

Energy expenditure and physical activity in subjects consuming full- or reduced-fat products as part of their normal diet

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It has been suggested that energy expenditure is higher in subjects consuming reduced-fat, high-carbohydrate diets than in subjects consuming full-fat, low-carbohydrate diets. In a 6-month randomized, controlled trial, seventeen women and twenty men (age 20–35 years; BMI 22–28 kg/m²) had free access either to a range of about forty-five reduced-fat products or the full-fat equivalents. At the end of the 6 months, energy intake, sleeping metabolic rate (SMR), average daily metabolic rate (ADMR), and physical activity (AO) were measured. The intervention resulted in a mean difference of the change of the fat content of the diet of 6% of energy ($P < 0.01$) between the two groups. SMR, ADMR and AO were virtually the same in both groups. The results suggest that the change in fat content of the diet has no effect on physical activity and energy expenditure. However, subjects with a higher activity level consumed more carbohydrate (ADMR/SMR: $r = 0.49$, $P < 0.01$; AO: $r = 0.57$, $P < 0.001$).

Fat intake: Carbohydrate intake: Average daily metabolic rate: Physical activity

The shift in the composition of the diet to a higher contribution from fats in Western countries has often been quoted as the reason for the increasing incidence of overweight, i.e. of a positive energy balance. First, there is experimental evidence that a change to a diet higher in fat leads to an increase in body weight (Lissner *et al.* 1987). Combining this with the fact that these people tend to eat a diet higher in fat (Jiang & Hunt, 1983; Dreon *et al.* 1988; Tremblay *et al.* 1989; Miller *et al.* 1990; Bolton-Smith & Woodward, 1994) could lead to the conclusion that overweight can be prevented by reducing the fat content of the diet. Second, there is evidence that the body has a limited tendency to oxidize fat compared with the tendency to oxidize carbohydrate and protein (Westertep, 1993). Third, there is evidence that energy expenditure is higher when subjects consume a reduced-fat diet as measured after short-term interventions (< 1 week) in a respiration chamber (Hurni *et al.* 1982; Lean & James, 1988). Prewitt *et al.* (1991) reported data on eighteen women who consumed a standard diet for 4 weeks (carbohydrate:protein:fat 44:19:37 as a percentage of energy) followed by a reduced-fat diet for 20 weeks (carbohydrate:protein:fat 60:19:21 as a percentage of energy). Energy intake of the subjects was adjusted to maintain body weight throughout the study period, i.e. intake was increased or decreased when body

weight decreased or increased by more than 1 kg respectively. On the reduced-fat diet the mean energy intake increased by 19% and the mean body weight decreased by 2 kg compared with the initial 4-week interval on the standard diet. Thus, a reduced-fat diet resulted in a significant reduction in body weight despite a substantial increase in energy intake aimed at weight maintenance. However, the change in energy balance could have been influenced by changing conditions in time as the two diets were not presented simultaneously to two groups in a parallel design or to one group in a crossover design. Leibel *et al.* (1992) gave subjects fluid formula diets with widely varied fat contents, in a metabolic ward, keeping physical activity constant and feeding subjects to maintain body weight. There was no indication of significant variation in energy need as a function of percentage fat intake.

Convincing evidence that energy expenditure is different for subjects consuming reduced-fat, high-carbohydrate diets than for those consuming full-fat, low-carbohydrate diets is not yet available. Current studies include measurement of energy expenditure over short time-intervals, up to 24 h in a respiration chamber (Hurni *et al.* 1982; Lean & James, 1988; McNeill *et al.* 1988; Abbott *et al.* 1990; Verboeket-van de Venne *et al.* 1994), or calculation of energy expenditure from energy intake and changes in body composition (Prewitt *et al.* 1991; Leibel *et al.* 1992). The present study included direct measurement of energy expenditure in subjects consuming diets containing full- or reduced-fat products. The study was part of a multicentre study on the long-term health effects of realistic consumption of reduced-fat products. In a 6-month randomized, controlled trial, free-living non-obese volunteers received either reduced-fat or full-fat products and energy expenditure was measured at the end of the 6 months over 2-week intervals under normal living conditions with doubly-labelled water. Simultaneous measurements of physical activity allowed further analysis of possible differences with regard to the most variable component of energy expenditure under normal living conditions.

