Eur J Appl Physiol (1991) 62:11-17

European Journal of Applied Physiology
and Occupational Physiology

The effect of a 5-month endurance-training programme on physical activity: evidence for a sex-difference in the metabolic response to exercise

G. A. L. Meijer, G. M. E. Janssen, K. R. Westerterp, F. Verhoeven, W. H. M. Saris, and F. ten Hoor

University of Limburg, Department of Human Biology, P.O. Box 616, NL-6200 MD Maastricht, The Netherlands

Accepted July 17, 1990

Summary. The effect of a 5-month endurance training programme on physical activity and average daily metabolic rate (ADMR) was studied. Subjects were 16 males and 16 females preparing for a half marathon. Total physical activity, measured using an accelerometer, had increased by 62% and 63% after 20 weeks in males and females, respectively. Physical activity during the non-exercise part of the day did not change although in males it tended to increase (15%, NS). The ADMR had increased significantly in males after 8 and 20 weeks (+2.3 and +3.3 $\mathrm{MJ \cdot day^{-1}}$, respectively, $P<0.05$) and exceeded the net energy expenditure for endurance-training three to four times. In females no significant increase in ADMR was found (+1.5 and +1.3 $\mathrm{MJ \cdot day^{-1}}$, after 8 and 20 weeks, respectively). In females the change in ADMR could be largely attributed to the net cost of running itself and a small increase (10%) in resting metabolic rate during the time of day they were awake. In males a discrepancy was observed between the increase of ADMR and the expenditure due to exercise and non-exercise activities. We suggest exercise stimulates habitual physical activity and diet-induced thermogenesis in males but not in females.

Key words: Physical activity - Endurance-training - Energy metabolism - Doubly labelled water - Accelerometer

Introduction

In Western society there has been a general trend towards a decrease in physical activity which has occurred as a result of more automation and mechanization (Reiff et al. 1967). Since work itself has become less strenuous in terms of energy expenditure, an increase in physical activity can only be achieved by stimulating leisure-time activities. During the last decade sports like running and jogging have become very popular, stimulating health and a feeling of wellbeing. Moreover, physical activity may reduce the risk for coronary heart disease (Paffenbarger and Hyde 1985) and exercise may be a successful strategy in the prevention of obesity (Garrow 1987). Exercise in combination with a slimming diet has been reported to result in a larger mass loss compared with diet alone (Tremblay et al. 1984), reducing the concomitant loss of fat free mass (FFM) (Pavlou et al. 1985). As the energy expenditure resulting from exercise itself is only a minor component of average daily metabolic rate (ADMR), it has been suggested that this effect is due to inhibition of a reduction in resting metabolic rate (RMR) which usually occurs with dieting (Molé et al. 1989; Ravussin et al. 1985; Weigle et al. 1988; Elliot et al. 1989), whereas diet-induced thermogenesis (DIT) might even be increased (Tremblay et al. 1985).

The modulation of RMR and DIT as a result of increasing activity is probably mediated by activation of the sympathetic nervous system (Saris 1989; Thompson and Blanton 1987; Weststrate et al. 1989a; Kjœr 1989), although the regulatory mechanism is still largely unknown. Thompson and Blanton (1987) have suggested a model in which physical activity initially stimulates the sympathetic nervous system after which adaptive reductions in sympathetic arousal may occur as a result of intensive training. Subsequently, higher training levels are needed to produce pre-training levels of physiological arousal. This might explain the exercise dependence as usually reported by highly trained athletes and suggests training stimulates physical activity. However, it might also imply reduced physical activity in subjects training moderately and thereby compensation for the added exercise.

In studies investigating the long term effect of exercise on energy metabolism, physical activity has usually been assumed to increase, although mostly no measurements have been conducted to verify this. It might be

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Offprint requests to: G. A. L. Meijer, Research Institute for Livestock Feeding and Nutrition, Department of Physiology and Biochemistry, P.O. Box 160, NL-8200 AD Lelystad, The Netherlands questioned whether the added exercise is compensated for by lower activity levels during the rest of the day. The sometimes disappointing results of adding exercise to a diet in weight-loss programmes (van Dale et al. 1987) might be partially due to such a compensatory mechanism. However, so far only one study has reported on the effect of exercise on physical activity during the rest of the day (van Dale et al. 1989). This has probably been due to the lack of a valid method for measuring physical activity under free living conditions. The accelerometer we have described (Meijer et al. 1989) in combination with the doubly labelled water technique enables changes in this part of ADMR to be monitored. In this study we have examined the effect on the physical activity level and ADMR of a 5-month training programme for endurance-running in 32 untrained non-obese subjects, not interfering with energy intake.

