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Exercise-induced suppression of appetite: effects on food intake and implications for energy balance*

N. A. King, V. J. Burley and J. E. Blundell

Biopsychology Group, Psychology Department, Leeds University, Leeds LS2 9JT, UK

Objective: To examine the effects of exercise on short term energy intake and to investigate the existence of exercise-induced anorexia.
Design: Two studies were conducted, both with three treatment conditions and employing a repeated measures design.
Setting: The Human Appetite Research Unit at Leeds University Psychology department.
Subjects: Twenty three healthy, lean male subjects ($n = 11$ and $n = 12$ respectively) were recruited from the student/staff population of Leeds University.
Interventions: Subjects were randomly assigned to a control, low intensity and high intensity exercise treatment in the first study and to a control, short duration and long duration exercise treatment (high intensity) in the second. Motivation to eat was measured by visual analogue rating scales and by the length of the time between the end of exercise and the volitional onset of eating. Energy and macronutrient intakes were measured by means of a free-selection test meal and by recorded intakes for the next 2 days.
Results: Subjective feelings of hunger were significantly suppressed during and after intense exercise sessions ($P < 0.01$), but the suppression was short-lived. Exercise sessions had no significant effect on the total amount of food consumed in the test meal but intense exercise delayed the start of eating ($P < 0.05$). When energy intake was assessed relative to the energy expended during the exercise or control periods, only the long duration, high intensity session created a significant short-term negative energy balance ($P < 0.001$).
Conclusions: These studies indicate that exercise-induced anorexia can be characterized by a brief suppression of hunger, accompanied by a delay to the onset of eating. The temporal aspects of exercise-induced anorexia may best be measured by the resistance to begin eating rather than the amount of food consumed.
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Descriptors: appetite, energy intake, exercise, exercise intensity, hunger

Introduction

The inter-relationship between physical activity and food intake is important since both are major behavioural contributors to energy balance. In addition to exercise being associated with health benefits such as feeling of well-being (Plante & Rodin, 1990), reduced risk of coronary heart disease (Leon *et al.*, 1987) and reduction of hypertension (Martin, Dubbart &

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Correspondence to: Dr N. A. King.

Cushman, 1990), it has an important role to play in energy balance. Although energy expenditure (exercise/physical activity) and energy intake are two independent measures which separately contribute to energy balance, it has been frequently proposed that exercise can influence energy balance indirectly by modulating energy intake (appetite) (Oscai, 1973; Wilmore, 1983; Saris, 1991). A number of possibilities can be considered. Firstly exercise may suppress appetite and induce the so-called exercise-induced anorexia. Secondly the extra energy expenditure induced by exercising may stimulate appetite and increase energy intake to compensate for the energy used. A third possibility is that over-stimulation of appetite caused by exercise may create a positive energy balance. Questions still remain unanswered regarding the response of appetite to exercise.

The findings from studies investigating the relationship between exercise and food intake have been equivocal and as a result no clear picture exists. Some of the appetite-suppressive effects of exercise are anecdotal and few studies have employed a full range of measures necessary to describe the nature of the appetite response. Although some studies have detected the suppression of feelings of hunger immediately following a vigorous bout of exercise (Reger *et al.*, 1984; Thompson *et al.*, 1988; Kissileff *et al.*, 1990), the measurement of the effects of exercise on energy intake (and therefore energy balance) have often failed to take into account the net energy expenditure induced by exercise. Most of these studies have only examined the effect of exercise on direct food intake (absolute energy intake). Therefore some results have been interpreted in a way that suggests that exercise-induced changes in appetite do not operate as a modulator of energy intake. If energy expenditure had been taken into account in these studies it is highly likely that the computed 'relative' energy intake would have been significantly reduced. Other studies have measured energy intake but have not measured the motivation to eat. This has implications for assessing the short-term relationship between exercise (energy expenditure) and energy intake and also for the 24 h energy balance. In either case, in assessing the biologically meaningful energy intake, energy expenditure must be taken into account. Therefore only a partial picture has emerged from previous studies on exercising and appetite.