METHODS

Subjects

Subjects were recruited in May 1993 to allow a run-in period of 4 weeks in June to familiarize with the food products and the shopping system (see pp. 786–787). The 6-month study started in August 1993 and finished in February 1994. Subjects were nineteen female and twenty-one male volunteers, living within 30 km of Maastricht. Selection criteria were: age 20–35 years; BMI 22–28 kg/m²; sporting activities < 7 h/week; alcohol consumption women < 21 drinks/week, men < 28 drinks/week; no dietary restrictions. All subjects were healthy as assessed by a medical examination and routine clinical chemistry, and gave informed consent to participate in the study after procedures were explained to them. The protocol was approved by the university ethics committee.

Subjects were randomized over the two treatment groups, full-fat group (full-fat products) and reduced-fat group (reduced-fat products), ensuring an equal distribution of both sexes, eating behaviour characteristics and type of household, as far as possible. Three subjects dropped out during the study: one woman (who could not fit the laboratory visits into her timetable) and one man (who moved to another part of the country) in the full-fat group and one woman in the reduced-fat group (who became pregnant). Table 1 shows the characteristics of the thirty-seven subjects completing the study.

Dietary intervention

Subjects visited the laboratory at least once a week to make a free choice of food products, arranged in a shop setting. Additionally, they were free to consume food products obtained outside the laboratory shop. In the laboratory shop was a selection of about forty-five

Table 1. *Subject characteristics*
(Mean values and standard deviations)

	n	Age (years)		Height (m)		BMI (kg/m ²)	
		Mean	SD	Mean	SD	Mean	SD
Full-fat group							
Women	9	27	6	1.67	0.07	24.3	1.6
Men	10	29	5	1.82	0.05	24.6	2.9
Total	19	28	5	1.75	0.10	24.5	2.4
Reduced-fat group							
Women	8	24	4	1.67	0.06	22.4	1.3
Men	10	27	6	1.79	0.05	23.4	2.1
Total	18	26	5	1.73	0.08	23.0	1.8
Total group	37	27	5	1.74	0.09	23.7	2.2

products, each in a full-fat version and a reduced-fat version. The products ranged from spreads, dressings, cheeses and meat to biscuits, snacks, frozen meals, pizzas and desserts. The difference in fat content between the full-fat product and its reduced-fat equivalent was on average 50%. Consumption of products from the shop was assessed by weekly monitoring on an individual basis: shop products in stock at home at the beginning and end of the week, products taken from the shop in that week and products thrown away in that week. Subjects were encouraged to consume a minimum of 37 g fat/d from shop products in the full-fat group and 17.5 g fat/d in the reduced-fat group. All subjects in the study complied with this condition.

Dietary intake

Dietary intake was measured four times by means of a 3 d dietary record. The first (baseline) measurement was before the start of the run-in period of the study, in which subjects were still unaware of their assignment to the full-fat group or the reduced-fat group. The second, third and fourth measurements took place directly after the start, halfway and just before the end of the 6 months respectively.

Energy expenditure and physical activity

Energy expenditure was measured over a 2-week period while subjects consumed the study diets, at the end of the 6 months, with doubly-labelled water. Dose, sampling protocol, sample analysis and calculation procedure were as described before (Westerterp *et al.* 1995). Subjects were given a weighed dose of water with a measured enrichment of about 5 atoms % ²H and 10 atoms % ¹⁸O so that baseline levels were increased by 150 ppm for ²H and 300 ppm for ¹⁸O. Urine samples for isotope measurement were collected before dosing at night, from the second and last voidings on the next day, and after 7 and 14 d. Isotope abundances in the urine samples were measured with an isotope-ratio mass spectrometer (Aqua Sira; VG Isogas, Middlewich, Ches.). CO₂ production was calculated from isotope elimination rates, as calculated from the slope of the elimination curve, correcting for changes in body water assumed to be proportional to changes in body mass from the start to the end of the observation interval. CO₂ production was converted to average daily metabolic rate (ADMR) using an energy equivalent based on the individual macronutrient composition of the diet (Elia, 1991).

