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Effects of Dietary Fat and Carbohydrate Exchange on Human Energy Metabolism

W. P. H. G. VERBOEKET-VAN DE VENNE and K. R. WESTERTERP
University of Limburg, Maastricht, The Netherlands

Short-term effects of low-fat (10% fat energy), mixed (30% fat energy), and high-fat (50% fat energy) diets on 24-h energy expenditure, and on its components sleeping metabolic rate, diet induced thermogenesis and energy expenditure for physical activity were studied for 3 days using a respiration chamber in twelve normal-weight female volunteers classified as restrained or unrestrained eaters. There were no significant differences in any of the four measures between the restrained and unrestrained eating subjects on any of the diets. Within the group of restrained eaters, 24-h energy expenditure was significantly decreased during consumption of the mixed diet (8·21 ± 0·21 MJ/d; $p<0{\cdot}01$) and tended to be decreased on the high-fat diet (8·22 ± 0·25 MJ/d; $p=0{\cdot}055$), relative to the low-fat diet (8·58 ± 0·21 MJ/d). Diet composition had no effect on 24-h energy expenditure in the women with unrestrained eating. The results suggest that a low-fat diet would be beneficial in the treatment of obesity, especially if subjects have a restrained type of eating behaviour.

Introduction

High-fat diets have been associated with obesity in humans (Dreon *et al*., 1988; Romieu *et al*., 1988; Tremblay *et al*., 1989). Because obesity results from a positive energy balance, i.e. energy intake exceeding energy expenditure, two possible mechanisms are involved. Firstly, a high-fat diet could result in an increase of energy intake (Duncan *et al*., 1983; Lissner *et al*., 1987; Tremblay *et al*., 1989). The second possibility is that high-fat diets lower energy expenditure, which in turn has been shown to be a risk factor for weight gain (Ravussin *et al*., 1988). Changing the macronutrient ratio of the diet may have consequences for the regulation of energy balance through changes in one or more of the three components of daily energy expenditure: sleeping metabolic rate (SMR), diet induced thermogenesis (DIT) and energy expenditure for physical activity (ACT). According to Flatt (1985), dietary fat storage is at a cost of 3% of ingested energy, whereas the cost of storing dietary carbohydrate as fat requires the expenditure of 23% of ingested energy. Furthermore, variations in the thermogenic response were reported with respect to the composition of the diet. A lower thermogenic response to fat than to carbohydrate was described for both normal weight and obese subjects (Schwartz *et al*., 1985) and post-obese

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Correspondence to: Dr W.P.H.G. Verboeket-van de Venne, Department of Human Biology, University of Limburg, P.O. Box 616, 6200 MD Maastricht, The Netherlands.

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subjects (Lean & James, 1988). Thus, the contribution of DIT to energy metabolism is expected to be lower on a high-fat diet.

Another aspect that has to be considered in the processes leading to obesity is the between-subject variation in the response to dietary fat. Nair *et al.* (1983) found no differences in the magnitude of the thermic response to isoenergetic protein, carbohydrate or fat meals between groups of lean and obese subjects. Other studies, however, support the view that there is a defect in thermogenesis in response to fat in obese subjects (Swaminathan *et al.*, 1981; Zed & James, 1986). Less is known about the metabolic response to food stimuli of latent obese subjects. By means of the scores of psychometric questionnaires a distinction can be made between subjects with a restrained or unrestrained attitude towards eating. Laessle *et al.* (1989) and Tuschl *et al.* (1990) reported less energy consumption and higher preferences for low-energy foods in restrained eating subjects compared with unrestrained eating subjects, despite having a higher body mass index. Furthermore, energy expenditure was lower in restrained eating subjects, reflecting diminished energetic requirements.

In the present study, the short-term effects of dietary fat and carbohydrate exchange on human energy metabolism were investigated. Furthermore, the subjects' attitude towards eating was taken into account, in order to determine metabolic responses to diet composition of subjects being more (restrained eating subjects) or less (unrestrained eating subjects) susceptible to becoming obese.

Method

Subjects

Twelve healthy women of normal weight were selected for this investigation. Their physical characteristics are presented in Table 1. The procedures to be used in the study were carefully explained to each subject before she gave her consent to participate. The protocol was reviewed and approved by the University of Limburg Ethical Committee.

