Acute effects of exercise on energy intake and feeding behaviour

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The main objective of the present study was to evaluate the short-term effects of exercise of different intensities on energy intake. Eleven young men were submitted to three randomly assigned sessions (one control and two exercise sessions) in which they ate, *ad libitum*, foods from a buffet-type meal. The energy cost of exercise was the same in the two exercise sessions. Results showed that there was no significant change in post-exercise subjective levels of hunger and fullness as well as total energy and macronutrient intakes in comparison with the control session. However, when energy intake relative to expenditure was considered by subtracting the surplus of energy expended during exercise from total energy intake, high-intensity exercise exerted a greater reducing effect on this variable compared with the control and low-intensity exercise sessions. These results suggest that for a given level of energy expenditure, high-intensity exercise favours negative energy balance to a greater extent than low-intensity exercise.

Appetite: Energy expenditure: Physical activity: Hunger

The ability of exercise to induce a negative energy balance depends on its impact on energy expenditure and is also related to variations in post-exercise energy intake. Indeed, a high-fat diet has been shown to induce a considerable increase in post-exercise energy intake (Tremblay *et al.* 1994*a*; King & Blundell, 1995). This effect of diet composition on energy intake also emphasizes the importance of taking into account the potential effect of exercise on food preferences and relative macronutrient intake. In several studies, exercise has been shown to induce a substantial increase in carbohydrate intake (Thompson *et al.* 1988; Verger *et al.* 1992) whereas an increase in post-exercise protein intake was found in another study (Verger *et al.* 1994). However, other investigators did not find a significant effect of exercise on macronutrient intake (King *et al.* 1994).

Experimental evidence suggests that post-exercise energy intake is also influenced by the composition of the substrate mix oxidized during exercise. Indeed, Alméras *et al.* (1995) observed that high-fat oxidizers during exercise displayed a lower post-exercise energy intake adjusted for the energy cost of exercise compared with individuals expending less energy as fat during exercise. This observation is concordant with our previous finding that exercise may attenuate the impact of a high-fat diet on energy intake depending on its enhancing effect on fat oxidation (Tremblay *et al.* 1989).

Other studies have also investigated the effects of exercise on energy intake and feeding behaviour. In human subjects, most of the reported studies have shown that exercise does not significantly modify appetite or the subjective feelings of hunger and fullness (Reger *et al.* 1986; Reger & Allison, 1987; Thompson *et al.* 1988; Kissileff *et al.* 1990). On the other hand, Kissileff *et al.* (1990) found that energy intake was lower only after strenuous exercise in lean female subjects. King *et al.* (1994) have introduced the notion of 'relative energy intake' to account for the energy cost of exercise and they found that this variable was significantly modified by a long duration high-intensity exercise session.

The effect of the regular practice of vigorous exercise on body fatness has also been examined recently. For a given leisure time physical activity energy expenditure, individuals engaged in more vigorous activities display a lower subcutaneous adiposity than individuals practising low to moderate activities (Tremblay *et al.* 1990). Tremblay *et al.* (1994*b*) have also demonstrated that a high-intensity training programme induces a greater loss of subcutaneous fat compared with a training programme of moderate intensity. However, other recent findings suggest that body fat loss is more related to total energy expended than to exercise intensity in moderately overfat women (Grediagin *et al.* 1995). To investigate further the impact of high-intensity exercise on energy intake and balance, we performed the present study to evaluate the acute effects of exercise intensity at a standardized energy cost on energy intake and feeding behaviour.

METHODS

Subjects

We recruited eleven young male adults from the student and staff population of Laval University. Subjects completed questionnaires enquiring about physical activity and medical history before the start of the study. To be eligible in the present study, subjects had to be aged between 18 and 40 years and to be healthy. They were also requested not to follow a dietary restriction or to take medication. Their mean body weight and height were 71·8 (SD 11·4) kg and 1·755 (SD 0·086) m respectively. Their morphological characteristics are presented in Table 1 which shows that they were characterized by a low adiposity. They were moderately active individuals, i.e. they participated in physical activities of moderate intensity for 3–5 h/ week. Their mean $\dot{V}O_2max$ was 56·7 (SD 5·0) ml/kg per min. The experimental protocol had previously been reviewed and accepted by the Laval University Medical Ethics Commitee.