Physical activity was calculated as an index from ADMR and sleeping metabolic rate (SMR; physical activity level, PAL = ADMR/SMR), the commonly adopted method, and

Table 2. Energy intake (MJ/d) as measured with a 3 d dietary record, and body weight (kg) of subjects consuming full-fat or reduced-fat products, both before (0 months) and in the 6th month of the intervention period‡

(Mean values and standard deviations)

Time (months)...	Energy intake					Body weight			
	n	0		6		0		6	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Full-fat group									
Women	9	8.5	1.8	9.2	2.6	67.4	6.9	68.2	8.0
Men	10	11.4	3.5	11.0	3.2	82.0	12.2	84.9**	11.1
Total	19	10.0	3.1	10.1	3.0	75.1	12.3	77.0**	12.8
Reduced-fat group									
Women	8	8.1	2.1	9.1	1.8	62.1	4.1	62.3	5.8
Men	10	11.0	3.2	10.4	2.9	75.0	7.5	74.7†	8.2
Total	18	9.7	3.1	9.8	2.5	69.3	9.0	69.2†	9.5
Total group	37	9.9	3.0	10.0	2.7	72.3	11.1	73.2	11.8

** Mean values were significantly different from those for 0 months, $P < 0.01$.

† Mean values were significantly different from those for the full-fat group, $P < 0.05$.

‡ For details of subjects and procedures, see Table 1 and pp. 786–787.

measured with a triaxial accelerometer (accelerometer output, AO). SMR was observed at night, during a 36 h stay in a respiration chamber at the start of the ADMR measurement. SMR was measured over a 3 h interval between 01.00 and 07.00 hours with the minimal activity level judged from Doppler radar observation. Subsequently, subjects wore a triaxial accelerometer (Bouten *et al.* 1994) over a 7 d period, i.e. the first week of the 2-week ADMR measurement. The accelerometer consisted of three uniaxial piezoresistive accelerometers, attached to the low back of the subjects using an elastic belt around the waist, with measurement directions along the antero-posterior, medio-lateral, and longitudinal axes of the trunk. A flexible cable ran from the accelerometer to a portable unit (110 × 70 × 35 mm, 250 g) for on-line acquisition, processing, and storage of acceleration signals. The unit was programmed to calculate the sum of the rectified and integrated acceleration curves from all three measurement directions. The time period for integration was set at 1 min and the output finally obtained from the accelerometer and data unit was expressed as counts/min. Subjects wore the accelerometer during waking hours.

Statistics

Paired *t* tests were used to compare results within groups. Unpaired *t* tests were used to compare results between groups. Linear regression was used to assess the contribution of diet composition as predictor for differences in ADMR and physical activity.

RESULTS

Dietary intake

Daily energy intake of the subjects was the same in the 6th month, when energy expenditure was measured, as before the start of the intervention (Table 2). Differences between the full-fat and reduced-fat groups did not reach significance at any time point of the study.

Diet composition was nearly the same for the two groups before the start of the study (Table 3). Comparing diet composition in absolute amounts (g/d) of the four

Table 3. Composition of the diet (% energy) of subjects consuming full-fat or reduced-fat products, before and in the 6th month of the intervention period†

(Mean values and standard deviations)

	Full-fat group						Reduced-fat group					
	Women (n 9)		Men (n 10)		Total (n 19)		Women (n 8)		Men (n 10)		Total (n 18)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Before												
Carbohydrate	49	5	48	5	49	5	47	6	52	5	50	6
Protein	15	2	14	2	14	2	15	3	13	3	14	3
Fat	34	7	37	6	35	7	36	6	31†	6	33	6
Alcohol	2	3	1	2	2	3	2	5	4††	2	3	4
Month 6												
Carbohydrate	43**	3	39**	8	41***	6	48	7	50††	7	50†††	7
Protein	15	2	16	5	16	4	15	3	15	3	15	3
Fat	39*	4	42	9	41**	7	35	8	31††	7	33††	8
Alcohol	2	2	2	4	2	3	1	2	3	3	2	3

Mean values were significantly different from initial values: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
 Mean values were significantly different from those for the full-fat group: † $P < 0.05$, †† $P < 0.01$, ††† $P < 0.001$.
 ‡ For details of subjects and procedures, see Table 1 and pp. 786-787.