Attitude towards eating

Restrained and unrestrained eating subjects were selected by means of the scores on psychometric questionnaires. Two types of psychometric questionnaires were used: the Herman–Polivy (H–P) restraint scale (Herman & Polivy, 1980) which is designed to identify dieters and is mainly weight-concerned (Westerterp-Plantenga *et al.*, 1991), and the Three Factor Eating Questionnaire (TFEQ) of Stunkard and Messick (1985) which is designed to measure successful dieting and is mainly food-concerned (Westerterp-Plantenga *et al.*, 1991). Using the H–P restraint scale, we can discriminate between being a restrained or unrestrained eater. Considering studies of Westerterp-Plantenga *et al.* (1990a, 1990b, 1991) the median of the H–P scores in the subject population used at the Department of Human Biology, University of Limburg, Maastricht was 15. Thus, subjects with a score >15 were classified as restrained eaters and subjects with a score ≤ 15 were classified as unrestrained eaters. The TFEQ of Stunkard and Messick (1985) was used to discriminate between cognitive restraint and unrestraint, concerning the scores on the cognitive restraint factor F_1. The median of the scores on F_1 in the population of subjects was 9

TABLE 1
Physical characteristics of the subjects and order of treatment

Subject	Age (yr)	Weight (kg)	Height (m)	Percentage body fat	Questionnaire scores		Order of treatment
					H–P	F_1	
1	20	65·5	1·75	19·8	13	11	LF-HF-M
2	20	71·1	1·73	21·1	18	7	LF-HF-M
3	21	64·5	1·71	26·5	17	11	LF-HF-M
4	21	67·7	1·75	21·7	19	15	LF-HF-M
5	21	59·5	1·60	22·7	17	7	HF-LF-M
6	21	67·2	1·73	28·6	17	6	HF-LF-M
Mean	21	65·9	1·71	23·4	17	10	
SE	0	1·6	0·02	1·4	1	1	
7	20	80·1	1·71	32·0	6	3	LF-HF-M
8	22	68·4	1·71	28·6	12	1	HF-LF-M
9	19	69·7	1·71	28·9	11	4	HF-LF-M
10	19	57·7	1·70	22·2	10	0	LF-HF-M
11	24	62·6	1·76	21·0	7	0	LF-HF-M
12	20	61·9	1·63	28·4	6	4	HF-LF-M
Mean	21	66·7	1·70	26·9	9	2	
SE	1	3·2	0·02	1·8	1	1	

H–P: score on the Herman–Polivy dietary restraint questionnaire (Herman & Polivy, 1980).
F_1: score on the cognitive restraint factor of the Three Factor Eating Questionnaire (Stunkard & Messick, 1985).
LF, low-fat diet; M, mixed diet; HF, high-fat diet.

(Westerterp-Plantenga *et al*., 1990a, 1990b, 1991) implying that subjects with an F_1 score >9 were classified as cognitive restraint, and a score ≤ 9 as unrestraint. Overall, subjects in the present study were classified as restrained eaters when H–P score >15 *or* F_1 score >9; unrestrained eating subjects had an H–P score ≤ 15 *and* an F_1 score ≤ 9. From the six subjects classified as restrained eaters, three subjects were restrained by being weight-concerned (subjects 2, 5 and 6), one subject by being food-concerned (subject 1), and two subjects by being weight- and food-concerned (subjects 3 and 4).

Experimental design

Subjects were fed to energy balance consuming a low-fat (LF), a mixed (M) and a high-fat (HF) diet over 3-day intervals. The order of administration of LF and HF diet was randomized; for practical reasons the M diet was always administered last. The interval between two experimental periods was at least 4 days. The first 2 days on each dietary regimen the provided food was consumed at home, followed by the last day of each period while the subjects stayed in a respiration chamber for approximately 36 h. In this chamber oxygen consumption, carbon dioxide production, and hence respiratory quotient (RQ) and energy expenditure (EE), were the main measurements (see below). Energy intake for the maintenance of energy balance was based on the calculated basal metabolic rate (BMR) (Harris & Benedict, 1919) of the subjects multiplied by 1·76 on days 1 and 2 (Verboeket-van de Venne *et al*., 1993); energy intake on day 3 while being in the respiration chamber equalled $1{\cdot}29 \times$ BMR (Verboeket-van de Venne & Westerterp, 1991).