The lack of consensus concerning the relationships among exercise, appetite control and energy balance draws attention to the need to comprehensively assess the parameters of the appetite response when physical activity is manipulated. In particular there is a need to make a number of simultaneous measures in order to fully describe the relationship (in the short term) between exercise and appetite. These measurements include the temporal changes in the strength of subjective feelings of the motivation to eat, the willingness to start eating, the absolute energy intake, and the relative energy intake (taking into account the energy cost of the exercise). In addition, in view of the important postulated relationship between macronutrient and energy balance (Astrup & Raben, 1993) it is essential to measure the macronutrient composition of food consumed after exercise. The following experiments have employed these measurements in order to fully characterize the effect of manipulation of exercise on the response of the appetite control system. These studies are intended to make a particular contribution to understand the effects of exercise on appetite by charting the time course of the short-term responses occurring immediately after the termination of exercise. In addition we have used the concept of energy intake to evaluate the effects of the exercise treatments. This information may suggest ways in which exercise could be judiciously employed to aid voluntary control of appetite.

Method: Study 1

Subjects

Twelve lean, healthy males were recruited from the student/staff population of Leeds University. Their age range was 21–27 years and mean body mass index 24.2 kg/m^2. Subjects completed questionnaires inquiring about physical activity and medical history and an eating inventory questionnaire (Stunkard & Messick, 1985) before the start of the study. Results of these questionnaires revealed that all subjects accepted into the study participated in at least 3 h of physical activity per week, were not dieting, not taking any form of medication and were of sound mental and physical health.

Table 1. Features of major recent experimental studies on the effects of exercise on food intake

Author/year	*Subjects*	*Exercise session*	*Effects on hunger/food intake*
Woo *et al.* (1982*a*)	Obese females	Treadmill walking 3 × 19 day phases: sedentary, 110% and 125% of daily expenditure	No difference between energy intakes for three periods, therefore no compensation for physical activity and significant difference in resulting energy balances
Woo *et al.* (1982*b*)	Obese females	Treadmill walking: 57 days at 125% of sedentary expenditure	No compensation in energy intake, therefore negative energy balance
Reger *et al.* (1984)	Non-obese females	Treadmill running: 60 min at 50% VO_2 max 30 min at 50% VO_2 max 30 min (1 min at 70% VO_2 max, alternating 3 min at 40% VO_2 max)	Brief depression of hunger following intermittent exercise session, and appetite ratings following both continuous sessions. No effect on test meal
Woo & Pi-Sunyer (1985)	Lean females	As Woo *et al.* (1982a)	Compensation in energy intake with increased activity. No significant difference in resulting energy balances
Thompson *et al.* (1988)	Non-obese males	Low intensity (35% VO_2 max) cycling High intensity (68% VO_2 max) cycling	Feelings of hunger suppressed briefly following intense exercise. No reduction in energy intake
Kissileff *et al.* (1990)	Obese/lean females	Low intensity cycling (40 min at 30 W) High intensity cycling (40 min at 90 W)	Food intake reduced in lean but not obese
Staten (1991)	Non-obese males/females	5 days treadmill running for 1 h/day (70% VO_2 max)	Increased intake for males; females' intake unchanged. Both males and females in negative energy balance
Verger *et al.* (1994)	Non-obese males	2 h of athletic activity. Estimated (gross) expenditure of 800 kcal	Significant increase (440 kcal) in food intake following exercise
Verger *et al.* (1992)	Non-obese males	75 min of continuous swimming. Estimated (gross) expenditure of 500 kcal	No effect on food intake

Leeds University Psychology ethical committee had approved the study.

Before commencing any of the trial days, subjects' maximum oxygen uptake (VO_2 max) was measured during an incremental exercise test using a bicycle ergometer. Subjects cycled until volitional exhaustion at which stage VO_2 max was reached using the following criteria: (1) a final respiratory exchange ratio (RER) of >1.15; (2) oxygen consumption increased by <2.0 ml/kg with an increase in intensity.

Study design

The study was designed to assess differences between high and low intensity exercise with total energy expenditure remaining constant. Therefore the durations of the exercise sessions were adjusted. Since the sessions differed in duration the starting time for each session was adjusted so as to ensure a concurrent finishing time. It therefore follows that total energy expenditure is related to exercise time.