Methods

Subjects. Thirty two subjects (16 men, 16 women) were selected from 370 people who replied to advertisements in two local newspapers and on a local radio station. Those who participated in any sport such as running or jogging or who were active for more than 1 h per week in other recreational sports were excluded. Further criteria were applied to select groups of men and women homogeneous and comparable for age, body mass and Quetelet index (QI) (Quetelet 1971). The subjects' characteristics are presented in Table 1. Ages ranged from 28-41 years and QI from 19.4-26.4 $kg \cdot m^{-2}$. After two information sessions all subjects gave their written informed consent. A medical examination was part of the prestudy procedure.

Training programme. After initial control measurements (0 weeks) a training programme was started which aimed at running a half marathon competition after 10 months. The schedule was essentially the same as previously described by Janssen et al. (1989). Every week training consisted of 1 h supervised by one of the authors (GMEJ) while the subjects had to work in three other training sessions by themselves. The total distance covered was about 15-25 $km \cdot week^{-1}$ after 8 weeks of training and about 25-40 $km \cdot week^{-1}$ after 20 weeks. The training included three elements: long slow distance running (85% of distance covered at an intensity of 70%-80% of maximal heart rate), running at a higher speed (5%-10% of distance covered at an intensity of 80%-95% of maximal heart rate), and interval training (10%-15% of distance covered at an intensity of 95%-100% of maximal heart rate). In addition to this, attention was paid to the style and technique of running, stretching, warming-up and cooling down. To motivate the subjects, they were individually advised on running shoes, for the initial expense of which an allowance was given. In addition, competitions were included at regular intervals. Subjects ran a 10-km- and 15-km race after and 24 weeks, respectively.

Table 1. Subject characteristics (control measurement, week 0)

	Age (year)	Height (m)	Body mass (kg)	Quetelet index ($kg \cdot m^{-2}$)	Body fat[a] (%)
Men (*n*, 16)					
mean	37.1	1.78	72.3	22.7	20.7
SD	3.0	0.05	6.1	1.7	5.0
Women (*n*, 16)					
mean	35.3	1.68	65.9	23.3	30.5
SD	3.9	0.07	7.7	2.0	6.0

[a] % body fat was determined using underwater weighing

Protocol and techniques. Body composition, sleeping metabolic rate (SMR), ADMR, physical activity and exercise performance were measured in all subjects before the start of the training programme, after 8 to 10 weeks just before the 10-km competition, and after 20-24 weeks in anticipation of the 15-km race. The three measurement periods will be referred to as 0, 8, and 20 weeks, respectively. The results of the measurements of body composition and SMR are reported elsewhere (Meijer et al. 1991). Here we will focus on changes in physical activity and ADMR.

Accelerometry. Physical activity was measured for 1 week using an accelerometer (Meijer et al. 1989). The accelerometer consisted of a piezo-electric sensor which determined accelerations resulting from body movement. Data was stored in 16 kbyte random access memory which enabled monitoring during 11 days with a time resolution of 1 min. Afterwards data was read out and further processed on a personal computer. The sensor and the data acquisition unit were worn on a belt, with the sensor at the lower part of the back. Subjects wore the accelerometer for 7 consecutive days while they were awake. Accelerometer output (AO) was calculated as the average of the 7 days. Training times were reported by the subjects and could be easily recognized and checked from recordings (Fig. 1). The AO attributed to running (AO_{run}) was calculated for all recordings. Exercise was also expressed as running time ($min \cdot day^{-1}$) based on the accelerometer readings, representing actual running time which was usually less than the total training time reported. As the subjects trained on 3 or 4 days of the week, the $min \cdot day^{-1}$ value presented here is lower than the running time per training session.