Table 4. Energy expenditure and physical activity of subjects consuming full-fat or reduced-fat products for 6 months, together with values for a subgroup on whom simultaneous accelerometer recordings were made*

(Mean values and standard deviations)

	n	ADMR (MJ/d)		SMR (MJ/d)		ADMR/SMR		AO (counts/min)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
All subjects									
Full-fat group									
Women	9	10.8	1.5	6.3	0.5	1.73	0.17		
Men	10	14.3	2.5	8.1	1.1	1.77	0.15		
Total	19	12.7	2.7	7.2	1.3	1.75	0.16		
Reduced fat group									
Women	8	11.5	1.6	6.2	0.4	1.87	0.30		
Men	10	13.0	1.6	7.5	0.6	1.75	0.18		
Total	18	12.4	1.8	6.9	0.8	1.80	0.25		
Subgroup									
Full-fat group									
Women	7	10.7	1.7	6.1	0.5	1.74	0.20	1070	218
Men	8	13.6	1.8	7.7	0.9	1.76	0.12	979	226
Total	15	12.3	2.3	7.0	1.1	1.75	0.16	1022	219
Reduced-fat group									
Women	7	11.6	1.8	6.1	0.3	1.91	0.31	1233	408
Men	8	13.4	1.5	7.7	0.3	1.75	0.21	1029	159
Total	15	12.6	1.8	6.9	0.9	1.82	0.26	1125	308

ADMR, average daily metabolic rate; SMR, sleeping metabolic rate; AO, accelerometer output.

* For details of subjects and procedures, see Table 1 and pp. 786–787.

macronutrients there were no differences. Comparing the energy contribution of the four macronutrients to the diet (% energy), the men in the reduced-fat group already consumed relatively less fat ($P < 0.05$) and consumed relatively more alcohol ($P < 0.01$) than men in the full-fat group. In the 6th month of the intervention period diet composition was changed, resulting in pronounced differences between the two groups. Subjects in the full-fat group reduced carbohydrate intake ($P < 0.01$), a reduction mainly observed in men ($P < 0.01$). In the reduced-fat group, women increased carbohydrate consumption ($P < 0.05$). Differences between groups were as planned, subjects in the reduced-fat group consumed less fat than subjects in the full-fat group ($P < 0.05$). The proportion of carbohydrate in the diet decreased in the full-fat group ($P < 0.001$), while values in the reduced-fat group were not significantly different from the initial value. The proportion of fat in the diet increased in the full-fat group ($P < 0.01$), while values in the reduced-fat group were not significantly different from the initial value. This resulted in a difference of the carbohydrate contribution to the diet ($P < 0.001$) and a difference in the fat contribution to the diet ($P < 0.001$) between groups. The changes in carbohydrate and fat intake were not related to the initial (habitual) intake in the group as a whole or in the subgroups.

Energy expenditure and physical activity

Energy expenditure, as measured in the 6th month of the study, did not differ between the two groups (Table 4). ADMR and SMR were virtually the same in the two groups. In seven subjects data on AO were not available due to battery problems ($n 2$), problems with the

