. (Percentage of energy).
[c] Significantly different from control, $P<0.01$.
[d] Significantly different from control, $P<0.001$.
[NS] Not significantly different from control, $P>0.05$.

preoccupation with thoughts of food, and significantly greater perceived fullness after the test yoghurt throughout the day. There were no treatment × time interactions for any parameter measured. Although the volume of water intake on both study days was not recorded, no significant differences in thirst were observed after the test or control yoghurts. No significant difference in the subjectively rated pleasantness of the test and control yoghurts was observed.

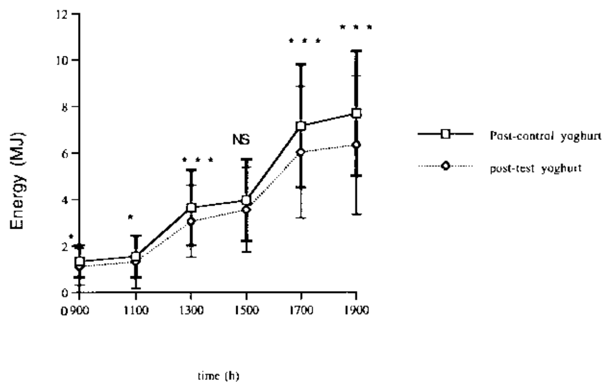

Figure 1 Cumulative (mean ± s.d.) energy intake (MJ) during the post-study day (all subjects). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS $P > 0.05$.

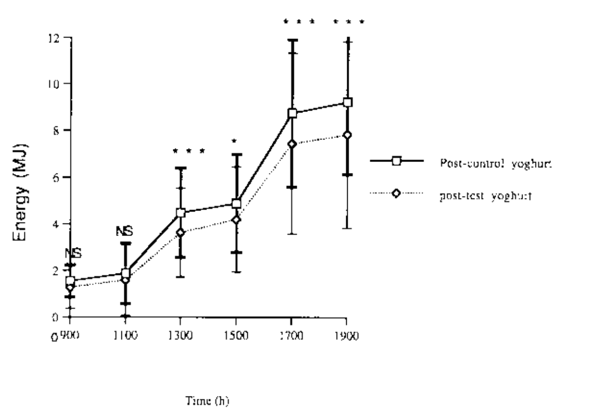

Figure 2 Cumulative (mean ± s.d.) energy intake (MJ) during the post-study day for non-overweight subjects (BMI 20–24.9 kg/m^2). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS $P > 0.05$.

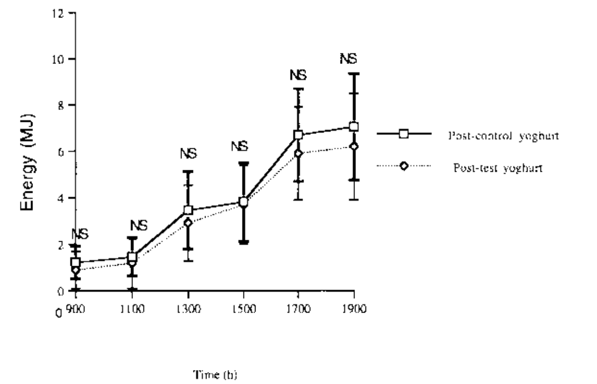

Figure 3 Cumulative (mean ± s.d.) energy intake (MJ) during the post-study day for overweight subjects (BMI 25–29.9 kg/m^2). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS $P > 0.05$.

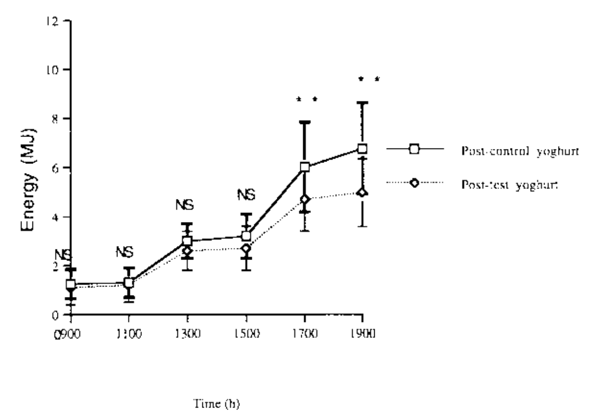

Figure 4 Cumulative (mean ± s.d.) energy intake (MJ) during the post-study day for obese subjects (BMI > 30 kg/m^2). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS $P > 0.05$.