Doubly labelled water. From 8 male and 8 female subjects chosen at random, initial ADMR was measured using the doubly labelled water technique. On day 0 (2230 hours) preceeding the week of accelerometry, the isotope drink was administered after emptying the bladder (background sample). The calculation of the dose was based on body composition to create a ^{2}H excess of 150 ppm and an ^{18}O excess of 300 ppm. Further urine samples were collected on day 1, 8, and 15 at 2000 hours. The ADMR was calculated using the equations of Schoeller et al. (1986). The ADMR was measured again after 8 and 20 weeks in 4 men and 4 women. Because one of these women withdrew from the study after 10 weeks, in the third period (20 weeks) ADMR was measured in another woman from the group of 8 measured originally.

Exercise performance. This was tested in the laboratory by measuring energy expenditure using indirect calorimetry (Ergoscreen, Fenyvus and Gut, Basel, Switzerland) during different activities (sitting, standing and treadmill walking and running at 3, 5, 7 and 10 $km \cdot h^{-1}$. Running at 10 $km \cdot h^{-1}$ was added to the exercise test on the treadmill only during the second and third measurement periods as this was the average speed at which subjects ran during the training sessions.

Results

Physical activity

The AO was significantly higher after 8 weeks (men) and after 20 weeks (men and women) when compared with the control measurement (0 week) (Fig. 2). This increase was almost entirely due to the extra running activity (AO_{run}) resulting from the training schedule. Activities other than exercise ($AO_{n\text{-}ex}$) increased about 15% in men, although this change was not significant

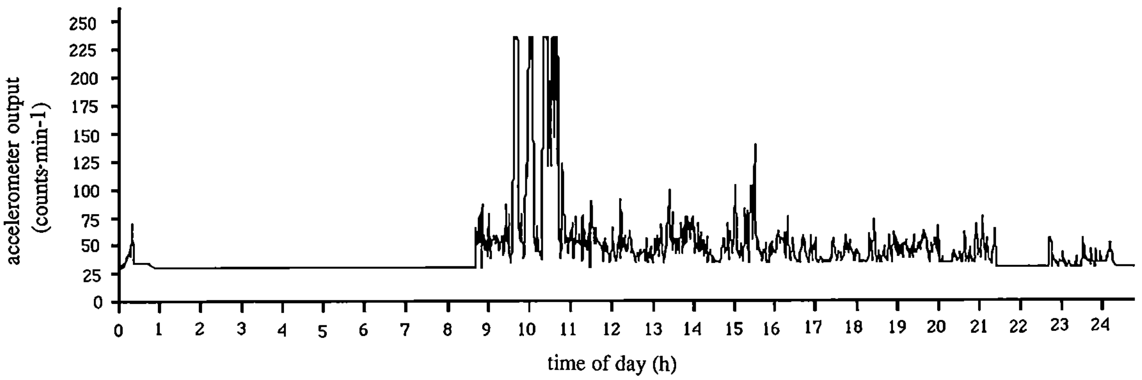

Fig. 1. Accelerometer recording from 1 day showing a training-session from 0930–1045 hours (subject M8, 8 weeks)