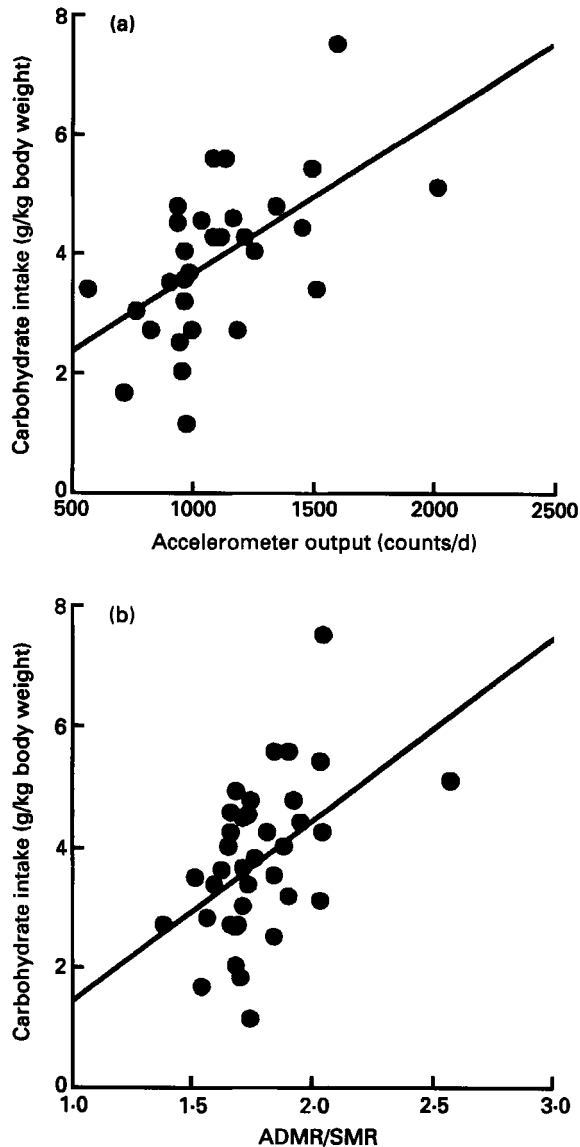


Fig. 1. Carbohydrate intake (g/kg body weight) plotted as a function of (a) physical activity expressed as accelerometer output (counts/d) and (b) physical activity expressed as (average daily metabolic rate)/(sleeping metabolic rate) (ADMR/SMR), with the linear regression lines.

activity sensor (n 2) or because subjects did not want to wear the accelerometer (n 3). Women in the reduced-fat group had on average a slightly (non-significantly) higher PAL and average weekly AO (Table 4). For the men, the differences in PAL and AO between the two groups were negligible.

Comparing energy intake (Table 2) and energy expenditure (Table 4) allowed the calculation of energy balance. Reported intake minus measured expenditure values, expressed as a percentage of measured expenditure, were -15 (SD 20) and -21 (SD 27), and -16 (SD 19) and -20 (SD 20) for women and men in the full-fat group and in the reduced-

fat group respectively. Thus, reported intake was significantly lower than measured expenditure in the full-fat group and in the reduced-fat group ($P < 0.001$). On the other hand, there was no significant change in body mass (0.00 (SD 0.69) kg) over the 2-week observation interval for energy expenditure. Apparently subjects underreported energy intake or consumed less energy over the 3 d food record interval compared with the 2-week observation interval for energy expenditure. The discrepancy between reported intake and measured expenditure tended to be positively related to BMI ($r 0.31$, $P = 0.06$) as observed previously (Westerterp *et al.* 1992). There was no relation between underreporting and PAL ($P = 0.87$) or AO ($P = 0.57$).

Using physical activity as a predictor for diet composition, in the full-fat group and the reduced-fat group together, PAL and AO did not explain any variation in macronutrient intake expressed as the relative contribution to ADMR (% energy). However, normalizing the macronutrient intake for body size by dividing intake of each nutrient by body mass showed that carbohydrate intake was related to physical activity. Subjects with a higher physical activity consumed more carbohydrate: $r 0.49$ ($P < 0.01$) and $r 0.57$ ($P < 0.001$) for PAL and AO respectively (Fig. 1).

DISCUSSION

Dietary intake

The design of the study, a long-term change of the fat content of the diet, was successful in the experiment as a whole as well as in the presented subgroup including measurements of energy expenditure and physical activity. In absolute figures the intervention created, as planned, a difference in the fat intake between the full-fat group and the reduced-fat group (Table 3). Subjects initially consumed a comparable moderately low-fat diet with on average 35% energy as fat or less. In the 6th month of the intervention, subjects in the full-fat group consumed a diet with a high fat content of 41 (SD 7)% energy as often observed in Western countries. The reduced-fat group had a fat consumption of 33 (SD 8)% energy in accordance with the present recommendations to reduce fat consumption below 35% energy. In theory, reported food consumption might not be representative if the observed underreporting or undereating was nutrient specific. However, this is unlikely to have affected the main outcomes as groups behaved identically with regard to this aspect.