The protocol consisted of three experimental days on each of which subjects attended the Human Appetite Research Unit in the morning to be served with a standard breakfast and remained there until mid-afternoon. Each of the three experimental days differed according to the mid-morning activity and were identified as follows:

(1) Rest (control). Subjects remained seated and were allowed to read/write quietly for ~45 min.
(2) High intensity exercise. Subjects cycled on the bicycle ergometer at 70% of their VO_2 max for ~30 min (mean time = 27 min).
(3) Low intensity exercise. Subjects cycled on the bicycle ergometer at 30% of their VO_2 max for ~60 min (mean time = 63 min).

A within-subjects design was used in which each subject served as his own control. Subjects underwent each of the three experimental sessions with 1 week separating each experimental day. The order of experimental sessions was systematically counterbalanced and subjects were accordingly assigned to a particular sequence. Subjects were instructed to refrain from heavy exercise and from consuming alcohol on the 2 days prior to each experimental day and to keep habits and activities as constant as possible during the course of the study.

Experimental procedure

Exercise sessions. Subjects cycled on a bicycle ergometer during each of the exercise sessions and were allowed up to 250 ml of water during that period. Expired air was collected periodically during each of the exercise sessions using a modified Douglas bag system (Cranlea UK). The modified Douglas bag system was designed so that eight bags were arranged in series. Two 4-day stopcocks and valves used to direct the expired air into the appropriate bag to ensure that there was no loss of air during collection or analysis. At specified times (four equally spaced intervals) subjects were asked to breathe into a mouthpiece for 1 min. The oxygen and carbon dioxide content of the expired air was analysed using a Servomex (57OA1) oxygen analyser and a Servomex (PA04040) carbon dioxide analyser. The volume of expired air was measured by extracting the air through a Harvard digital dry gas meter using an exhaust pump and variac control unit. This provided information regarding substrate utilization and also ensured that the appropriate workload/intensity had been administered. Both gas analysers were calibrated before each exercise session using a 100% N_2 gas cylinder (Cryoservice Ltd) and a 4.0% CO_2, 14.8% O_2 and 81.2% N_2 mixture gas cylinder (Cryoservice Ltd).

Test meal. During the first 15 min after exercise subjects were asked to shower (within the research unit) and to return afterwards to a specified part of the research unit. 15 min after the termination of exercise (and rest) sessions subjects were placed in an individual room with desk and chair within the Appetite Research Unit. They were informed that the *ad libitum* test meal was available when required and were instructed to collect the food from a nearby refrigerator whenever they felt hungry and to return to their own room to eat. Subjects ate alone and were told that they could eat as much or as little as they wanted. Subjects were obliged to remain in the laboratory until 2 p.m. This time limit was set to ensure that subjects left the unit at the same time on each experimental occasion and did not hasten their eating to meet personal commitments outside the laboratory.

The *ad libitum* test meal consisted of a selection of sandwiches, fruit cocktail, strawberry yoghurt and plain biscuits (see Table 2 for energy and nutrient values). All subjects had shown a preference for these foods in a pleasantness rating assessment prior to the study. All the foods were weighed before and after lunch to the nearest 0.1 g. The total energy

Table 2. Energy and nutrient values of the test meal foods used in studies 1 and 2

Food item	*kcal*	*Protein (g)*	*Fat (g)*	*Carbohydrate (g)*	*FQ*
Sandwich	64	4.2	2.1	6.9	0.90
Strawberry yoghurt	86	3.0	4.0	1.1	0.80
Fruit cocktail	49	0.1	0.4	12.5	0.98
Digestive biscuit	499	6.5	22.1	67.0	0.92

Sandwich values per quarter of sandwich, remainder of foods per 100 g.

and nutrient content of foods eaten were calculated using manufacturers' values.

On leaving the laboratory at 2 p.m., subjects were provided with a food diary and digital weighing scales accurate to 2 g (Sochale), and asked to record their food intake for the remaining 48 h. Subjects had been trained in the correct use of the scales and food diary prior to the experiment. These data were converted to estimates of energy and macronutrient intakes using a computerized version of food tables (Compeat 4.0).

Subjecting ratings. Subjective feelings of motivation to eat were monitored during the course of each experimental day using visual analogue scales (VAS). These were (word-anchored at both ends): 'how hungry are you?' (very hungry–not at all hungry), 'what is your desire to eat?' (very strong–not at all strong), 'how full are you?' (very full–not at all full) and 'how much food could you eat?'. These rating scales have been used previously and have been shown to be sensitive to changes in physiological state and nutritional challenges (Hill & Blundell, 1986). The completion of these scales entailed subjects making a vertical mark on a 150 mm horizontal line depending on the intensity of perceived sensations. These VAS were given to subjects immediately before and after breakfast and lunch, as well as before, during and immediately after the exercise or rest sessions.