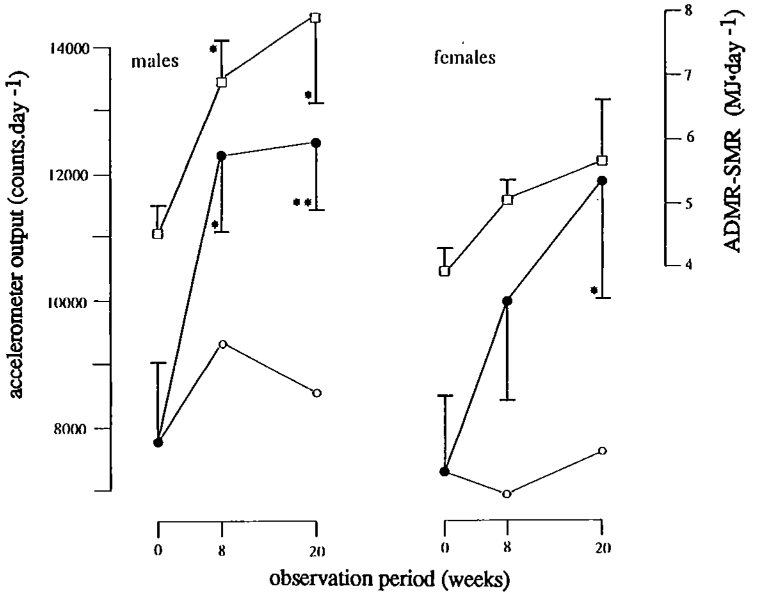

Fig. 2. Average daily metabolic rate minus sleeping metabolic rate (*ADMR – SMR*, □, *axis to the right*), accelerometer output (●, *axis to the left*) as measured over 1-week intervals and accelerometer output during the nonexercise part of the day (○), in males (*left*) and females (*right*) at 0, 8, and 20 weeks after the start of the training programme (*error bars* represent SEM; * $P<0.05$; ** $P<0.01$ compared with values at week 0)

Table 2. Compliance with the training schedule after 8 and 20 weeks as measured by the accelerometer (averages of 7-day recordings)

	8 weeks		20 weeks	
	Running ($\mathrm{min \cdot day^{-1}}$)	AO_{run} ($\mathrm{counts \cdot day^{-1}}$)	Running ($\mathrm{min \cdot day^{-1}}$)	AO_{run} ($\mathrm{counts \cdot day^{-1}}$)
Men (*n*, 14)[a]				
mean	14	2911	20*	4040*
SD	4	761	8	1699
Women (*n*, 12)				
mean	15	3098	21	4302
SD	4	730	12	2434

[a] 2 men and 4 women were not able to comply with the training programme and/or withdrew from the study

* $P<0.05$ compared with week 8 values (Wilcoxon signed-rank test); AO_{run}, accelerometer output attributed to running

(Fig. 2). After 8 weeks the subjects ran on average 105 $\mathrm{min \cdot week^{-1}}$ which was divided into four sessions, and increased to 140 $\mathrm{min \cdot week^{-1}}$ after 20 weeks (Table 2). These figures corresponded with the training schedule at that time and indicate good compliance with it. The resulting AO from running (about 200 $\mathrm{counts \cdot min^{-1}}$) indicates that the subjects ran at an average speed of 10 $\mathrm{km \cdot h^{-1}}$. After 20 weeks 4 subjects (1 man, 3 women) had withdrawn from the programme. One woman (F20) had severe problems with breathing during running and complained about an ache in the lower back. The other two had no major problems, yet they could not keep up with the training schedule nor with the timetable of the different measurements.

Metabolic rate

The ADMR increased during the first 8 weeks of the experimental programme by 2.3 and 1.5 $MJ \cdot day^{-1}$ in men and women, respectively, and showed a further increase in men of 1 $MJ \cdot day^{-1}$ after 20 weeks (Table 3). Changes in ADMR minus SMR were slightly more pronounced (2.5 and 1.2 $MJ \cdot day^{-1}$ after 8 weeks, 3.5 and 1.8 $MJ \cdot day^{-1}$ after 20 weeks in men and women, respectively) (Table 3, Fig. 2). The ADMR was significantly lower in women in all three periods of the study, which was due to their lower body mass. When expressing ADMR normalised for body mass or FFM, this difference disappears. The changes over time in ADMR adjusted for body mass or FFM are in concordance with the changes in ADMR.

Table 3. Average daily metabolic rate (ADMR) and ADMR minus sleeping metabolic rate (SMR) before and 8 and 20 weeks after start of the training programme

Subject no.	ADMR ($MJ \cdot day^{-1}$)			ADMR − SMR ($MJ \cdot day^{-1}$)		
	0 weeks	8 weeks	20 weeks	0 weeks	8 weeks	20 weeks
Men						
1	10.8	12.0	13.4	4.2	5.5	6.7
2	13.8	—[a]	—	6.4	—	—
5	9.2	—	—	2.6	—	—
8	12.8	14.3	18.2	5.7	7.4	11.4
11	11.0	—	—	3.1	—	—
13	12.1	15.5	15.5	5.0	8.3	8.7
14	10.4	—	—	3.8	—	—
16	12.3	13.8	12.3	4.8	6.6	5.1
mean	11.6	13.9°	14.9	4.5	7.0°	8.0°
SD	1.5	1.5	2.6	1.3	1.2	2.7
Women						
19	10.7	10.6	9.1	4.9	4.8	3.8
20	9.1	—	—	2.6	—	—
25	11.1	—	—	4.9	—	—
26	10.6	12.4	14.3	4.5	5.5	7.8
29	9.6	—	—	2.9	—	—
30	10.5	—	11.6	5.2	—	6.8
31	8.1	10.3	10.3	3.2	4.5	4.5
32	10.5	12.7	—[b]	3.4	5.6	—
mean	10.0	11.5	11.3	3.9	5.1	5.7
SD	1.0*	1.2*	2.2*	1.0*	0.5	1.9