Diets

The diets were taken as four meals daily: a breakfast at 0800 hrs containing 20% of the daily energy intake, a lunch at 1300 hrs (25% of energy intake), a dinner at 1800 hrs (45% of energy intake), and an evening snack at 2030 hrs (10% of energy intake). Between the meals no extra consumptions were allowed, except for coffee and tea (without milk and sugar), mineral water, and tap water. The total energy intake was the same for the three diets. As a percentage of energy content, the LF diet provided 15% protein, 10% fat (4% as saturated fatty acids, 4% as monounsaturated fatty acids, 2% as polyunsaturated fatty acids), and 75% carbohydrate; the M diet provided 15% protein, 30% fat (13% saturated, 12% monounsaturated, 5% polyunsaturated fatty acids), and 55% carbohydrate; and the HF diet provided 15% protein, 50% fat (23% saturated, 20% monounsaturated, 7% polyunsaturated fatty acids), and 35% energy as carbohydrate (see Appendix for a description of the diets). Energy content and macronutrient composition of the diets were calculated using the Dutch food composition table (Hautvast, 1975).

Determination of 24-h RQ, 24-h EE, SMR, DIT and ACT

Oxygen consumption and carbon dioxide production were measured on the third day of each dietary regimen using a respiration chamber. The chamber was 14 m^3 and furnished with a bed, chair, table, television, radio, telephone, wash-bowl and toilet facilities, and was ventilated with fresh air at a rate of 50 l/min (Schoffelen *et al*., 1984). The ventilation rate (l) was measured with a dry gasmeter (Schlumberger, type G6). The concentration of oxygen and carbon dioxide was measured using a paramagnetic O_2 analyser (Servomex, type OA 184) and an infrared CO_2 analyser (Hartmann & Braun, type URAS 3G). Air samples were analysed every minute. Each 15-min period contained 12 outgoing samples, one ingoing sample, a span gas sample (certified calibration gas: 0·800% CO_2, 18·0% O_2) and an N_2 sample for zeroing. In this way the system was providing full calibration values every 15 min. The gas samples to be measured were selected by a computer which also stored and processed the data. During daytime subjects were not restricted and their activity was spontaneous: they were allowed to move freely within the chamber, to sit, lie down, study, telephone, listen to the radio and watch television, but no strenuous exercise, gymnastics or sleeping were allowed. Therefore, most activities performed were of a sedentary nature. The physical activity was inconspicuously monitored by means of a radar system (Schutz *et al*., 1982). The unit continuously emitted a radar signal of constant frequency into the respiration chamber. The signal, which was reflected by the walls of the chamber and objects within it, was detected by a radar transreceiver working on the Doppler principle.

RQ was calculated as the ratio of CO_2 produced to O_2 consumed; EE was calculated according to Weir (1949) from O_2 consumption and CO_2 production. Twenty-four-hour values were calculated from 0730 hrs to 0730 hrs. SMR was determined from 0300 hrs to 0600 hrs, when energy expenditure was lowest and radar output was at baseline level. The method used for determination of DIT was previously described by Schutz *et al*. (1984) and was based on simultaneous measurements of both physical activity and energy expenditure of the subjects. The individual relationship between the physical activity and energy expenditure both averaged over 30 min periods was plotted. Only the intervals after the first meal until bedtime were used, i.e. from 0800 hrs to 2300 hrs (=15 postprandial hours). The intercept of the regression line at zero activity represented the energy expenditure in the inactive state ($EE_{0\ activity}$) consisting of two components: SMR and DIT. By subtracting SMR from $EE_{0\ activity}$ we obtained DIT, and corrected it for the relevant time interval. ACT was assessed by 24-h EE minus $EE_{0\ activity}$. Thus, the separate components of energy metabolism were obtained by the following equations

$$\text{SMR} = \text{measured from 0300 to 0600 hrs}$$

$$\text{DIT} = (EE_{0\ activity} - \text{SMR}) \times (\text{postprandial hours}/24)$$

$$\text{ACT} = \text{24-h EE} - EE_{0\ activity}$$

Body weight and body composition

Subjects weighed themselves (without clothing) in the morning of days 1, 3 and 4 upon rising, after voiding and before any food/drink consumption, on a digital balance (Seca delta, model 707) accurate to 0·1 kg.