Discussion

The present study confirms and extends our previous observations[12] that yoghurt containing Olibra™ fat emulsion significantly reduces energy and macronutrient intakes relative to control conditions. Our previous studies demonstrated a significant reduction (12–14%) in energy intake 4 h post consumption in non-overweight subjects. Similarly in the present study at 4 h post-consumption energy intakes were significantly reduced in non-overweight (30%) and overweight (28%) subjects and the corresponding macronutrients were also significantly reduced. While the obese subjects also reduced their food intake at 4 h, the reduction was not significant. However, energy and macronutrient intakes were significantly reduced for all BMI groups by 8 h post-consumption. Furthermore, there was no evidence from self-reported food diaries of energy or macronutrient compensation for the remainder of the study evening and over the following 24 h in all BMI groups. Indeed, the evidence suggests that the suppression of food intake following the test yoghurt may even last as long as 36 h. However, this latter observation is based on the subject's self-reported food intakes which are notoriously susceptible to under-reporting, particularly in the obese.[15,16] While the possibility of under-reporting by the subjects cannot be excluded, nevertheless, this study used a within-subject design, so consequently any errors in recorded intake would apply equally to both test and control study conditions. Finally since food intakes were not recorded after 21:00 h on the post-study day, it is not known if at what point, if at all, subsequent compensation occurred. The magnitude of the responses observed were not as significant in the overweight and obese group compared to the non-overweight group. The reasons for this are not known, but it may be a consequence of the lower doses (expressed relative to body weight) received by the overweight and obese. These doses were 77.6, 65.3 and

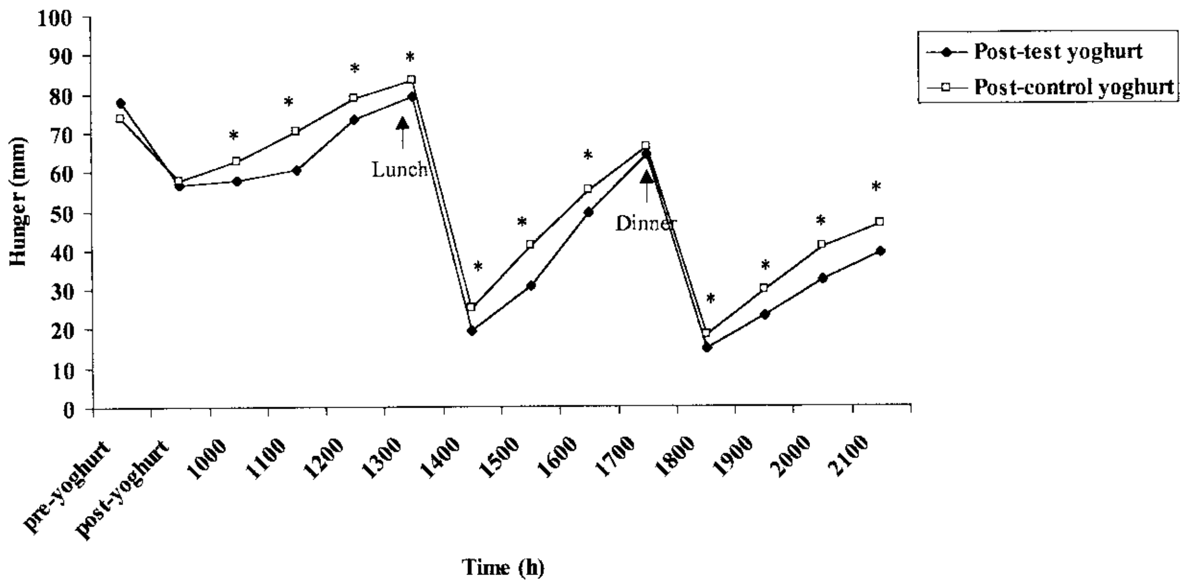

Figure 5 Subjective scores for hunger (mm) from 09:00 h until 21:00 h for all subjects. Arrows indicate initiation of test meals. *$P<0.05$; NS $P>0.05$.