[a] Not measured;
[b] subject withdrew from the study;
* $P < 0.05$ compared to men in the same time interval (Mann Whitney);
° $P < 0.05$ compared with control measurement at 0 weeks (Wilcoxon signed rank test)

Energy expenditure measured during different activities showed no significant changes in the men during the three measurement periods (Table 4). In the women energy expenditure was higher after 20 weeks while standing and running at 10 $km \cdot h^{-1}$ ($P < 0.05$). Differences in energy expenditure between men and women during comparable activities are due to differences in body mass, as there were no sex differences when expressing energy expenditure normalised for body mass.

Discussion

We questioned the influence of an endurance-training programme on the level of habitual (non-exercise) activity. Summarizing the results of this study, ADMR minus SMR increased both in the men ($P < 0.05$) and in the women. When calculating the net energy expenditure due to running [$min \cdot day^{-1}$ (Table 2) times $kJ \cdot min^{-1}$ (Table 4)], it appears to be only part of the total increase in ADMR minus SMR (Table 3). This suggests that nonexercise activity had increased by 55% and 28% after 20 weeks in men and women, respectively. However, the accelerometer data did not confirm this finding. Here, in men, an increase of 21% was found during the second period (8 weeks), which decreased to 10% after 20 weeks, while in women $AO_{n\text{-}ex}$ was reduced by 5% after 8 weeks and showed an increase of 4% after 20 weeks (Fig. 2). None of these changes were significant. Yet changes in AO_{run} were strongly correlated (r, 0.78, n, 14, $P < 0.01$) with changes in ADMR minus SMR (Fig. 3), suggesting that both measurements were accurate.

The following potential factors may explain the discrepancy found:

1. Although AO_{run} correlated well with changes in ADMR minus SMR, and the running time recorded corresponded with the training schedule, it might have been that $AO_{n\text{-}ex}$ was underrecorded after 8 and 20 weeks as the subjects did complain about wearing the instrument for a whole week. The total times that the accelerometer was worn were 908, 892 and 875 $min \cdot day^{-1}$ during the three successive periods. The decrease is not significant. This means that of the expected 16 h per day of non-sleep activities on average 15 h were covered by accelerometry. Start and end times of the daily recordings suggest that most time was lost just after waking up and in the late evening. Assuming activities at this time to have been sitting, washing, dressing etc., the metabolic rate may be estimated to have been 1.4 times SMR (WHO 1985). The resulting net value is 0.1 $MJ \cdot day^{-1}$ for men and women (Table 5; $EE_{n\text{-}ex}$ missed).
2. Assuming diet induced thermogenesis to be 10% of ADMR (Sims and Danforth 1987) this energy compartment increased by 0.2 and 0.3 $MJ \cdot day^{-1}$ in men and by 0.1 $MJ \cdot day^{-1}$ in women after 8 and 20 weeks, respectively (Table 5), assuming that ADMR was matched by intake and subjects were in energy balance.

Table 4. Energy expenditure of men and women for six activities, during the three periods of measurement (0, 8, and 20 weeks)

Activity	Sex	0 weeks		8 weeks		20 weeks	
		Energy expenditure (kJ·min^{-1})		Energy expenditure (kJ·min^{-1})		Energy expenditure (kJ·min^{-1})	
		mean	SD	mean	SD	mean	SD
Sitting	M	5.7	1.3	5.6	1.3	5.8	0.7
	F	4.6	0.8	4.9	0.7	5.0	0.4
		**				**	
Standing	M	6.2	1.2	6.3	1.0	6.4	0.9
	F	5.1	1.0	5.3	0.6	5.6°	0.4
		**		**		**	
Walking (3 km·h^{-1})	M	14.6	3.0	12.5	1.7	14.5	1.4
	F	14.0	2.4	11.6	1.5	12.8	0.7
						***	
Walking (5 km·h^{-1})	M	19.6	3.4	17.2	1.7	19.5	1.8
	F	18.4	3.0	16.7	1.8	17.5	1.2
						**	
Walking (7 km·h^{-1})	M	30.5	4.0	26.5	2.6	31.0	2.2
	F	29.1	3.3	25.2	3.1	28.0	3.3
Running[a] (10 km·h^{-1})	M			55.2	5.7	53.6	4.3
	F			46.6	5.0	48.0°	5.5
				***		**	

