The energy cost of aerobic exercise in fed and fasted normal subjects[1,2]

Paul J Pacy, MRCP, Nicola Barton, Joan D Webster, BSc, and John S Garrow, FRCP

ABSTRACT It has been claimed that there is a prolonged thermogenic effect of aerobic exercise although the evidence is by no means conclusive. We have therefore studied the thermogenic effect of moderate aerobic exercise in the fasted and fed state in four lean subjects during weight maintenance. Exercise was performed at a constant rate on a bicycle ergometer during the initial 20 min for four successive hours. The first two exercise periods were in the fasted state while the last two followed an 800 kcal (3.4 MJ) mixed meal. Oxygen uptake increased 22% over the 165 min after the meal on rest days ($p < 0.001$). There was a significant but similar elevation of mean O_2 uptake during 40 min postexercise by 13.6% in both the fasted ($p < 0.001$) and fed state ($p < 0.001$). Sixty minutes after ceasing exercise mean O_2 uptake was not different from preexercise levels ($p > 0.05$). We conclude that there is no prolonged thermogenic effect of moderate repeated aerobic exercise in weight-maintaining lean subjects. In addition there was no interaction between exercise and dietary induced thermogenesis. *Am J Clin Nutr* 1985;42:764–768.

KEY WORDS Aerobic exercise, thermogenesis, energy balance

Introduction

It has been estimated that only some 20% of total energy expenditure in active subjects is attributable to physical activity (1). Despite this observation it has been claimed that the energy cost of exercise may far exceed the duration of the actual exercise period (2–5). On this basis it has been suggested that exercise is beneficial in weight reduction (6, 7).

An early study to report a prolonged effect of exercise on basal metabolic rate (BMR) came from Germany in 1926 (2). Among nine students in training for marathon running their BMR (compared with standard values) at the end of a working day was +14.7 ± 8.6%, and at the end of a rest day was +5.0 ± 6.6% (mean ± SD). Among five untrained subjects one showed very little increase in BMR on the day after exercise compared with the day before: among the other four subjects the increase ranged from 9.7% after 1200 m running to 0.2% after 800 m running.

The next report was an attempt to explain why members of the Harvard football team in 1935 required to eat 5600 kcal (23.4 MJ)/day (3). The BMR for the three players was +13 ± 13%, +14 ± 6%, and +6 ± 11% on the mornings after games or training periods, and 0 ± 8%, +9 ± 13%, and +6 ± 11% after rest days.

These two reports suggest that after very strenuous exercise (possibly involving bruising or other injury) resting metabolic rate is slightly increased. However the protocols and measurement techniques were such that it is not possible to assess the statistical significance of the results.

A better designed study was that of Passmore and Johnson in 1960 (4). They undertook a 10 mile walk on a treadmill at 4 mph in the fasting state. During the exercise metabolic rate was increased about fivefold over basal levels, but after the exercise was completed it remained on average 15% above basal levels for the next 6 h. There was no indication that the metabolic rate was falling towards baseline values at the end of the experiment. Unfortunately no control measurements were

[1] From the Nutrition Research Group, Clinical Research Centre, Watford Road, Harrow HA1 3UJ, UK.

[2] Reprints not available.

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made over the same time-scale, but without exercise, to see if the prolonged elevation of metabolic rate was simply a reflection of the diurnal variation in metabolic rate (8).

The most recent report (5) concerns one subject who undertook exercise for 80 min at 75% of his maximal oxygen uptake, and his oxygen uptake was measured hourly for the next 12 h, and again at 24 h. On another day a week or two later the same subject undertook the same protocol but without the exercise. The oxygen uptake during the 12 h after the exercise period was 19.3% higher than that during the corresponding 12 h on the control day. After 24 h the oxygen uptake was similar on the 2 days. Rectal temperature, heart rate, and pulmonary ventilation were also increased above control values during the 12 h after exercise. The authors conclude that metabolic rate is increased after prolonged severe exercise, that this prolonged elevation of metabolic rate may effectively double the energy cost of the exercise, and hence exercise may play an important role in weight control.

There is no doubt that after intense exercise there is an oxygen debt which causes an elevation of the metabolic rate in the period immediately after the exercise ceases, but this is a relatively small effect, which is seen only in subjects fit enough to undertake prolonged severe exercise. In all these studies the intensity and duration of exercise are probably beyond the capacity of the average obese patient concerned with weight control, for whom aerobic exercise is usually advocated. It is not clear if there is a prolonged thermogenic effect of aerobic exercise. We have therefore undertaken to determine, by indirect calorimetry, the energy cost of moderate aerobic exercise and the period during which metabolic rate is increased, in lean weight-maintaining subjects in the fasted and fed state.

Methods

Subjects

Four nonobese subjects were studied while on a weight-maintaining diet assessed by no weight change over at least the previous 1 mo. Their clinical details are shown in **Table 1**. Only one of the subjects (PH) smoked cigarettes (10–15/day). None of those studied was a competitive athlete although all indulged in recreational sporting activities. The protocol was approved by the Northwick Park Hospital Ethical Committee and all subjects gave informed consent.