Measurements before experimentation

Body composition. Body mass and fatness were measured at least 1 week before the experimental protocol. Body fat mass was determined from underwater weighing. The Siri equation (Siri, 1956) was used to estimate the proportion of fat from body density, while the He dilution technique was employed for the determination of residual lung volume (Meneely & Kaltreider, 1949).

Table 1. *Descriptive characteristics of subjects*

Variables	Mean	SD	Range
Age (years)	24·4	3·3	19·0–31·0
Body weight (kg)	71·8	11·4	53·1–83·9
Height (m)	1·755	0·086	1·570–1·840
Body fat (%)	11·8	6·0	4·6–18·4
$\dot{V}O_2max$ (ml/kg per min)	56·7	5·0	50·1–66·9
BMI (kg/m^2)	23·2	2·3	19·9–27·2

Maximal oxygen uptake ($\dot{V}O_2max$). $\dot{V}O_2$max was also measured at least 1 week before the beginning of the protocol. $\dot{V}O_2$max was measured during a progressive exercise test using an automated open circuit gas analysis system. Pulmonary ventilation was measured using a Fleish pneumotacograph, whereas an Applied Electrochemistry analyser (S3-A, Sunnyvale, CA, USA) and an Anarad analyser (R1, Santa Barbara, CA, USA) were used to determine the fractions of O_2 and CO_2 respectively in expired air. The test consisted of running on a treadmill with an increasing work output to the point of exhaustion. The following criteria were used to establish if $\dot{V}O_2$max had been reached: (1) a final respiratory exchange ratio (RER) > 1·15; (2) O_2 consumption increased by < 2 ml/kg with an increase in exercise intensity.

Experimental sessions

A cross-over experimental design was used in this study where each subject was submitted to the three following randomly assigned sessions.

(1) Control: subjects remained seated and were allowed to read and/or write quietly for the same duration as that of the low-intensity exercise.
(2) Low-intensity exercise: subjects walked on a treadmill at a target exercise intensity of 35 % $\dot{V}O_2$max for a period that was sufficient to induce an exercise energy expenditure of about 2050 kJ.
(3) High-intensity exercise: subjects ran on a treadmill at a target exercise intensity of 75 % $\dot{V}O_2$max for a duration allowing an exercise energy expenditure of about 2050 kJ.

Subjects were requested to abstain from vigorous activities for at least 2 d before the experimental sessions. A period of at least 4 d elapsed between each session. Subjects were instructed to eat a fixed predetermined breakfast (2095 KJ) at 07.30 hours at home. At 10.15 hours, subjects arrived at the laboratory where their resting energy expenditure was measured for 30 min. This measurement was followed by exercise or control sessions. The subject was asked to take a shower after each session. After having completed a visual analogue scale for the determination of hunger and fullness levels, a buffet-type meal was offered 15 min after the end of exercise or control sessions and the subject was instructed to eat *ad libitum*. Immediately after this meal, subjective ratings of hunger and fullness were repeated. The testing session was completed by a second measurement of resting energy expenditure which was performed immediately after eating.

Resting energy expenditure assessment

Energy expenditure of each subject was measured in a sitting position for 30 min by indirect calorimetry using an open-circuit computerized ventilated hood system to collect respiratory gases. The subject rested during the first 15 min and we retained the last 15 min for resting energy expenditure measurement.

Submaximal exercise test

As described earlier, the exercise sessions consisted of high- and low-intensity sessions with constant energy cost. Heart rate, $\dot{V}O_2$ and $\dot{V}CO_2$ were measured throughout exercise and the work load was adjusted from mean O_2 consumption and CO_2 production; the energy equivalent of $\dot{V}O_2$ was determined using the Weir formula (Weir, 1949). Carbohydrate and lipid oxidation during exercise were calculated assuming that the contribution of protein to energy metabolism was 10 % of the energy cost of exercise, and that the measured RQ was equal to the non-protein RQ.