[a] No control measurements;
* $P<0.05$ compared to men at the same time interval (Mann-Whitney test);
** $P<0.01$ compared to men at the same time interval (Mann-Whitney test);
*** $P<0.001$ compared to men at the same time interval (Mann-Whitney test);
° $P<0.05$ compared to value at week 0 (standing) and at week 8 (running); (Wilcoxon signed-rank test)

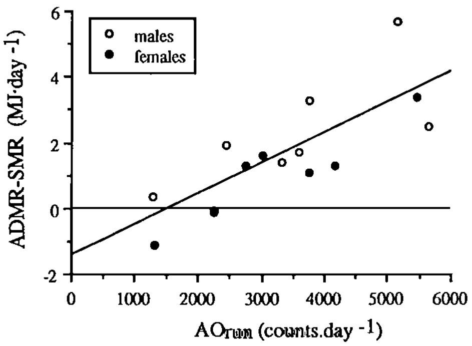

Fig. 3. Change in average daily metabolic rate minus sleeping metabolic rate ($ADMR-SMR$) vs accelerometer output due to running (AO_{run}) exercise in males and females. Data of observations from 8 weeks and 20 weeks after start of the training programme are combined (n, 14; r, 0.61; $P<0.05$)

3. We found no change in SMR measured from 0300–0600 hours in a respiration chamber (Meijer et al. 1991). However, RMR might have been increased when the subjects were awake. The measurements of energy expenditure for different activities (Table 4) showed a significant increase in energy expenditure while standing of 10% in women and a comparable tendency while sitting; in men, however, no such increases were found. Using the value of a 10% increased RMR during the active part of the day resulted in an increase of 0.4 MJ·day^{-1} of ADMR minus SMR in women.

4. Apart from an increase in RMR, we may have overlooked a short-term effect of exercise on SMR as SMR was measured at least 36 h after the last training session. Although evidence for this short-term effect is contradictory (Tremblay et al. 1985), it may be estimated to increase SMR by 10% at most. Calculations based on this assumption resulted in an increase of metabolic rate of 0.4 MJ·day^{-1} both for men and women (Table 5).

5. The AO_{run} was about 200 counts·min^{-1} in all subjects which indicated a running speed of about 10 km·h^{-1}. This speed was also reported by the subjects who generally knew the distance covered as well as their running times. The energy expenditure we measured on the treadmill at 10 km·h^{-1} (54 and 47 kJ·min^{-1} in men and women, respectively) corresponded with values reported by others (Durnin and Passmore 1967; Cotes and Meade 1960). However, these are all values from laboratory (treadmill) studies. Expenditure in the field may be higher, due to hills on the course, or lower because no face mask was carried. Therefore, we think these figures represent a reasonable estimate of the cost of outdoor running. The assumption of an error of 10% in either direction has very little effect on total metabolic rate due to the short time these activities were performed.

The result of these calculations was that the difference [(ADMR – SMR) – $EE_{(run+n\text{-}ex)}$], as found in the women after 8 and 20 weeks, may be explained using one or more of the assumptions made (Table 5). How-

Table 5. Mean changes in the energy compartments ADMR − SMR, energy expenditure due to running (EE_{run}) and non-exercise activities ($EE_{n\text{-}ex}$) as measured by indirect calorimetry and the accelerometer. Assumptions on changes in diet-induced thermogenesis (DIT) and resting metabolic rate (RMR) are added. See discussion