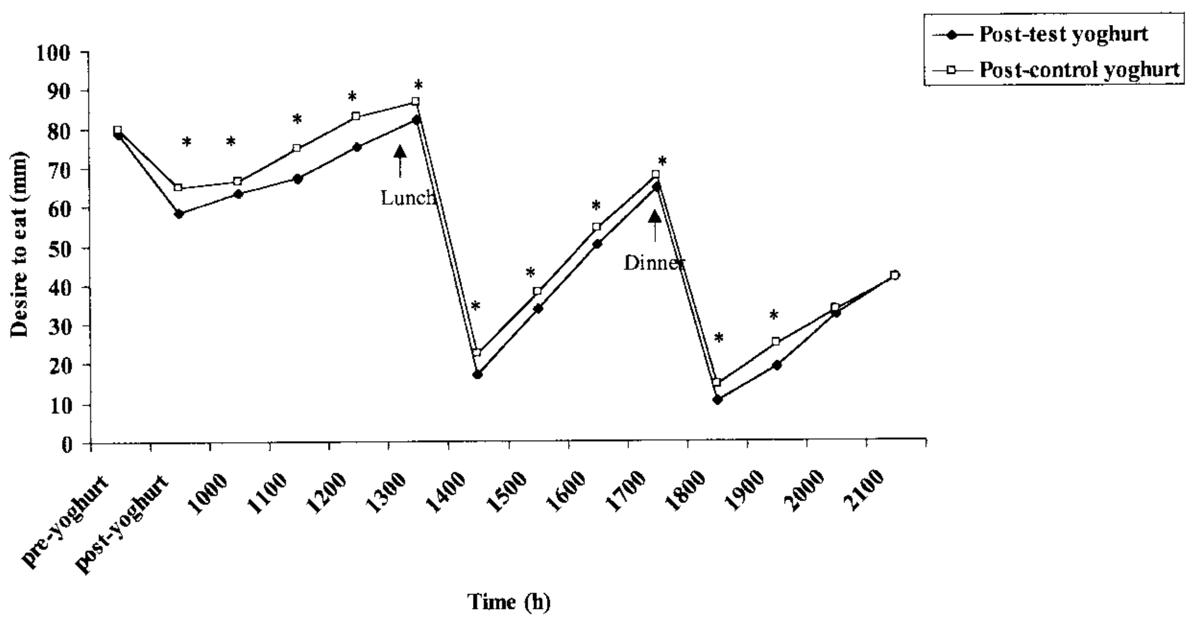

Figure 6 Subjective scores of desire to eat (mm) from 09:00 h until 21:00 h for all subjects. Arrows indicate initiation of test meals. *$P<0.05$; NS $P>0.05$.

52.8 mg/kg for the non-overweight, overweight and obese respectively. Given the magnitude of the responses to such a small dose, this is a plausible explanation. Age may also have contributed to the differences seen, as the obese subjects were significantly older than the non-overweight and overweight subjects, and it has been shown that appetite, food intake and gastric mobility can be affected by increasing age.[17]

At this stage it is only possible to speculate on a possible mode of action of Olibra™. It is conceivable that the

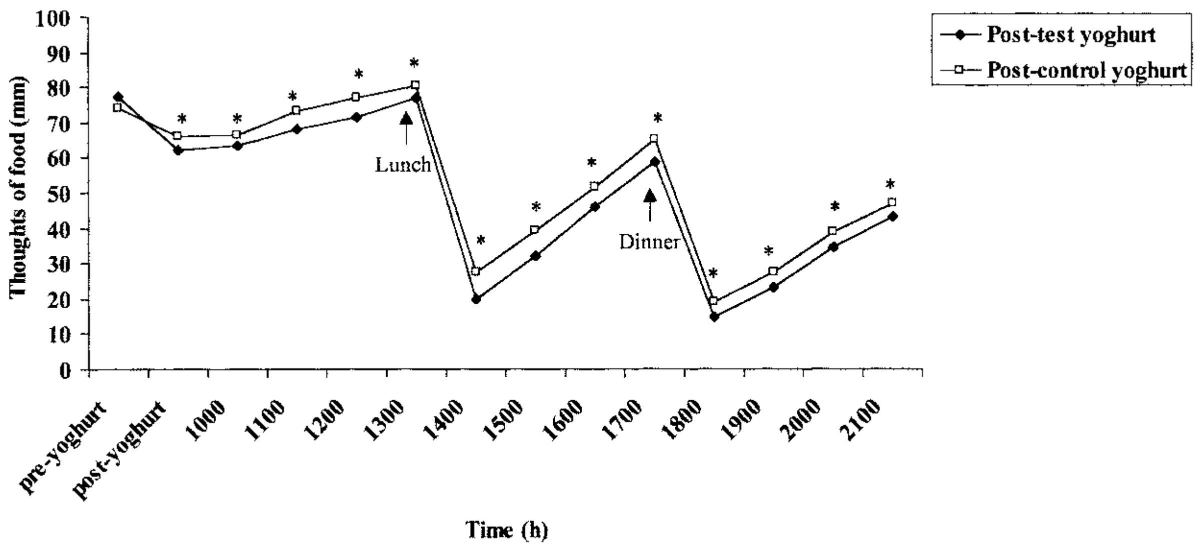

Figure 7 Subjective scores of thoughts of food (mm) from 09:00 h until 21:00 h for all subjects. Arrows indicate initiation of test meals. $*P<0.05$; NS $P>0.05$.