Energy intake assessment

To replicate free-living conditions, subjects had access to a buffet-type meal immediately after the shower following the exercise or the control sessions. According to the satiety cascade described by Blundell & Halford (1994), the strategy used in the present experimental design did not integrate the effect of post-absorptive (late) factors on feeding behaviour. The meal contained a large variety of foods with different macronutrient compositions (Appendix A). Subjects were tested one at a time and were instructed to eat, *ad libitum*, foods prepared and pre-portioned by nutritionists. Subjects were instructed to eat until they had reached satiety and no time limit was imposed on the duration of the meal. After each meal, quantities of foods that were not completely consumed were reweighed to the nearest 0·1 g to determine the net intake of each food. The Canadian Nutrient File (Health and Welfare Canada, 1988) was used to derive energy, protein, lipid, and carbohydrate intakes from these measurements. In addition, we calculated 'relative energy intake' (REI) which corresponded to post-exercise energy intake during the buffet-type meal from which we subtracted the energy cost of exercise above resting level. REI energy intake was calculated as follows:

$$\text{REI} = \text{EI} - (\text{ECE} - (\text{exercise time} \times \text{REE}))$$

where EI is the *ad libitum* energy intake during the buffet-type meal, ECE is the measured energy cost of exercise, and REE is the measured pre-exercise resting energy expenditure.

Hunger and fullness measurements

Subjective indicators of motivation to eat were evaluated before and after the buffet-type meal. The subjects had to rate their perception on a 150 mm horizontal line in response to questions such as: "how hungry are you?", (very hungry–not at all hungry) and "how full are you?", (very full–not at all full). These rating scales have been shown to be sensitive to changes in physiological state and to nutritional challenges (Hill & Blundell, 1986).

Statistical analysis

A univariate approach to repeated measures was used to determine whether there were differences between the three sessions in energy and macronutrient intakes as well as motivation to eat. A repeated measures ANOVA, with time and exercise as the within-subjects measures was used to assess the effect of exercise time and intensity on RQ and macronutrient oxidation during exercise. When the ANOVA revealed significant statistical effects, a contrast analysis was applied to detect between which conditions a statistical difference was found. Pearson correlation analysis was performed to evaluate the association between exercise RQ and the post-exercise food quotient (FQ) for the low- and the high-intensity exercise sessions.

RESULTS

Table 2 shows the energy expenditure and duration of each exercise bout. As indicated earlier, the intensity of the exercise bouts was different but their energy cost was identical.

As expected, RQ was greater during the high- than the low-intensity exercise session (Fig. 1). No interaction effect was found between exercise time and intensity on RQ. Accordingly, carbohydrate oxidation was substantially increased during the high-intensity exercise session whereas a small but non-significant increase in fat oxidation was observed during this session (Fig. 2).

The pre-exercise and control resting energy expenditure values were almost identical for experimental sessions, ranging from 5·5 to 5·8 kJ/min. As expected, the postprandial energy expenditure increased by about 10% but no difference was found between each experimental session (Table 3). RQ measured at the beginning of the control session was the same (0·88) as values obtained before exercise. However, after the buffet-type meal of the exercise sessions, RQ was lower than in the control session but this difference was not statistically significant.

The analysis of subjective indicators of hunger and fullness did not reveal an effect of exercise on these variables (Table 4). In accordance with these results, postexercise and energy macronutrient intakes were comparable in the three sessions (Fig. 3). Moreover, there was no significant relationship between the exercise RQ and the postexercise FQ (Fig. 4).