	Difference (between week 0 and week 8 measurement) (MJ·day^{-1})		Difference (between week 0 and week 20 measurement) (MJ·day^{-1})	
	Men	Women	Men	Women
Measured				
ADMR − SMR	+2.5°	+1.2	+3.5°	+1.8
EE_{run}	+0.7	+0.6	+1.0	+0.7
$EE_{n\text{-}ex}$	+0.3	0.0	+0.2	0.0
Discrepancy: (ADMR − SMR) − $EE_{(run+n\text{-}ex)}$	+1.5	+0.6	+2.3	+1.1
Assumptions[a]				
$EE_{n\text{-}ex}$ missed 1 h at 1.4 times SMR (1)	+0.1	+0.1	+0.1	+0.1
DIT (10% of ADMR) (2)	+0.2	+0.1	+0.3	+0.1
10% increase in RMR (3)	—	+0.4	—	+0.4
SMR increase (short-term effect) (4)	+0.4	+0.4	+0.4	+0.4
Remaining discrepancy	+0.8	−0.4	+1.7	+0.1

[a] Numbers in parenthesis refer to the text (Discussion);

° $P < 0.05$ compared to the control measurement at 0 weeks (Wilcoxon signed rank test); $EE_{n\text{-}ex}$ missed, energy value for period of non-exercise activity not otherwise accounted for; for other definitions see Table 3

ever, in the men a discrepancy remained of 0.8 and 1.7 M·day^{-1} after 8 and 20 weeks, respectively.

In a recent study Bingham et al. (1989) have reported an increase of ADMR of 4.0 MJ·day^{-1} in 3 men and 1.0 MJ·day^{-1} in 2 women who were maintained on a constant intake of energy and nutrients while taking part in a 9-week training schedule that was slightly more intensive than ours. They also found no change in SMR. Estimating net energy expenditure from the exercise added in their study revealed a similarly large discrepancy in males as we have found in our present study here. Although we did not interfere with the diet, results from food intake diaries suggested that no quantitative or qualitative changes in diet occurred during the study. Janssen et al. (1989) have reported an increase of 21% in energy intake in men as a response to an endurance-training programme while no increase in intake were found in women. When comparing studies on the effect of exercise added to a slimming diet, it would appear that a positive effect can be found in men (Tremblay et al. 1984), but not in women (van Dale et al. 1987). Saris (1989) has concluded that the difference between the sexes might be due to differences in patterns of fat distribution, the male abdominal fat-cell being more sensitive to the release and storage of triglyceride. The abdominal fat-cell has been shown to have more β-receptors than fat cells in the femoral region (Leibel et al. 1985). Recently, Weststrate et al. (1989b) showed that men had a higher diet induced thermogenesis (DIT) than women after a standard test meal. The obligatory component of DIT was 77% in men and 99% in women, suggesting that no facultative component of DIT exists in women. In another study, Weststrate et al. (1989a) have shown that psychological stress significantly increases DIT in men, indicating the role of the sympathetic nervous system.

To summarize we found no effect of exercise on physical activity during the rest of the day although in men there was a slight increase (15%, NS). The increase in ADMR exceeded the energy expenditure due to exercise by three to four times in men and by two times in women. No sustained effect on SMR was found in either sex. The discrepancies between the increase in ADMR minus SMR in women could be largely explained by a 10% increase in RMR during the active part of the day and by assuming that DIT increases in parallel with metabolic rate. However, these factors were not sufficient to explain the discrepancy found in men. These results fit in with other recent studies on the influence of exercise on energy metabolism and showed that the metabolic response to exercise was much larger in men than in women and exceeded the net cost of the exercise itself. We suggest that in men exercise leads to stimulation of both physical activity and DIT, possibly through activation of the sympathetic nervous system, whereas women do not show such a response.

Acknowledgements. The authors wish to thank Loek Wouters for the analyses of the isotopes, Hans Koper for technical assistance, and Fons Bovens and Sjef Vrencken for the medical examinations.

References

Bingham SA, Goldberg GR, Coward WA, Prentice AM, Cummings JH (1989) The effect of exercise and improved physical fitness on basal metabolic rate. Br J Nutr 61:155–173

Cotes JE, Meade F (1960) The energy expenditure and mechanical energy demand in walking. Ergonomics 36:97–119

Dale D van, Saris WHM, Schoffelen PFM, Hoor F ten (1987) Does exercise give an additional effect in weight reduction regimes? Int J Obes 11:367–375

Dale D van, Schoffelen PFM, Hoor F ten, Saris WHM (1989) Effects of adding exercise to energy restriction on 24-hour energy expenditure, resting metabolic rate and daily physical activity. Eur J Clin Nutr 43:441–451