Protocol

Each subject underwent two exercise and two rest periods which were always performed between 08:30 h and 14:30 h. A Latin square design was employed to minimize any effect of training and familiarity with the protocol. The period (mean ± SD) between exercise studies was 7.5 ± 4.6 days while for rest was 16.5 ± 9.7 days.

The timetable during exercise and rest periods is depicted in **Figure 1**. Following a 12-h overnight fast a face mask was fitted and O_2 uptake recorded with the subject in the supine position, for subject comfort, at all times except during exercise periods. We felt that such O_2 uptake values would more likely represent the nonexercising state than if the subject was uncomfortable while seated on the bicycle ergometer for the 8 h.

Exercise was performed on a bicycle ergometer (Monark, Varberg, Sweden) for a 20 min period each hour for four consecutive hours. Constant work was ensured by peddling at 50 rpm against a fixed load of 1–2 kiloponds/min (50–100 W) and represented 35–55% $\dot{V}O_2$ maximum for each individual. This was chosen as it was thought to represent the type and size of meal appropriate for such levels of physical exercise.

The face mask was worn continuously throughout the 345 min of each study except for the 15-min period between 165–180 min when an identical mixed meal of 800 kcal (3.4 MJ) was ingested. The composition of the meal was fat 57%, protein 14%, and carbohydrate 29% and consisted of wholemeal cheese sandwiches and chocolate biscuits. Throughout both exercise and rest days the heart rate was monitored continuously by means of infrared telemetry (9).

Analysis of variance was performed using the Minitab package (10) to determine the significance of results.

Indirect calorimetry

The metabolic rate was measured by means of O_2 uptake using a modification of the ventilated hood technique

TABLE 1
Clinical details of the subjects

Subject	Sex	Age	Initial wt	Ht	Quetelet index	Work load	Final wt
		yr	*kg*	*m*	*kg/m²*	*kiloponds/min*	*kg*
1	F	29	64.7	1.64	24.2	450 (75 W)	62.9
2	F	21	50.0	1.60	19.5	300 (50 W)	50.9
3	M	23	70.0	1.70	24.2	600 (100 W)	70.4
4	M	32	55.4	1.70	19.2	600 (100 W)	55.1

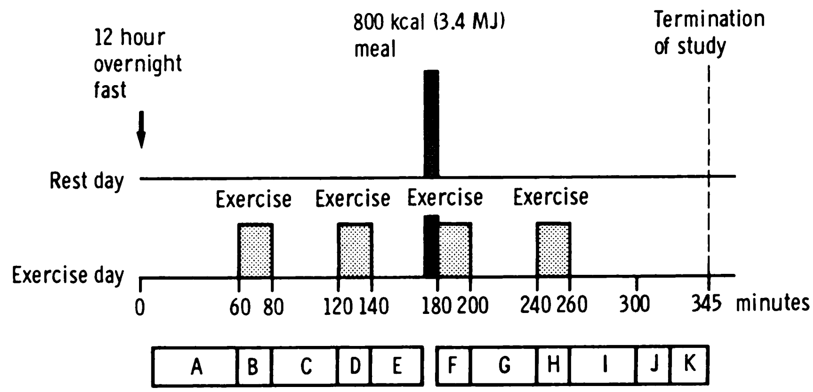

FIG 1. Timetable of metabolic rate determination by the ventilated hood technique during rest and exercise.

(11). The modifications included increased O_2 flow (40 L/min) and the wearing of a perspex face mask rather than the head box. In addition a microcomputer had been fitted to the system to enable continuous analysis on several channels.

The apparatus was programmed to record mean O_2 uptake, CO_2 production, and respiratory quotient between 2 and 5, and 12 and 15 min during each quarter of an hour.

To allow comparison of O_2 uptake between the rest and exercise days the 345 min were divided into 11 intervals, A to K (Fig 1). In period A the mean O_2 uptake recorded between 2 and 5 min was always discarded.

Results

The mean O_2 uptakes during the rest and exercise days are shown in **Table 2.** This confirms that the Resting Metabolic Rate (RMR) was similar on both occasions. In addition RMR was highly reproducible over the entire 165 min in the fasted state. Dietary-induced thermogenesis (DIT) increased fasting resting metabolic rate by approximately 22% and remained constant over the entire 165 min following the mixed meal. The postprandial elevation of O_2 uptake, comparing periods D and F, was highly significant ($p < 0.001$).

In the fasted state mean O_2 uptake was higher ($p < 0.001$) at the end of both rest periods, C and E, on the exercising comparing to nonexercising days. However, there was no significant difference in O_2 uptake between periods C and E following exercise.