Table 2. *Energy expenditure and duration of the low- and high-intensity exercise sessions*

	Low-intensity		High-intensity	
	Mean	SD	Mean	SD
Energy expenditure (kJ)	2054	45	2022	38
Duration (min)	72	14	34	6
Intensity (% $\dot{V}O_2$max)	35	2	72	4

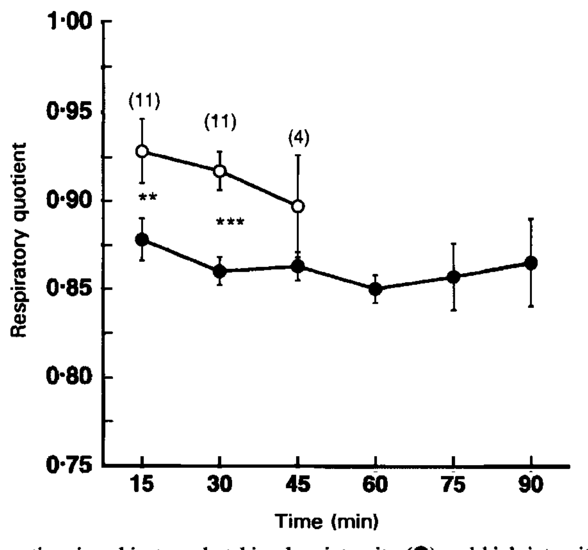

Fig. 1. Changes in RQ over time in subjects undertaking low-intensity (●) and high-intensity (○) exercise sessions. Numbers in parentheses refer to the number of subjects who had to exercise at this time to expend about 2050 kJ. Mean values for the low- and high-intensity exercise sessions were significantly different: $**P < 0{\cdot}01$, $***P < 0{\cdot}001$.

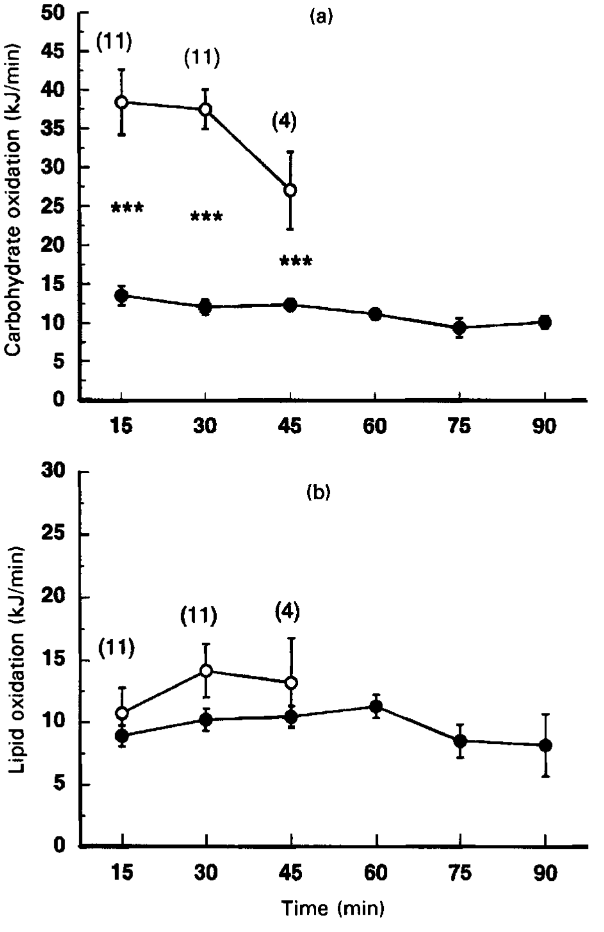

Fig. 2. Changes in (a) carbohydrate and (b) lipid oxidation over time in subjects undertaking low-intensity (●) and high-intensity (○) exercise sessions. Numbers in parentheses refer to the number of subjects who had to exercise at this time to expend about 2050 kJ. Mean values for the low- and high-intensity exercise sessions were significantly different: $^{***}P < 0{\cdot}001$.

To investigate further the effect of exercise on energy intake, we calculated REI which corresponded to post-exercise energy intake during the buffet-type meal corrected for the energy cost of exercise above resting level. REI thus represented an estimate of the acute effect of exercise on energy balance. The contrast analysis revealed that there was a significantly lower REI after the high-intensity exercise compared with the control ($P < 0{\cdot}001$) and the low-intensity exercise session ($P < 0{\cdot}05$; Fig. 3).