Method: Study 2

Subjects

Twelve subjects were recruited using the same criteria as in the previous study. Before taking part in the study subjects underwent the standard VO_2 max evaluation on the bicycle ergometer. Their age range was 22–31 years and mean body mass index 23.2 (±2.23).

Study design

The design was similar to that used in study 1 but subjects underwent a control session and two high intensity exercise sessions, one of short duration (mean time = 26 min) and one of long duration (mean time = 52 min). The order of presentation of the sessions was systematically counterbalanced.

Procedure

Apart from the different exercise sessions, all other aspects of the procedure were identical to those used in study 1. However, a more sensitive measure of motivation to eat was obtained by giving subjects rating scales every 5 min (instead of on one single occasion) during the immediate post-exercise (and post-rest period).

Statistical analysis

A repeated measures analysis of variance (ANOVA), with time and exercise as the within-subjects measures, was used to analyse the VAS and test meal data using the computerized statistical package SAS (Statistical Analyses Systems, Inc., Box 8000, North Carolina). Student's t-test for paired values was used where necessary to make comparisons between any pair of treatments.

Results

Study 1

Prescribed exercise sessions. Table 3 shows the characteristics of the low and high intensity exercise sessions as measured from the expired air samples. As expected there was a highly significant difference between intensities (t= 5.2, d.f. = 10, $P < 0.001$) of the two exercise sessions, but no significant difference between the energy expenditures (t = 1.66, d.f. = 10, n.s.).

Visual analogue scales. Analysis of the visual analogue scales revealed a main effect of

Table 3. Intensities and energy expenditures for low and high intensity exercise sessions (mean ± SD)

	Low intensity exercise	*High intensity exercise*
Intensity (% VO_2 max)	36 (6.6)	72 (23.3)
Energy expenditure (kcal)	359 (41.5)	340 (27.6)
Duration (min)	63.2 (6.4)	26.7 (2.5)

VO_2 max of subjects = 44.4 ± 5.7 ml/kg/min.

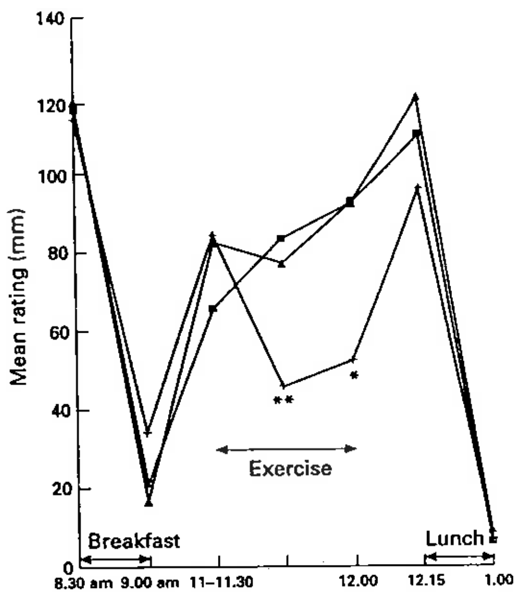

Fig. 1. Hunger profiles associated with a period of low or high intensity exercise or rest. The rating of hunger is significantly suppressed during and immediately after the high intensity cycling. Ratings did not significantly differ prior to the test lunch. See text for statistical analysis. The lines indicate the profile of hunger ratings under control (⊠), low intensity (▲) and high intensity (+) exercise. *P* values indicate significant differences between high intensity and control treatments: $*P < 0.05$ $**P < 0.01$.

exercise on feelings of hunger ($F[2,20] = 6.74$, $P < 0.01$) and a significant interaction between exercise and time ($F[12,20] = 3.36$, $P < 0.001$). Low intensity exercise did not produce any suppression of hunger either during or after the exercise session. Paired comparison tests indicated that there was a significant suppression of hunger both during ($t = 3.3$, d.f. = 10, $P < 0.01$) and immediately after ($t = 2.6$, d.f. = 10, $P < 0.05$) the high intensity exercise compared to the control session. Figure 1 shows the hunger profiles during the course of each treatment and indicates a significant suppression of hunger with high intensity exercise. The other scales measuring desire to eat and potential consumption showed a similar pattern to hunger whilst fullness showed an inverse profile.