TABLE 2
O_2 uptake (ml/min) of the four subjects at rest and during exercise in the fasted and fed state

	Fasted state					Fed state					
Period Minutes sampling	A 12–60	B 62–80	C 87–120	D 122–140	E 147–165	F 182–200	G 207–240	H 242–260	I 267–300	J 302–320	K 327–345
REST DAY											
Mean	233	245	251	247	256	312†	288	293	303	295	295
SD	39	48	46	47	44	74	46	42	50	56	53
EXERCISE DAY			*		*		*		*		
Mean	245	1126	278	1161	298	1118	327	1132	346	317	301
SD	37	146	56	125	59	224	63	188	82	39	37
Difference in O_2 uptake between rest and exercise days	12	881	27	914	42	806	39	829	43	22	6

Figures = Mean ± SD. 20 min exercise performed during periods B, D, F, and H. Mixed meal of 800 kcal (3.4 MJ) ingested between periods E and F. Statistics by analysis of variance.

* $p < 0.001$ between periods C, E, G, and I on exercise and rest days.

† $p < 0.001$ between periods D and F on rest but not exercise days.

Postprandially there appeared to be no interaction, either additive or synergistic, between exercise and dietary-induced thermogenesis as there was no statistical difference between periods D and F on exercising days. In the fed state mean O_2 uptake in periods G and I was higher following exercise than during rest days ($p < 0.001$) but this was of the same magnitude as preprandially. This effect had disappeared within 60 min of ceasing exercise, period J. However, when each 3 min period is analyzed (**Fig 2**), O_2 uptake although greater following exercise than on rest days, this difference was only statistically significant for 10 min ($p < 0.001$).

During the first exercise period mean heart rate increased from 66 beats/min to 140 beats/min. Mean heart rate tended to plateau at higher levels on each successive exercise period such that during the fourth occasion this was 150 beats/min. Following cessation of exercise mean heart rate had returned to preexercise levels within 10 min.

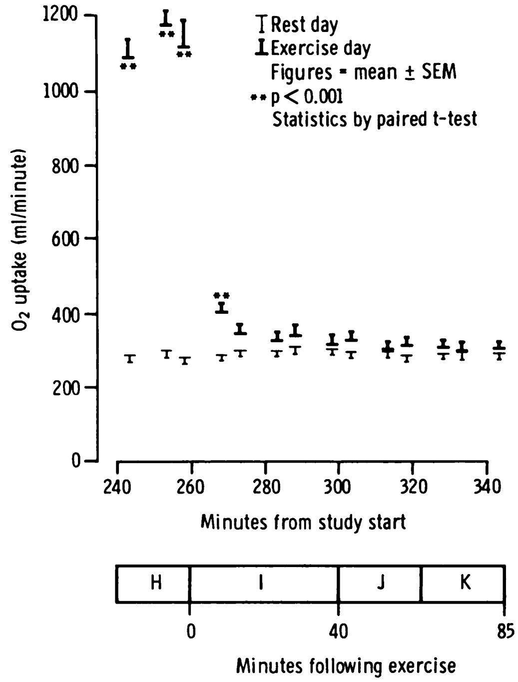

FIG 2. Comparison of mean O_2 uptake on rest and exercise days over the final 105 min of the study.

Discussion

This study in weight-maintaining nonobese subjects has failed to confirm either a prolonged thermogenic effect of repeated moderate aerobic exercise or an interaction between exercise and dietary-induced thermogenesis. We believe the inability to show a prolonged thermogenic effect of exercise as reported previously (2–5) is most likely due to their technical problems, described earlier, rather than any fundamental discrepancies. However, we cannot rule out the possibility that the more prolonged and intensive exercise of the earlier studies is a factor.

In addition we have not confirmed the finding of any interaction between exercise and DIT (12–14) which is similar to two recently published papers (15, 16). These apparently conflicting data may relate to differences in energy intake during or in the preexercise period between the studies. Exercise potentiation of DIT appears to occur either when the test meal is at least 900 kcal (3.8 MJ) or if the subject has previously been consuming a weight-increasing diet (12, 13, 17, 18). This is clearly different from the situation in the present study as the weight of our subjects had remained constant over several months and the test meal was 800 kcal (3.4 MJ). However, potentiation of DIT by exercise is not universal following a 900 kcal (3.8 MJ) meal (19, 20).

The work load chosen was considered the maximum amount most would achieve during weight-reducing programs. It is unlikely that the lack of interaction between exercise and DIT in this study was the result of the moderate exercise performed; similar work loads on a bicycle ergometer have been reported to influence DIT (13, 18).

In summary this study of moderate aerobic exercise has demonstrated no interaction between exercise and dietary-induced thermogenesis. In addition it appeared that the increased thermogenesis following exercise is of short duration. We conclude therefore that such exercise would be of little benefit aiding weight reduction unless combined with decreased calorie intake.[3]

[3] Since this manuscript was written, a study of fit and unfit subjects exercising for 20 min at approximately their anaerobic threshold has also failed to document any prolonged thermogenic effect of exercise. (Freedman-Akabas S, Kissileff HR, Pi-Sunyer FX.) Lack of sustained increase in VO_2 following exercise in fit and unfit subjects. Am J Clin Nutr 1985;41:545–9.

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