DISCUSSION

The common belief among health professionals is that low-intensity, long-duration exercise is the most appropriate exercise prescription for the treatment of obesity. However, we have recently reported data from cross-sectional and intervention studies which suggest that increasing exercise intensity promotes fat loss (Tremblay *et al.* 1990, 1994*b*).

Table 3. *Postprandial resting energy expenditure (REE), RQ, and macronutrient oxidation values for subjects during periods of sitting (control), low-intensity exercise and high-intensity exercise**

(Mean values and standard deviations for eleven subjects)

	Control		Low-intensity		High-intensity	
	Mean	SD	Mean	SD	Mean	SD
REE (kJ/min)	6·2	0·3	6·2	0·2	6·2	0·4
RQ	0·92	0·10	0·88	0·07	0·88	0·11
Lipid oxidation (kJ/min)	1·8	0·5	2·1	0·3	2·3	0·6
Carbohydrate oxidation (kJ/min)	3·8	0·4	3·5	0·3	3·4	0·5

*For details of subjects and procedures, see Table 1 and pp. 512–514.

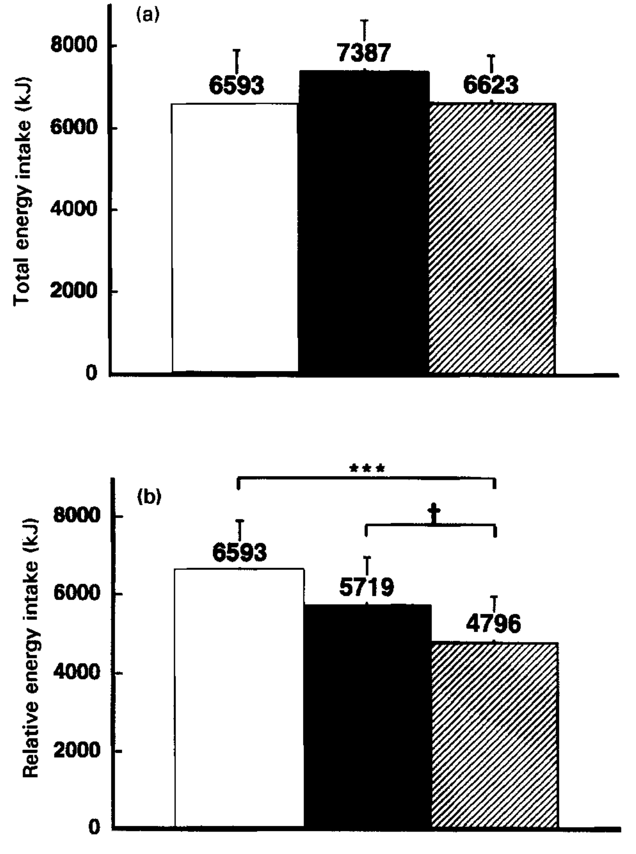

Fig. 3. (a) Total energy intake and (b) relative energy intake by subjects after sessions of sitting (control, (□)), low-intensity exercise (■) and high-intensity exercise (▨). Relative energy intake = total energy intake − exercise energy expenditure above resting energy expenditure. Values are means for eleven subjects with their standard errors represented by vertical bars. ***Mean values for the control and high-intensity exercise sessions were significantly different, $P < 0{\cdot}001$. †Mean values for the low- and high-intensity exercise sessions were significantly different, $P < 0{\cdot}05$.