Whole-body density was determined once by underwater weighing in the fasted state, after the subjects left the respiration chamber. Lung volume was measured simultaneously with the He dilution technique using a spirometer (Volugraph 2000, Mijnhardt, The Netherlands). Percentage body fat was calculated using the equations of Siri (1956).

Analysis of data

The effects of diet composition on 24-h EE, SMR, DIT and ACT of all subjects were analysed by repeated measures analysis of variance (ANOVA) and Scheffé *F*-tests. Differences between the groups of restrained and unrestrained eating subjects on the three diets were tested using two-factor repeated measures ANOVA, with "attitude towards eating" as the grouping factor and "diet composition" as the repeated measures factor. Correlation between physical activity and energy expenditure was analysed using the Pearson correlation coefficient. Data are presented as the mean and standard error of the mean (*SE*). Probability values and power statistics are given with statistic values and degrees of freedom.

Results

Subject characteristics

Mean age, weight, height and percentage body fat were not significantly different between the restrained and unrestrained eating subjects (Table 1). Scores on the psychometric questionnaires were significantly higher for the restrained eating subjects (H–P score: $F=35{\cdot}62$, $p<0{\cdot}0001$; F_1 score: $F=21{\cdot}77$, $p<0{\cdot}001$) compared with the unrestrained eating subjects.

TABLE 2

Mean respiratory quotient (24-h RQ), energy intake (EI), energy expenditure (24-h EE) and energy balance (EI-24-h EE) for all subjects on the three diets (n = 12). The absolute and relative contributions of the components sleeping metabolic rate (SMR), diet induced thermogenesis (DIT) and energy expenditure due to physical activity (ACT) are also presented (n = 11)

	Low-fat		Mixed		High-fat	
	Mean	*SE*	Mean	*SE*	Mean	*SE*
24-h RQ*	0·90	0·01	0·86	0·00	0·82	0·00
EI day 1 and 2 (MJ/d)	11·76	0·08	11·78	0·09	11·80	0·10
EI day 3 (MJ/d)	8·60	0·08	8·51	0·09	8·61	0·09
24-h EE (MJ/d)†	8·70	0·18	8·44	0·14	8·47	0·16
EI-24-h EE (MJ/d)	−0·10	0·17	+0·07	0·15	+0·14	0·15
SMR (MJ/d)	6·18	0·14	6·13	0·14	6·02	0·12
DIT (MJ/d)‡	1·23	0·07	1·10	0·10	0·99	0·09
ACT (MJ/d)	1·28	0·12	1·20	0·10	1·45	0·15
SMR (% of 24-h EE)	71·2	0·9	72·8	1·3	71·3	1·4
DIT (% of 24-h EE)	14·2	0·8	13·0	1·1	11·8	1·1
ACT (% of 24-h EE)	14·6	1·2	14·2	1·1	16·9	1·6

*Low-fat vs. mixed: $F(1,11) = 65{\cdot}65$, $p < 0{\cdot}0001$; low-fat vs. high-fat: $F(1,11) = 249{\cdot}62$, $p < 0{\cdot}0001$; mixed vs. high-fat: $F(1,11) = 117{\cdot}48$, $p < 0{\cdot}0001$.

†Low-fat vs. mixed: $F(1,11) = 6{\cdot}64$, $p < 0{\cdot}05$.

‡Low-fat vs. high-fat: $F(1,10) = 4{\cdot}58$, $p = 0{\cdot}058$ (NS).