Energy expenditure and physical activity

The experimentally induced long-term difference in the fat intake between the two groups did not cause a significant difference in energy expenditure. Earlier studies, which have measured energy expenditure after shorter diet-intervention periods, have shown that reduced-fat diets increase energy expenditure (Hurni *et al.* 1982; Lean & James, 1988) or have no significant effect (McNeill *et al.* 1988; Abbott *et al.* 1990). Roust *et al.* (1994) suggested that this discrepancy might be caused by the size of the intervention. Studies reporting positive results examined diets with a lower dietary fat content (< 10% energy) and greater differences in the proportion of fat between diets (> 30%) than studies finding no effect. The difference between the two groups in the present study did not meet either of the two criteria for a positive effect. On the other hand one has to realize that a dietary fat content below 10% energy or a difference greater than 30% between individuals is not very realistic in Western countries. The 1987–8 Dutch National Food Consumption Survey revealed, for instance, that total fat intake for men aged 22–49 years ranged from 20 to 55% energy (Hulshof *et al.* 1993).

The present study did not show a long-term effect of a reduction in the fat content of the food on ADMR. First of all the components of ADMR as measured in a respiration

chamber did not change. SMR, the main component of ADMR, was not different between the two groups (Table 4). The diet-induced thermogenesis was not different either (Verboeket-van de Venne *et al.* 1996). Measuring ADMR under normal living conditions with doubly-labelled water, combined with simultaneous measurements of physical activity with an accelerometer, allowed analysis of possible differences with regard to the third and the most variable component of energy expenditure, the energy expenditure for physical activity. The two activity measures, i.e. PAL, calculated from SMR and ADMR measured over the first week of the observation interval when subjects wore, simultaneously, the accelerometer, and AO (Table 4) were closely related ($P < 0.001$). In women there was a tendency for a higher PAL and a higher AO in the reduced-fat group but the interindividual differences were too great to reach significance with the number of subjects observed. In men there was no systematic trend as mean PAL was slightly lower and mean AO was slightly higher in the reduced-fat group. Thus, the two groups did not show a systematic difference in the activity component of ADMR.

Although the diet intervention did not result in a detectable difference in the activity component of ADMR, there was a relation between the diet and the level of physical activity (PAL, AO) over the group as a whole. Subjects with high physical activity showed a higher carbohydrate intake while protein, fat and alcohol intakes were not related to the level of physical activity. The relation between carbohydrate intake and physical activity is in line with results of exercise studies in which it has often been observed that athletes consume relatively more carbohydrate or subjects selectively increase carbohydrate intake when energy requirements increase during a training programme (Janssen *et al.* 1989; Van Erp-Baart *et al.* 1989). To our knowledge, this is the first study showing that subjects with a higher level of spontaneous physical activity, i.e. subjects within the normal range of PAL, consume more carbohydrate.

In the present study the lack of a relationship between fat intake and energy expenditure, while we could detect a relationship with carbohydrate, suggests that fat is not the primary nutrient to change when subjects increase their activity level. Subjects consuming more or less fat at the same daily energy intake (Table 2) can consume less or more carbohydrate, protein or alcohol. It is unlikely that alcohol would be increased because it is a minor component of the diet. This leaves two alternatives: carbohydrate and protein. Neither of the two showed significant differences between the two groups before the intervention. In the intervention period, subjects in the full-fat group, mainly men, reduced the daily carbohydrate intake from a mean of 291 g to 247 g ($P < 0.01$) resulting in a significant difference between the two groups (Table 3). However, the data do not indicate that macronutrient intake exerted any influence on levels of physical activity.

The fact that the induced difference in fat intake did not induce a difference in energy expenditure between the two groups, at first glance, does not agree with the results of Prewitt *et al.* (1991). The intervention in the study of Prewitt *et al.* (1991) decreased the energy contribution of dietary fat by 16% energy (from 37 to 21% energy). In the current study, under 'realistic circumstances', the induced difference in fat intake between the two groups was on average 8% energy (41 v. 33% energy, Table 3). Additionally, subjects in the study of Prewitt *et al.* (1991) concomitantly increased the carbohydrate intake to the same extent as the reduction in fat intake. Thus, the increase in energy expenditure could have been caused by the larger decrease in fat intake and/or by the increase in carbohydrate intake of the same extent. The results agree with those of Leibel *et al.* (1992), who found no indication of significant variation in energy need as a function of percentage fat intake at a restricted physical activity in a metabolic ward. In the current study a change in the fat content of the diet did not affect energy needs under normal living conditions.

Conclusion

The present study did not show a long-term effect of a difference in the fat content of the food on physical activity and energy expenditure under normal living conditions. However, subjects with a higher level of spontaneous physical activity within the normal range of PAL consumed more carbohydrate.

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