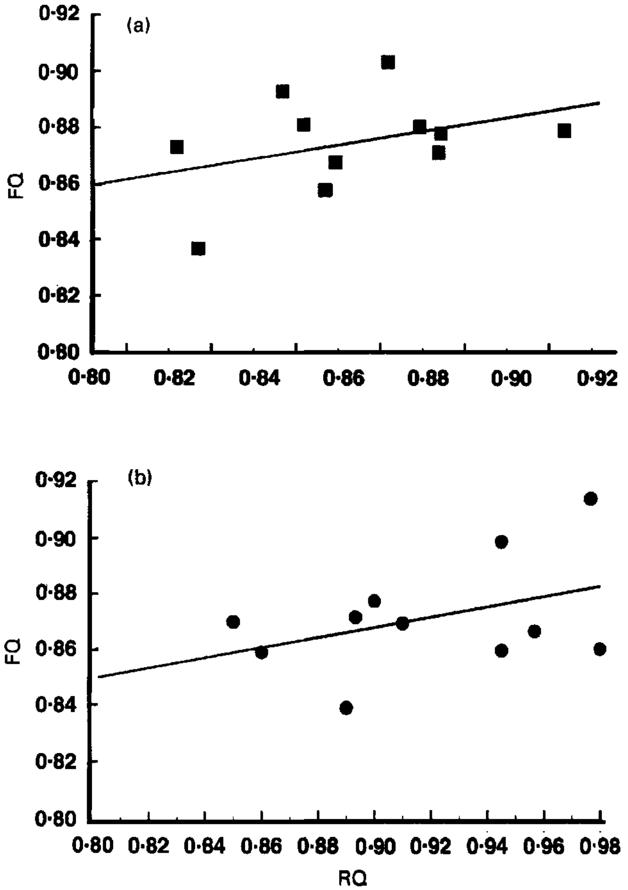

Fig. 4. Relationship between the exercise RQ and the post-exercise food quotient (FQ) for (a) the low-intensity exercise session (r 0·37, $P=0·27$) and (b) the high-intensity exercise session (r 0·41, $P=0·21$).

Table 4. *Subjective indicators of hunger and fullness (mm on a rating scale) made by subjects before and after a buffet-style meal following periods of sitting (control), low-intensity exercise and high-intensity exercise**

(Mean values for eleven subjects)

	Control			Low-intensity			High-intensity		
	Before	After	Δ	Before	After	Δ	Before	After	Δ
Hunger	74	5	69	93	9	84	93	7	86
Fullness	60	138	78	26	137	111	43	141	98

*For details of subjects and procedures, see Table 1 and pp. 512–514.

The present study was performed to investigate this issue further by examining the acute effect of exercise intensity on energy intake. The main hypothesis of this study was that short-term high-intensity exercise induces a greater suppressing effect on energy intake than low-intensity exercise of the same energy cost. Eleven young men were submitted to three randomly assigned sessions after which they ate foods *ad libitum*. The results showed that energy intake tended to be lower after the high-intensity than the low-intensity exercise session but this difference did not reach statistical significance. To evaluate further the acute effect of exercise on energy intake, the REI was calculated by taking into account the excess energy expenditure during exercise. This provided an estimate of the acute impact of exercise on energy balance. Once this adjustment was performed, high-intensity exercise was found to induce a greater reducing effect on energy intake compared with low-intensity exercise. This observation supports our previous observation that for a given energy expenditure, high-intensity exercise could contribute to a greater negative energy balance and fat loss (Tremblay *et al.* 1990, 1994*b*).

Hunger and fullness levels measured immediately after exercise were not significantly different between the high-intensity and low-intensity exercise sessions. In addition, the postprandial levels of these variables were identical under the two exercise conditions. Thus these observations suggest that an increased exercise intensity allows satiety with a reduced energy intake relative to energy expenditure.