Within 15 min of termination of the high intensity exercise session, subjective feelings of hunger had begun to return to control (rest treatment) values. Immediately prior to the test meal, hunger was still lower but not significantly different from the control values ($P = 0.059$).

Energy intake. There was no significant difference in the absolute energy intake at the test meal between the three treatments ($F[2,20] = 0.54$, n.s.). Therefore absolute food intake was not affected by either high or low intensity exercise. There was no significant effect of exercise on macronutrient intake.

Analysis of the food diary data showed that there was no significant difference in energy intake between the three treatments for the remainder of the day ($F[2,20] = 0.76$, n.s.) or the following day ($F[2,20] = 1.31$, n.s.). Table 4 shows energy intake for the test meals and over the whole experimental day.

Table 4. Energy intakes and food quotient values of foods eaten during the test meals, relative energy intake and energy intake for the whole experimental day in study 1 (mean ± SD)

	Control	*Low intensity*	*High intensity*
Test meal energy intakes (kcal)	1540 (312)	1649 (338)	1539 (425)
Food quotient	0.908 (0.011)	0.908 (0.012)	0.907 (0.008)
Relative energy intakes (kcal)	1485 (311.8)	1290 (344)	1199 (434)
Whole-day intakes (breakfast, test meal, diaries) (kcal)	3895 (1067)	3723 (906)	3632 (1429)

Whole-day intake includes measured breakfast and test lunch plus weighed diary records for the rest of the day.

Study 2

Exercise sessions. Table 5 shows the intensities and gross energy expenditures of the two exercise sessions. As intended, the intensities of the two exercise sessions were not significantly different (t = 1.38, d.f. = 11, n.s.), whereas the differences in gross energy expenditure of the sessions was significant (t = 7.18, d.f. = 11, P < 0.001).

Subjective ratings. A two-way ANOVA revealed that there was a significant main effect of exercise (F[2,22] = 5.83, P < 0.01) and a significant interaction between exercise and time (F[18,198] = 6.67, P < 0.001). Paired comparison of treatments with t-tests indicated that hunger was significantly suppressed during both the short duration (t = 3.59, d.f. = 11, P < 0.005) and long duration (t = 5.31, d.f. = 11, P < 0.001) exercise sessions, when compared to the control treatment. Hunger also remained suppressed immediately after both exercise sessions when compared to the control. However, the suppression was greatest after the long duration exercise session (t = 2.99, d.f. = 11, P < 0.05).

Hunger values were not significantly different between any of the three treatments 10 min after the end of exercise (t = 1.81, d.f. = 11, P > 0.05). Figure 2 displays the hunger profiles during each of the three treatments and shows clearly the strong suppression of hunger during and immediately after the two high intensity exercise sessions, as well as the rapid return of hunger in the first 10 min of the immediate post-exercise period.

Table 5. Intensity, energy expenditure and duration of the two exercise sessions in study 2 (mean ± SD)

	Short duration, high intensity	*Long duration, high intensity*
Intensity (% VO_2 max)	77 (8.71)	74 (6.98)
Energy expenditure (kcal)	296 (38.4)	541 (52.2)
Duration (min)	25.9 (1.9)	51.8 (2.4)

VO_2 max of subjects = 42.9 ± 4.16 ml/kg/min.

