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Long-term effect of physical activity on energy balance and body composition

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We studied the effect of an increase in physical activity on energy balance and body composition without interfering with energy intake (EI). Sixteen women and sixteen men, aged 28–41 years, body mass index 19·4–26·4 kg/m^2, not participating in any sport before the start of the experiment, prepared to run a half-marathon competition after 44 weeks. Measurements of body composition, EI and energy expenditure (EE) were performed before (0 weeks), and 8, 20, and 40 weeks after the start of training. Body composition was measured with hydrodensitometry and isotope dilution, and EI with a 7 d dietary record. EE was measured overnight in a respiration chamber (sleeping metabolic rate (SMR)) and in a number of subjects over 2-week intervals with doubly-labelled water (average daily metabolic rate (ADMR)). ADMR showed an average increase of 30% in both sexes from the start of training onwards while SMR tended to decrease. EI showed a tendency to drop from week 20 to week 40 in the men and a tendency to increase from week 20 to week 40 in the women. Body mass (BM) did not change in both sexes until the observation at 40 weeks when the median value of the change in men was −1·0 kg ($P < 0·01$; Wilcoxon signed-rank) while the corresponding change of −0·9 kg in the women was not statistically significant. Body composition changes were most pronounced in men as well. Based on changes in BM, body volume and total body water, men lost 3·8 kg fat mass (FM) ($P < 0·001$; Wilcoxon signed-rank) and gained 1·6 kg protein mass ($P < 0·01$; Wilcoxon signed-rank) while the corresponding changes in women were 2·0 kg ($P < 0·05$; Wilcoxon signed-rank) and 1·2 kg ($P < 0·05$; Wilcoxon signed-rank). In men the loss of FM was positively correlated with the initial percentage body fat (Pearson r 0·92, $P <$ 0·001). In conclusion, body fat can be reduced by physical activity although women tend to compensate for the increased EE with an increased EI, resulting in a smaller effect on BM and FM compared with men.

Physical activity: Energy balance: Body composition

In the Western world many people struggle with overweight due to excessive fat storage. It is obvious that this form of overweight is a consequence of a discrepancy in the energy balance but it is not known whether a raised food intake or a lowered metabolic rate is responsible. A small but persistent bias in the energy balance can have a large effect and the techniques for measurement of both energy intake (EI) and energy expenditure (EE) may not be sufficiently precise to detect this.

Animal studies have shown that exercise causes an increase in EE without a proportional increase in EI (Mayer *et al.* 1954; Crews *et al.* 1969). On the contrary, a decrease in EI may occur (Mayer *et al.* 1954). Thus, body mass (BM), specifically fat mass (FM), decreases when animals are exercised, despite an increase in fat-free mass (FFM). More recent studies have suggested that there is a sex difference. Female rats showed a better preservation of BM (Oscai *et al.* 1971; Nance *et al.* 1977; Applegate *et al.* 1982) through an increase in food intake, but a fall in intake has been observed in exercised male rats.

Similar observations have been made in man. Tremblay *et al.* (1984) found a significant loss of FM in men but not women in response to a 20-week exercise programme consisting of bicycle endurance training. Woo *et al.* (1982*a*, *b*, 1985) exercised lean and obese women in a metabolic ward over 3-week intervals. Lean women remained in energy balance but obese women did not increase their food intake and lost weight. We have studied the effect of an increase in physical activity on energy balance and body composition under normal daily living conditions without controlling EI. Subjects were sedentary men and women ranging from normal to slight overweight.

SUBJECTS AND METHODS

Subjects were recruited through the local media. Of 370 respondents, sixteen women and sixteen men were selected who did not participate in any sport like running or jogging and who were not active in any other sport for more than 1 h/week. Further criteria were applied to create a comparable group for both sexes with regard to age (28–41 years) and body mass index (BMI; 19·4–26·4 kg/m^2). Subjects were medically examined and gave written informed consent before participation.

The objective of the training programme was to run a half-marathon competition after 44 weeks, although subjects ran 10 km and 15 km races after 10 and 24 weeks respectively. The training was supervised by one of the authors (E.M.E.J.) and consisted of four sessions per week, increasing running time to 10–30 min, 20–60 min and 30–90 min per training session after 8, 20 and 40 weeks respectively, as described elsewhere (Janssen & ten Hoor, 1989; Meijer *et al.* 1991).

Overall design. EI was measured by means of a 7 d dietary record. EE was measured at rest overnight in a respiration chamber and over 2-week intervals using doubly-labelled water. Body composition was measured using hydrodensitometry and isotope dilution. Measurements were performed at four time-points: before the start of training and 8, 20 and 40 weeks afterwards. Measurements were synchronized with the training programme so that the subjects were still in their normal training regimen and not engaged in final preparation for the competition. The protocol was identical for each of the studies. Subjects entered the respiration chamber at 18.30 hours after their last meal of the day at home. In the chamber no food was consumed but coffee and tea were allowed until 22.00 hours. A baseline urine sample was then collected and subjects drank their dose of doubly-labelled water just before bedtime at 22.30 hours. Sleeping metabolic rate (SMR) was measured from 03.00 to 06.00 hours, at the minimal activity level judged from doppler radar observation. Upon rising between 07.00 and 08.00 hours BM was measured, after emptying of the bladder and without clothes. Subsequently, underwater weight was measured, subjects were instructed in keeping a dietary record and a urine sample was collected from the second voiding. They resumed their normal daily routines between 08.30 and 09.30 hours.

EI. This was calculated from the 7 d dietary record using the Dutch nutrient table (Hautvast, 1975). Subjects recorded their food intake in the diary in household measures, including brand names and cooking recipes where appropriate. A measuring beaker was provided to determine the content of cups and bowls used. Where possible, items were weighed as well. After filling in the diary, a trained nutritionist examined it to clarify and eliminate inconsistencies with the subject.