As expected, a high RQ (high carbohydrate oxidation) was observed during the high-intensity exercise session. Despite this increased carbohydrate utilization, we did not observe a higher energy intake immediately after exercise, as could have been predicted on the basis of the RQ : FQ concept (Flatt, 1987). This concept is based on the observation that energy balance occurs when the RQ : FQ equals 1·0, i.e. when an equilibrium is also reached between intake and oxidation of macronutrients. This notion also emphasizes that the precision with which a balance is reached is not the same for each macronutrient. Experimental data show that the regulation of lipid balance is much less accurate in comparison with protein and carbohydrate balance (Flatt, 1987). Furthermore, Flatt (1987) reported evidence suggesting that variations in carbohydrate stores exert a significant impact on energy balance. When applied in the context of the present study, this concept should normally lead to the assumption that a greater carbohydrate utilization and depletion would be followed by a more pronounced increase in energy intake. Accordingly, we have previously reported results demonstrating that men displaying a high exercise RQ, i.e. a high relative carbohydrate utilization, were less prone to a negative post-exercise energy balance compared with high-fat oxidizers (Alméras *et al.* 1995). Therefore, the reduced energy intake relative to expenditure that we measured after the high-intensity exercise, despite its enhancing effect on carbohydrate oxidation, may represent a disruption of the normal sequence of biological events linking peripheral metabolism and some neurosystems. It is well known that strenuous endurance exercise activates the pituitary-adrenal axis by increasing the plasma concentrations of adrenocorticotrophic hormone and corticosterone (Galbo, 1986). The activation of this system during exercise depends on the hypothalamic corticotropin-releasing hormone (CRH) which is usually released in response to stress. Recent data obtained in rats demonstrate that exercise favours anorexia via a stimulation of CRH (Rivest & Richard, 1990). This mechanism could explain why the acute change in energy intake observed after the high-intensity exercise could not have been predicted on the basis of the exercise-induced change in carbohydrate utilization.

From a clinical standpoint, it is clear that high-intensity exercise cannot be prescribed to individuals who are at risk of health problems or to obese individuals who are not used to exercise. In these cases, the most prudent approach remains a low-intensity exercise programme with a progressive increase in duration and frequency. Ultimately, an increase in exercise intensity might be relevant if this is compatible with the fitness and health of these individuals.

In summary, the results of the present study extend our previous research observations by demonstrating that the ability of high-intensity training to promote a greater fat loss (Tremblay *et al.* 1994*b*) at least depends on the acute effect of exercise on energy intake. In the regular exerciser, this effect may represent, in the long term, a substantial negative energy balance.

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APPENDIX A

Energy content and macronutrient composition of the food items served in the buffet-type meal

Food item	Fat (g/100 g)	Protein (g/100 g)	Carbohydrate (g/100 g)	Energy (kJ/100 g)
Coca-cola	0·0	0·0	10·0	163
7-up	0·0	0·0	11·0	180
Apple juice	0·1	0·1	11·7	197
Orange juice	0·1	0·7	10·8	188
Milk 2 % fat	1·9	3·3	4·8	208
Chocolate fudge	16·8	4·5	64·8	1792
Oreo cookies	22·5	4·8	69·3	2071
Chocolate chip cookies	21·0	5·4	69·7	1971
Tea cookies	20·0	0·0	80·0	1674
Yoghurt	1·4	4·9	18·6	440
Pudding	2·5	3·0	24·4	523
Bran muffin	11·0	4·5	57·3	1469
Red apple	0·4	0·2	15·3	247
Banana	0 5	1·0	23·4	385
Orange	0·1	0·9	11·8	197
Fruit salad	0·0	0·5	13·1	209
White bread	3·2	8·7	50·5	1130
Wheat bread	3·0	10·5	47·7	1017
Melba toast	6·2	12·7	73·0	1695
Soda crackers	13·1	9·2	70·6	1837
Chicken and rice soup	0·8	1·5	3·0	105
Pretzels	4·5	9·8	75·9	1632
Celery	0·1	0·9	3·9	71
Carrot	0·2	1·1	9·7	176
Cucumber	0·1	0·6	3·2	59
Lettuce	0·1	0·9	2·9	54
Tomato	0·2	1·1	4·7	92
Sliced ham	10·6	17·6	3·1	762
Brie cheese	27·7	20·8	0·5	1396
Cheddar cheese	33·1	24·9	1·3	1685
Sliced turkey	7·2	18·7	0·5	615
Creton *	45·0	10·0	0·5	2008
Liver pâté	28·0	14·2	1·5	1335
Boiled egg	11·1	12·1	1·2	658
Mayonnaise	80·4	1·1	1·1	3063
French dressing	39·7	0·4	13·7	1682
Butter	81·1	0·9	0·1	2999
Ketchup	0·4	2·0	25·4	444
Mustard	4·4	4·7	6·4	314

*Typical Canadian pâté which contains pork meat.