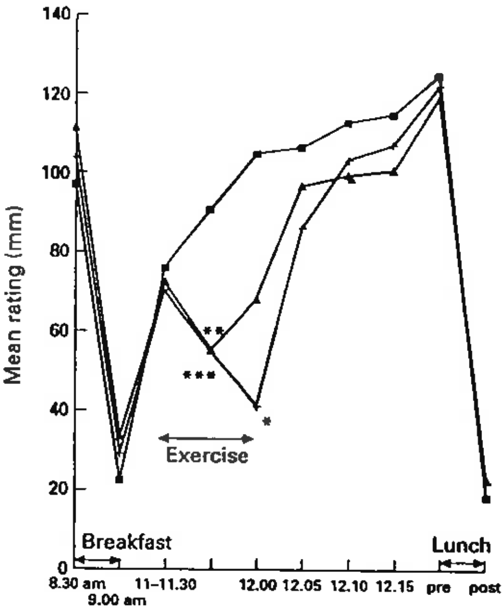

Fig. 2. Hunger profiles associated with an experimental period of short or long duration, high intensity exercise, or a period of rest. Hunger is significantly suppressed during and immediately after the exercise periods but recovery is very rapid. See text for statistical details. The lines indicate the profile of hunger ratings under control (⊠), high intensity, short duration (▲) and high intensity, long duration (+) exercise. P values indicate significant differences between the long duration exercise session and the control treatment (***P < 0.001), short duration and the control treatment (**P < 0.005) and between the two exercise sessions (*P < 0.05).

Time to onset of eating. There was a significant main effect of exercise on the time to onset of eating (F[2,22] = 6.23, P < 0.01). Paired comparison with t-tests indicated that there was a significant delay to the onset of eating following both the short duration (t = 3.51, d.f. = 11, P < 0.01) and long duration (t = 2.95, d.f. = 11, P < 0.05) exercise sessions when compared to the time of onset of eating following the rest period in the control treatment. Eating began within 10 min following the end of a control (rest) session but was delayed by a further 5 min after each of the high intensity sessions.

Test meal. Table 6 shows the energy intakes for the test meal and for the whole of the day calculated from the food diaries. There was no significant effect of the experimental treatments

Table 6. Energy intake during the test meal, relative energy intake, energy intake and relative energy intake for the whole day in study 2 (mean ± SD)

	Control	*Short duration, high intensity*	*Long duration, high intensity*
Test meal energy intake (kcal)	1396 (538)	1518 (545)	1428 (531)
Relative energy intake (kcal)	1348 (538)	1222 (547)	889 (512)
Whole of test day (breakfast, test meal, diaries) (kcal)	3675 (1067)	3604 (906)	3479 (577)
Whole of test day relative energy intake (kcal)	3627 (965)	3309 (813)	2940 (568)

on these values ($F[2,22] = 1.44$, $P > 0.05$; $F[2,22] = 0.28$, P . 0.05 respectively). Analysis also revealed that next-day energy intakes calculated from the food diaries did not differ according to the activity on the previous day ($F[2,22] = 1.09$, $P > 0.05$).

Computation of relative energy intakes. The exercise treatments did not produce any significant effect on energy intake in the test meal (or rest of day intake) in either study 1 or 2. However, it could be argued that a more appropriate measure of exercise on appetite would be the energy consumed relative to the energy expended during the exercise. This measure can be termed 'relative' energy intake. Analysis revealed that there was no significant difference between these 'relative' energy intakes ($F[2,22] = 2.41$, n.s.) (see Table 4). However, in study 2 there was a significant difference in 'relative' energy intake (Table 6), between the experimental treatments. Once energy expenditure during the exercise (and rest) sessions was accounted for, the remaining 'relative' energy intakes for the three treatments were significantly different ($F[2,22] = 10.01$, P , 0.001). Paired comparison with t-tests revealed that the 'relative' energy intake for the long duration high intensity exercise treatment was significantly lower compared to the 'relative' energy intake for the control treatment (t = 3.42, d.f. = 11, $P < 0.01$) and the short duration high intensity exercise session (t = 3.42, d.f. = 11, $P < 0.01$).

Analysis also revealed that the whole day 'relative' energy intakes were significantly different ($F[2,22] = 3.9$, $P < 0.05$) (see Table 6). Post-hoc t-tests showed that the whole day 'relative' energy intake during the long duration, high intensity exercise treatment was significantly lower than those of the control treatment (t = 2.96, d.f. = 11, $P < 0.05$) and the short duration, high intensity exercise treatment (t = 2.33, d.f. = 11, $P < 0.05$).

Discussion

In this study the effects of exercise on appetite were achieved by measures of subjectively perceived hunger, delay to onset of eating, total energy intake in a test meal and energy consumed for the rest of the day. Exercise-induced anorexia (suppression of appetite) can be fully charted using a battery of measuring devices.