Durnin JVGA, Passmore R (1967) Energy, work and leisure. Heineman, London

Elliot DL, Goldberg L, Kuehl KS, Bennet WM (1989) Sustained depression of the resting metabolic rate after massive weight loss. Am J Clin Nutr 49:93–96

Garrow JS (1987) Effect of exercise on obesity. Acta Med Scand [Suppl] 711:67–73

Janssen GME, Hoor F ten (1989) Marathon running: functional changes in male and female subjects during training and contests. Int J Sports Med 10 [Suppl 3] S118–S123

Kjœr M (1989) Epinephrine and some other hormonal responses to exercise in man: with special reference to physical training. Int J Sports Med 10:2–15

Leibel RL, Hirsch J, Berry EM, Gruen RK (1985) Alterations in adipocyte free fatty acid reesterification associated with obesity and weight reduction in man. Am J Clin Nutr 42:198–206

Meijer GA, Westerterp KR, Koper H, Hoor F ten (1989) Assessment of energy expenditure by recording heart rate and body acceleration. Med Sci Sports Exerc 21:343–347

Meijer GAL, Westerterp KR, Seyts GHP, Janssen GME, Saris WHM, Hoor F ten (1991) Body composition and sleeping metabolic rate in response to a 5-month endurance training programme in adults. 62:18–21

Molé PA, Stern JS, Schulz CL, Bernauer EM, Holcomb BJ (1989) Exercise reverses depressed metabolic rate produced by severe caloric restriction. Med Sci Sports Exerc 21:29–33

Paffenbarger RS, Hyde RT (1985) Exercise in the primary prevention of ischemic heart disease. In: Welsh RP, Shephard RJ (eds) Current therapy in sports medicine. BC Decker Inc, Toronto, Philadelphia, pp 76–80

Pavlou KN, Stefee WP, Lerman RH, Burrows BA (1985) Effects of dieting and exercise on lean body mass, oxygen uptake, and strength. Med Sci Sports Exerc 17:466–471

Quetelet LAJ. Antropométrie on mesure des différentes facultes de l'homme. Brussels. Muquardt

Ravussin E, Burnand B, Schutz Y, Jéquier E (1985) Energy expenditure before and during energy restriction in obese patients. Am J Clin Nutr 41:753–759

Reiff GG, Montoye HJ, Remington RD, Napier JA, Metzner HL, Epstein FH (1967) Assessment of physical activity by questionnaire and interview. J Sports Med Phys Fitness 7:135–142

Saris WHM (1989) Physiological aspects of exercise in weight cycling. Am J Clin Nutr 49:1099–1104

Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jéquier E (1986) Energy expenditure by doubly labeled water: validation in humans and proposed calculation. Am J Physiol 250:R823–R830

Sims EAH, Danforth E (1987) Expenditure and storage of energy in man. J Clin Invest 79:1019–1025

Thompson KJ, Blanton P (1987) Energy conservation and exercise dependence: a sympathetic arousal hypothesis. Med Sci Sports Exerc 19:91–99

Tremblay A, Després J-P, Leblanc C, Bouchard C (1984) Sex dimorphism in fat loss in response to exercise training. J Obes Weight Reg 3:193–203

Tremblay A, Després J-P, Bouchard C (1985) The effects of exercise-training on energy balance and adipose tissue morphology and metabolism. Sports Med 2:223–233

Weigle DS, Sande KJ, Iverius PH, Monsen ER, Brunzell JD (1988) Weight loss leads to a marked decrease in non-resting energy expenditure in ambulatory human subjects. Metabolism 37:930–936

Weststrate JA, Kooy K van der, Deurenberg P, Hautvast JGAJ (1989a) Surprisingly large impact of psychological stress on diet-induced thermogenesis but not on resting metabolic rate. Thesis, Wageningen, The Netherlands, pp 131–139

Weststrate JA, Deurenberg P, Hautvast JGAJ (1989b) Nature and magnitude of inter-individual differences in resting metabolic rate and diet-induced thermogenesis in lean and obese individuals. Thesis, Wageningen, The Netherlands, pp 140–159

World Health Organization (1985) Energy and protein requirements. Report of a joint FAO/WHO/UNO expert consultation. WHO, Geneva. Technical Report series no. 724, pp 71–79