Energy metabolism

Over the 3-day intervals, provided energy intake was based on the calculated BMR of individual subjects. They were instructed to consume all food items and returned any left overs. There was a highly significant effect of diet composition on 24-h RQ; repeated measures ANOVA, $F(2,22) = 144{\cdot}41$, $p < 0{\cdot}0001$ (Table 2). Twenty-four-hour EE was not significantly different between subjects on the LF, M or HF diet, although there was a trend towards a decreased 24-h EE on the M and HF diets; $F(2,22) = 3{\cdot}40$, $p = 0{\cdot}052$. Comparing the results of the LF and M diet, 24-h EE was significantly decreased on the M diet.

Within individuals, energy expenditure and physical activity were related significantly, except for subject 4 on the LF and HF diet (Table 3). Therefore, data on SMR, DIT and ACT of 11 subjects are presented (Table 2). SMR, DIT and ACT were not significantly affected by diet composition, not expressed in MJ/d nor expressed as a percentage of 24-h EE. The contribution of DIT to energy metabolism was highest on the LF diet and lowest on the HF diet, but differences were not statistically significant.

Restrained or unrestrained attitude towards eating

Twenty-four-hour RQ and 24-h EE were not significantly different between restrained and unrestrained eating subjects on the LF, M and HF diet; two-factor repeated measures ANOVA, 24-h RQ: $F(2,20) = 0{\cdot}51$, $p = 0{\cdot}61$; 24-h EE: $F(2,20) =$

TABLE 3

Energy expenditure (kJ/min) in the inactive state ($EE_{0\ activity}$) for individual subjects on the three diets

	Low-fat diet				Mixed diet				High-fat diet			
	$EE_{0\ activity}$				$EE_{0\ activity}$				$EE_{0\ activity}$			
Subject	Mean	CL	r	p	Mean	CL	r	p	Mean	CL	r	p
Restrained eaters												
1	5·34	4·51–6·18	0·44	0·015	4·63	3·99–5·27	0·66	0·0001	4·89	4·45–5·33	0·72	0·0001
2	6·20	5·87–6·53	0·66	0·0001	5·98	5·70–6·26	0·77	0·0001	5·17	4·60–5·74	0·67	0·0001
3	5·18	4·74–5·62	0·74	0·0001	5·14	4·94–5·34	0·82	0·0001	5·13	4·92–5·34	0·83	0·0001
4	6·57	5·93–7·21	0·27	0·16	6·14	5·77–6·51	0·52	0·003	6·46	5·86–7·07	0·37	0·066
5	5·27	4·96–5·57	0·72	0·0001	5·23	4·98–5·47	0·78	0·0001	5·27	4·74–5·80	0·50	0·005
6	5·74	5·38–6·09	0·80	0·0001	5·46	5·07–5·86	0·76	0·0001	4·71	4·04–5·37	0·83	0·0001
Unrestrained eaters												
7	6·09	5·52–6·67	0·60	0·0005	5·77	5·23–6·31	0·56	0·0013	5·52	4·82–6·22	0·67	0·0001
8	5·80	5·24–6·36	0·51	0·0042	5·90	5·34–6·45	0·56	0·0013	5·82	5·44–6·20	0·73	0·0001
9	5·89	5·24–6·54	0·38	0·037	5·64	5·03–6·26	0·60	0·0005	5·53	5·06–6·00	0·71	0·0001
10	5·68	4·61–6·76	0·39	0·033	5·23	4·57–5·88	0·64	0·0001	4·91	4·20–5·62	0·60	0·0004
11	5·83	5·01–6·64	0·71	0·0001	5·46	4·85–6·06	0·72	0·0001	5·70	5·25–6·14	0·73	0·0001
12	5·22	4·82–5·61	0·73	0·0001	5·77	5·48–6·06	0·66	0·0001	5·46	4·85–6·08	0·71	0·0001

CL, 95% confidence limits for $EE_{0\ activity}$.
r, Pearson correlation coefficient.
p, probability value.