The results of two studies have demonstrated the existence of a temporary suppression of appetite induced by exercise as reflected in a reduction in subjectively measured hunger. This suppression of hunger was influenced by the intensity and duration of exercise. Low intensity exercise did not induce a suppression of hunger and at no time did hunger ratings deviate significantly from the hunger profile in the session which included the rest period. Only high intensity exercise induced a suppression of hunger. Long duration, high intensity exercise was more effective than the short duration exercise period. Therefore, exercise can induce a form of anorexia (inhibition of appetite) which is reflected in a suppression of hunger.

However, this appetite suppression was short-lived and recovery was rapid. Hunger tended to return to near control levels within

~15 min. This recovery period was extended slightly (but not significantly) by doubling the duration of high-intensity exercise. This anorexia (inhibition of appetite) was also reflected in the time taken to voluntarily initiate eating after the end of the exercise period. This time was significantly longer after high intensity exercise than after rest. However, doubling the duration of high intensity exercise did not influence the delay to eating.

Exercise did not have any significant effect on the energy intake at the test meal. This finding is in line with previous results (Reger, Allison & Kurucz, 1984; Thompson, Wolfe & Eikelboom, 1988). Does this mean that exercise does not have an effect on food consumption (even though it suppresses hunger)? First, it is likely that if subjects had been obliged to eat within 15 min of the end of exercise, energy intake (like hunger) would have been suppressed. Second, when considering the effects of exercise on appetite and energy balance it is important to take into account the energy intake relative to the energy expended by the exercise. If energy expenditure is increased then it may be expected that energy intake should increase to compensate. However, if intake remains the same then this can be considered equivalent to a suppression of appetite (relative to intake expected to compensate for energy expended in exercise). Therefore energy intake can only be interpreted in relation to expenditure and we refer to this as 'relative' energy intake.

A reduction in 'relative' energy intake only occurred following the long duration, high intensity exercise period. Therefore exercise-induced suppression of appetite can be reflected not only in feelings of hunger but also in the amount of food freely consumed when subjects voluntarily initiate consumption (and when energy expenditure is taken into account). We have also shown that when the intake for the rest of the day is considered, there was no compensatory increase in intake to account for the reduction in 'relative' energy intake during the exercise treatments. Over the course of the whole day energy intake was reduced with long duration, high intensity exercise. However, these studies reflect short term effects and it is of course possible that there may be a delay in any compensation as suggested by the work of Edholm (1955). However, in these studies next-day energy intakes did not differ according to the activity on the previous day. Energy expenditure was not measured 'outside' of the treatment periods, therefore it is possible that on the exercise treatment days subjects' overall energy expenditure may not have differed from the rest treatment days as a result of reduced 'spontaneous' activity during the remainder of the day (hypokinesia).

The results from this study have both theoretical and practical implications. It appears that the physiological system does not allow an upward adjustment of energy intake to match an increase in energy expenditure (in the short term). One possibility is that post-ingestive satiety signals, mainly originating in the gastrointestinal tract, are sufficiently potent to prevent an increase in food intake occurring. These pre-absorptive processes which are believed to control the pattern of eating behaviour (Read, 1992) effectively override any metabolic signals reflecting increased tissue needs (due to exercise-induced energy utilization). Of course it should be recognized that a single period of high intensity exercise may not seriously compromise energy balance to the extent that physiological processes are threatened. Consequently, signals reflecting metabolic needs may be relatively weak. It may be expected that if high intensity, long duration exercise was repeated on a daily basis then eventually tissue needs would become so great that they would overcome the gastrointestinal inhibitory signals and force energy intake to increase by either extending the size of meals or by increasing the frequency of eating episodes. However, the study of Woo *et al.* (1982*a*) has illustrated that in obese women exercise bouts extending for at least 57 days do not lead to any compensatory increase in energy intake. From a practical point of view it is therefore worth drawing attention to two forms of exercise-induced anorexia disclosed by these two studies. First, the suppression of hunger and the decreased willingness to begin eating after exercise. These may be termed *direct* forms of anorexia. However, both are so short-lived that they are unlikely to have any significant influence over appetite control. Second, the reduction of 'relative' energy intake which can be considered an *indirect* form of exercise-induced anorexia. This occurred following a high intensity, long duration exercise period and appears to be capable of influencing the expression of appetite so as to prevent any compensatory increase in intake. This form of exercise, repeated on a daily basis, should create a negative energy balance and induce weight loss. However, it has to be recognized that such a severe exercise regime may be quite unacceptable as a method for reducing weight.