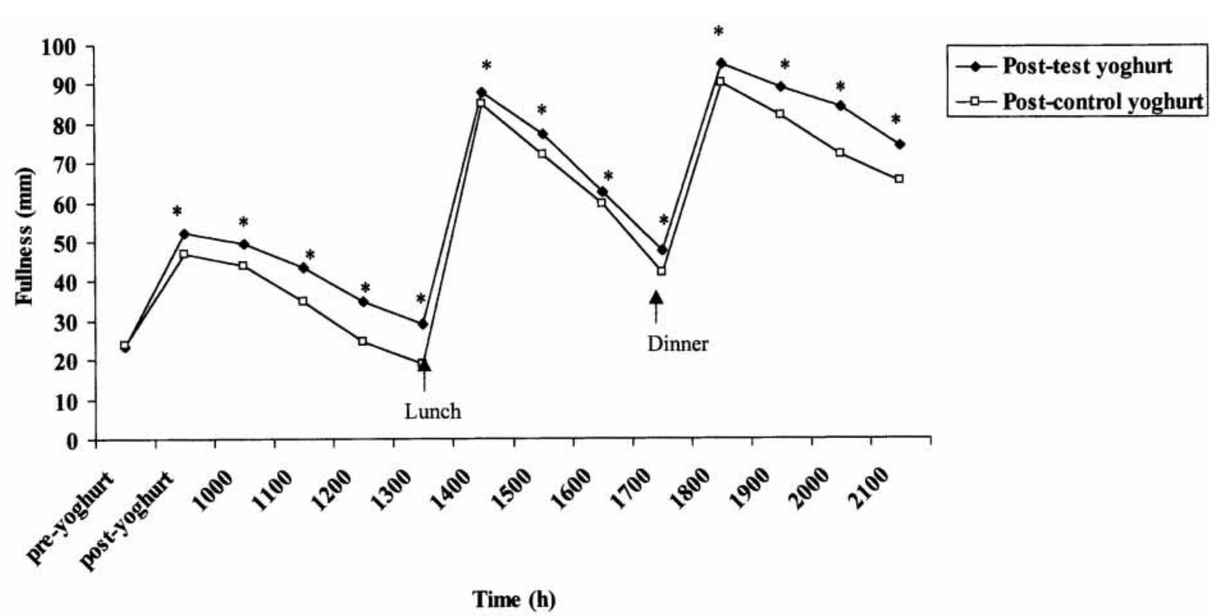

Figure 8 Subjective scores of fullness (mm) from 09:00 h until 21:00 h for all subjects. Arrows indicate initiation of test meals. $*P<0.05$; NS $P>0.05$.

observed effects of Olibra™ are a result of the 'ileal brake' mechanism ie the inhibition of upper gastrointestinal functions elicited by the presence of unabsorbed nutrients in the ileum.[18] The 'ileal brake' appears to be related to the release of one or more peptide hormones from the distal intestine,[19–21] although Dobson *et al*[22] have demonstrated that it can be activated along the entirety of the small intestine. Although to date we have no measurements of peptide hormone levels following the consumption of Olibra™, it may be that Olibra™ is acting through an increased and prolonged release of known satiety peptides such as enterostatin[23,24] and glucagon-like peptide-1 (GLP-1).[25] Both have been shown to reduce energy intake and particularly fat intake in the long term which was observed in our previous and current work.

In conclusion, this study has confirmed our previous observations[12] and has also shown that following the intake of Olibra™ overweight and obese subjects respond in a similar manner to their non-overweight counterparts. These results are at variance to the widely held belief that fat has little satiating efficiency[26] and highlights the potential importance of the physicochemical properties of fat in determining its satiating efficiency. If Olibra™ proves to be as effective in the longer term then in terms of efficacy, safety and cost, Olibra™ may have an potentially important advantage over pharmacological drugs in facilitating weight loss in overweight subjects, and weight maintenance in non-overweight subjects.[27]

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