TABLE 4

Mean respiratory quotient (24-h RQ), energy expenditure (24-h EE), sleeping metabolic rate (SMR), diet induced thermogenesis (DIT) and energy expenditure due to physical activity (ACT) for restrained and unrestrained eaters on the three diets

	Low-fat		Mixed		High-fat	
	Mean	*SE*	Mean	*SE*	Mean	*SE*
Restrained eaters						
24-h RQ*	0·91	0·00	0·86	0·01	0·83	0·00
24-h EE (MJ/d)†	8·58	0·21	8·21	0·21	8·22	0·25
SMR (% of 24-h EE)	71·8	0·8	75·2	1·7	73·3	1·9
DIT (% of 24-h EE)	13·7	0·7	11·5	1·6	10·2	2·1
ACT (% of 24-h EE)	14·4	1·5	13·3	1·6	16·5	3·2
Unrestrained eaters						
24-h RQ‡	0·90	0·01	0·86	0·00	0·82	0·00
24-h EE (MJ/d)	8·83	0·29	8·67	0·13	8·72	0·14
SMR (% of 24-h EE)	70·6	1·5	70·8	1·4	69·5	1·8
DIT (% of 24-h EE)	14·6	1·5	14·3	1·5	13·2	1·0
ACT (% of 24-h EE)	14·7	1·8	14·9	1·5	17·3	1·5

*Low-fat vs. mixed; $F(1,5)=40·99$, $p<0·01$; low-fat vs. high-fat; $F(1,5)=256·70$, $p<0·0001$; mixed vs. high-fat; p<0·01; $F(1,5)=38·61$, $p<0·01$.

†Low-fat vs. mixed; $F(1,5)=22·84$, $p<0.01$; low-fat vs. high-fat; $F(1,5)=6·24$, $p=0·055$ (NS).

‡Low-fat vs. mixed; $F(1,5)=23·09$, $p<0·01$; low-fat vs. high-fat; $F(1,5)=78·09$, $p<0·001$; mixed vs. high-fat; $F(1,5)=122·56$, $p<0·0001$.

0·67, $p=0·52$; Table 4. On the HF diet, there was a tendency towards a higher 24-h RQ for restrained eating subjects compared with unrestrained eating subjects; $F=4·52$, $p=0·06$. Considering the separate components of energy metabolism, SMR, DIT and ACT, no significant differences between restrained and unrestrained eating subjects were observed, not on the LF diet, nor on the M or HF diet.

Within the group of restrained eating subjects 24-h RQ was significantly different between the three diets, $F(2,10)=90·13$, $p<0·0001$. 24-h EE was significantly lower on the M and HF diet compared with the LF diet; $F(2,10)=6·45$, $p<0·05$. Comparing the results of one diet vs. another, 24-h EE on the M diet was significantly lower, and on the HF diet tended to be lower than on the LF diet.

Within the group of unrestrained eating subjects 24-h RQ was significantly different between the three diets; $F(2,10)=57·26$, $p<0·0001$. Diet composition had no significant effect on 24-h EE.

Body weight

Results of eight subjects on the three diets are presented; data of subjects 1, 7, 8 and 9 were not complete with respect to body weight measurements. Body weight did not change significantly over the 2 days in free-living conditions (LF diet: $+0·3\pm0·2$ kg; M diet: $+0·3\pm0·1$ kg; HF diet: $+0·2\pm0·2$ kg). During the subsequent day in the respiration chamber, body weight decreased significantly on the LF ($-0·5\pm0·1$ kg; $F(1,7)=16·68$, $p<0·01$), M ($-0·5\pm0·1$ kg; $F(1,7)=21·24$, $p<0·01$) and HF diet ($-0·6\pm0·1$ kg; $F(1,7)=26.47$, $p<0·01$). Over the 3-day intervals, body weight changes were not significantly different from zero (LF diet: $-0{\cdot}2 \pm 0{\cdot}1$ kg; M diet: $-0{\cdot}2 \pm 0{\cdot}2$ kg; HF diet: $-0{\cdot}3 \pm 0{\cdot}2$ kg). There were no significant differences in changes of body weight due to the composition of the diet.