It also has to be considered that the phenomenon disclosed by these studies reported here is due to a single form of exercise, namely cycling. In this exercise the body is relatively static (and non-weight-bearing) and this may minimize physiological distress. Exercise in which the body posture is continually disturbed or in which there is greater gastrointestinal upheaval may lead to considerably greater periods of *direct* exercise-induced anorexia (suppression of hunger and willingness to eat). This possibility is currently under investigation. In addition, the macronutrient composition of food habitually eaten may either exacerbate or eliminate the *indirect* forms of exercise-induced anorexia. Our data suggest that high levels of dietary fat can effectively block the *indirect* anorexia (i.e. prevent a lowering of 'relative' energy intake). These findings should contribute to a further understanding of the role of exercise in the overall control of appetite. By allowing a prediction of the response to exercise these studies may help in the prescription of appropriate forms of exercise for the control of appetite and body weight.

References

Astrup A & Raben A (1993): Obesity: an inherited deficiency in the control of macronutrient balance. *Eur. J. Clin. Nutr.* **46**, 611–620.

Edholm OG, Fletcher JG, Widdowson EM & McCance RA (1955): The Energy Expendigure and Food Intake of Individual Men. *Br. J. Nutr.* **9**, 286–300.

Hill AJ & Blundell JE (1986): Macronutrients and Satiety: The effects of high-carbohydrate and high protein meals on subjective motivation to eat and food preferences. *Nutr. Behav.* **3**, 133–144.

Kissileff HR, Pi-sunyer XF, Segal K, Meltzer S & Foelsch PA (1990): Acute effects of exercise on food intake in obese and non-obese women. *Am. J. Clin. Nutr.* **52**, 240–245.

Leon AS, Connett J, Jacobs DR & Raurauma R (1987): Leisure-time physical activity levels and risk of coronary heart disease and health. *J. Am. Med. Assoc.* **258**, 2388–2395.

Martin JE, Dubbart PM & Cushman WC (1990): Controlled trial of aerobic exercise in hypertension. *Circulation* **81**, 1560–1567.

Oscai LB (1973): The role of exercise in weight control. In *Exercise and sport sciences reviews*, vol 1, ed. JH Wilmore. New York: Academic Press.

Plante TG & Rodin J (1990): Physical fitness and enhanced psychological health. *Curr. Psychol.: Res. Rev.* **9**, 3–24.

Read NW (1992): Role of gastrointestinal factors in hunger and satiety in man. *Proc. Nutr. Soc.* **51**, 7–11.

Reger WE, Allison TA & Kurucz RL (1984): Exercise, post-exercise metabolic rate and appetite. *Sport Hlth Nutr.* **2**, 117–123.

Saris WHM (1991): Exercise, nutrition and weight control. In *Advances in nutrition and top sport*, ed. F Brouns, pp. 200–215. Basel: Karger.

Staten MA (1991): The effect of exercise on food intake in men and women. *Am. J. Clin. Nutr.* **53**, 27–31.

Stunkard AJ & Messick S (1985): The three factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J,. Psychosom. Res.* **29**, 71–83.

Thompson DA, Wolfe LA & Eikelboom R (1988): Acute effects of exercise intensity on appetite in young men. *Med. Sci. Sports Exerc.* **20**(3), 222–227.

Verger P, Lanteaume MT, Gournay JF & Louis-sylvestre J (1992): Choix alimentaire spontane apres un exercise physique de natation. *Med. et Nutr.* **28**, 73–77.

Verger P, Lanteaume MT & Louis-sylvestre J (1994): Human intake and choice of foods at intervals after exercise. *Appetite* **1**, 1–7.

Wilmore JH (1983): Appetite and body composition consequent to physical activity. *Res. Quart.* **54**(4), 415–425.

Woo R, Garrow JS & Pi-Sunyer FX (1982*a*): Effect of exercise on spontaneous calorie intake in obesity. *Am. J. Clin. Nutr.* **36**, 470–477.

Woo R, Garrow JS & Pi-Sunyer FX (1982*b*): Voluntary food intake during prolonged exercise in obese women. *Am. J. Clin. Nutr.* **36**, 478–484.

Woo R & Pi-Sunyer FX (1985): Effect of increased physical activity on voluntary intake in lean women. *Metabolism* **34**(9), 836–841.