Discussion

Several studies examining the metabolic effects of isoenergetic exchange of fat and carbohydrate reported no significant change in 24-h EE due to the composition of the diet (Hurni *et al*., 1982: diets with 5 or 40% fat energy and 78 or 43% carbohydrate energy for 7 days each; Abbott *et al*., 1990: a diet with 20% fat energy and 65% carbohydrate energy for 5–43 days, and a diet with 42% fat energy and 43% carbohydrate energy for 6–32 days; Hill *et al*., 1991: diets with 20, 45 or 60% fat energy and 60, 35 or 20% energy as carbohydrate for 3 and 7 days each). Others investigated the effect of a 24-h dietary change in lean, obese and post-obese subjects, using isoenergetic diets which varied in fat (3 or 40% as energy) and carbohydrate (82 or 45% as energy) content (Lean & James, 1988). In post-obese subjects only, they observed a lower 24-h EE on a high-fat diet compared with a low-fat diet. The results of the present study showed no significant effect of diet composition on 24-h EE over all subjects ($n = 12$). However, there was a trend towards a decreased 24-h EE on the M and HF diet, and 24-h EE on the M diet was significantly lower than on the LF diet. Results are not consistent for influence of diet composition on the separate components of energy metabolism. SMR was significantly decreased in normal-weight subjects on a mixed diet compared with a low-fat diet (Hurni *et al*., 1982), or was not affected at all (Lean & James, 1988; Abbott *et al*., 1990; Hill *et al*., 1991). In the present study, no significant effect of diet composition on SMR was observed. The method used for determination of DIT was based on simultaneous measurements of both physical activity and energy expenditure of the subjects. One minor shortcoming of this approach is that it does not measure work intensity. In general, two types of activity can be identified while being in a restricted space: (1) locomotor activity within the chamber (e.g. strolling around), and (2) movement of limbs with little displacement of the body's center of gravity (e.g. fidgeting) (Schutz *et al*., 1982). Although these two types of activity do not have the same energy cost, they cannot be discriminated by the radar system because the latter gives equal importance to all movements no matter what its apparent intensity. Studies of Bouten *et al*. (1994, personal communication) indicated that physical activity measured by a radar system in a respiration chamber correlated significantly with physical activity measured by an advanced triaxial accelerometer, resulting in similar values for $EE_{0\ activity}$ and DIT. The contribution of DIT to energy metabolism was expected to be lower on a high-fat diet (Schwartz *et al*., 1985; Lean & James, 1988). According to Acheson *et al*. (1984a) the explanation for this finding could be the greater obligatory cost of glycogen storage and a facultative increase in thermogenesis due to glucogenic stimulation of the sympathetic nervous system (Acheson *et al*., 1984b). Abbott *et al*. (1990), however, found no change in DIT due to the composition of the diet. In the present study no effect of dietary fat and carbohydrate exchange on DIT was observed either, although the contribution of DIT to energy metabolism was highest on the LF diet and lowest on the HF diet (Table 2). Considering the energy expenditure for physical activity, no significant effect of diet composition could be observed, not in the present study, nor in other studies (Abbott *et al*., 1990; Hill *et al*., 1991).

A second objective of this study was to examine whether the influence of diet composition was different for different types of subjects, to explain possible consequences of diet composition for developing obesity. Within the group of restrained eaters 24-h EE was significantly lower during the M diet and tended to be lower during the HF diet, compared with the LF diet (Table 4). Therefore, the decreased 24-h EE on the M and HF diet as observed for all subjects ($n = 12$) was on account of the group of restrained eating subjects (Tables 2 and 4). Tuschl *et al*. (1990) conducted a study on the relationship between average daily metabolic rate and the eating behaviour of normal-weight women. Although the restrained eaters in their study had a higher body mass index compared with the unrestrained eaters, self-reported energy intake and measured energy expenditure were significantly lower. Because body weight did not change during the observation period, this should mean that restrained eaters have diminished energetic requirements, which in turn can induce chronic weight concern. On the other hand, restrained eaters report multiple dieting periods with various weight fluctuations, resulting in a decreased energy expenditure. In the present study, body mass index and the percentage of body fat were not significantly different between the groups of restrained and unrestrained eaters. Nevertheless, the response of restrained and unrestrained eaters to dietary exchange of fat and carbohydrate differed substantially. Restrained eaters showed a decreased fat oxidation compared with unrestrained eaters in response to a high-fat low-carbohydrate diet, resulting in a positive fat balance for restrained eaters (Verboeket-van de Venne *et al*., 1994). This finding was also reflected in the observed tendency towards a higher 24-h RQ in restrained eaters on the HF diet. Therefore, a LF diet would be beneficial with respect to development and treatment of obesity, especially if subjects have a restrained type of eating behaviour.

One of the difficulties of a short-term study is in knowing whether it provides an indication of the long-term responses. For example, major dietary changes require alterations in enzyme levels, the level of carrier proteins, and gene expression in order that a different nutrient or metabolite flux can be handled appropriately. The present study focussed on the short-term effects of dietary fat and carbohydrate exchange on energy metabolism of normal-weight subjects being more or less susceptible to developing obesity. Longitudinal studies in a larger group of subjects will be necessary to examine whether the results found in the present study can be extended to the long-term, i.e. whether restrained eaters indeed become obese (sooner) in response to a diet with a higher fat content compared with unrestrained eaters.

In conclusion, short-term dietary exchange of fat and carbohydrate had no significant effect on 24-h EE, although there was a trend towards a decreased 24-h EE the M and HF diet. When the subjects' attitude towards eating was taken into account, 24-h EE was significantly lower for restrained eating subjects at the M diet and tended to be lower at the HF diet compared with the LF diet, reflecting a possible risk factor at diets with a higher fat content in developing obesity.

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Appendix

Food items of the low-fat, mixed, and high-fat diet, as consumed during the respiration chamber measurements.

Low-fat diet (8·5 MJ)		
Breakfast	orange juice	200 ml
	low-fat crackers	6 × 4 g
	cheese spread (20 +)	15 g
	jam	3 × 15 g
	meat-products (<10 g fat per 100 g)	2 × 15 g
Lunch	low-fat curd with fruits	90 g
	low-fat crackers	6 × 4 g
	cheese spread (20 +)	3 × 15 g
	jam	3 × 15 g
	apple, medium	120 g
Dinner	apple juice	200 ml
	mix for preparing goulash	13·8 g

	water	
	steak tartare, unprepared	75 g
	spaghetti, uncooked	87·5 g
	leek, raw	37·5 g
	onions, raw	37·5 g
	peaches on syrup	125 g
	red paprika, raw	75 g
	tomato-puree	17·5 g
	yoghurt with fruits	125 g
Evening snack	orange juice	200 ml
	cookies	2 × 15 g
Mixed diet (8·4 MJ)		
Breakfast	wholemeal bread	3 × 35 g
	low-fat table margarine	3 × 5 g
	jam	15 g
	meat-products (<10 g fat per 100 g)	15 g
	meat-products (20–30 g far per 100 g)	15 g
Lunch	semi-skim milk	150 ml
	whole-meal bread	3 × 35 g
	low-fat table margarine	3 × 5 g
	Gouda cheese, 48+	20 g
	jam	2 × 15 g
Dinner	mix for preparing goulash	13·8 g
	water	
	minced meat (50% beef, 50% pork), unprepared	80 g
	spaghetti, uncooked	87·5 g
	leek, raw	37·5 g
	onions, raw	37·5 g
	peaches on syrup	20 g
	red paprika, raw	62·5 g
	yoghurt with fruits	150 g
Evening snack	orange juice	200 ml
	cookies	2 × 10 g
High-fat diet (8·5 MJ)		
Breakfast	wholemeal bread	35 g
	rye-bread	2 × 25 g
	low-fat table margarine	3 × 5 g
	Gouda cheese, 48+	20 g
	meat-products (20–30 g fat per 100 g)	2 × 15 g
Lunch	semi-skim milk	100 ml
	whole-meal bread	2 × 35 g
	rye-bread	25 g
	low-fat table margarine	3 × 5 g
	Gouda cheese, 48+	20 g
	meat-products (>30 g fat per 100 g)	2 × 15 g

Dinner	minced meat (50% beef, 50% pork), unprepared	75 g
	spaghetti, uncooked	87·5 g
	Gouda cheese, 48+	30 g
	kitchen margarine	10 g
	leek, raw	37·5 g
	onions, raw	37·5 g
	red paprika, raw	50 g
	tomato-puree	17·5 g
	whipped cream	12·5 ml
Evening snack	cake	2 × 20 g

Note that these diets were consumed by all subjects, except subject 7 who received diets with an energy content of approximately 9·5 MJ.