SMR. This was measured in a 14 m^3 respiration chamber as described previously (Schoffelen *et al.* 1984). Briefly, fresh air was sucked through the chamber at a rate of about 50 l/min. Ventilation rate was measured using a dry-gas meter, oxygen and carbon dioxide in ingoing and outgoing air with a paramagnetic analyser (OA 184; Servomex) and an infrared analyser (URAS 3G; Hartman & Braun) respectively. Data were stored and

Table 1. *Subject characteristics in sequence of ascending percentage body fat as determined with hydrostatic weighing in male and female subjects*

	Age (years)	Height (m)	Body mass (kg)	Percentage body fat			Subject no.
Men							
	33	1·73	63·2	15·1			1
	34	1·88	75·6	15·1	*		5
	40	1·76	69·7	18·1	**		6
	39	1·75	59·4	19·4	*		7
	32	1·86	79·6	19·9			2
	40	1·79	66·3	20·2			3
	35	1·80	72·0	21·8	*		8
	40	1·80	75·7	24·1		†	—
	33	1·79	69·4	24·7	**		9
	39	1·85	74·2	25·4	**		10
	39	1·80	79·5	26·4		†	—
	40	1·73	77·0	26·5	**		11
	36	1·78	77·3	26·8		†	—
	37	1·69	70·3	26·8	*		12
	35	1·80	79·3	30·5		†	—
	41	1·73	68·0	31·5			4
Women							
	35	1·72	63·3	24·8			13
	32	1·63	54·0	25·5			14
	41	1·65	64·4	27·0	*		19
	32	1·57	52·6	27·7	**		20
	36	1·76	66·8	28·1			15
	35	1·67	60·1	29·6			16
	32	1·81	70·4	30·6	*		21
	38	1·73	68·5	32·6	**		22
	38	1·65	61·0	33·2			17
	41	1·68	65·8	35·0	**		23
	40	1·79	83·3	35·6		†	—
	32	1·58	61·1	36·0			18
	28	1·68	68·8	37·0		†	—
	35	1·67	73·7	38·4	**	†	—
	31	1·64	65·6	43·3	*	†	—
	39	1·68	74·6	45·4	*	†	—

*, **, Subjects participating in energy expenditure measurements with doubly-labelled water in weeks 0 and 8, and in weeks 0, 8, 20 and 40 respectively.
† Subjects withdrawn from the study.

processed on-line, using corrections for initial and final concentrations, and converted to EE using the Weir (1949) formula. The system was checked monthly with ethanol combustion. Differences (mean and SD) between calculated and measured O_2 consumption and CO_2 production were 0·5 (SD 1·2) and −2·5 (SD 1·6) % respectively.

Average daily metabolic rate (*ADMR*). This was measured with doubly-labelled water. Subjects were given a weighed dose of a mixture of 99·84 atoms % $^{2}H_2O$ in 10·05 atoms % $H_2{}^{18}O$ so that baseline levels (ppm) were increased with 150 (SD 10) for ^{2}H and 300 (SD 20) for ^{18}O. Urine samples for isotope measurement were collected before dosing at night, from the second voiding on the next morning, and after 7 and after 14 d. Isotope abundances in the urine samples were measured with an isotope-ratio mass spectrometer (Aqua Sira; VG Isogas) and CO_2 production was calculated as previously described (Westerterp *et al.* 1991). All samples were measured in duplicate. Differences between duplicates were always

Table 2. *Energy intake and sleeping metabolic rate before (0), and 8, 20, and 40 weeks after the start of training in male and female subjects*

	Energy intake (MJ/d)				Sleeping metabolic rate (MJ/d)			
Week ... Subject no.	0	8	20	40	0	8	20	40
Men								
1	12·7	12·6	11·5	12·2	6·9	7·2	7·0	7·2
2	9·8	10·2	10·0	10·0	7·4	7·5	7·7	7·0
3	11·6	11·6	11·4	9·4	6·1	6·1	6·3	6·0
4	9·8	9·0	9·3	9·2	6·5	6·7	6·5	5·8
5	13·0	11·9	11·6	10·3	7·8	7·3	8·2	6·9
6	12·3	10·1	11·2	8·7	6·7	7·2	7·2	6·3
7	8·9	9·7	9·5	9·6	6·5	6·4	6·2	5·8
8	16·9	15·0	12·9	14·6	7·2	7·7	7·9	7·3
9	10·9	11·9	10·5	12·7	6·5	6·5	6·7	6·2
10	11·9	12·1	12·5	12·9	7·1	6·9	6·8	7·1
11	13·8	11·9	13·4	13·6	7·2	7·2	6·8	7·0
12	10·1	8·3	8·5	7·5	6·6	6·3	6·3	6·2
Median	11·8	11·8	11·3	10·2	6·8	7·0	6·8	6·6*
Range	8·0	6·7	4·9	7·1	1·7	1·6	2·0	1·5
Women								
13	9·9	10·0	8·7	10·0	6·2	5·8	5·7	5·9
14	9·5	6·5	9·1	7·5	6·0	6·6	6·0	5·6
15	9·1	9·4	9·5	9·7	6·3	6·7	6·2	5·8
16	9·0	9·2	9·3	9·5	5·7	6·3	6·0	5·9
17	6·0	7·5	6·5	9·0	6·0	6·4	6·1	6·0
18	9·1	8·4	8·0	8·0	6·1	6·0	6·8	5·7
19	8·6	9·0	8·6	13·2	6·2	5·8	5·5	5·5
20	6·3	7·4	8·1	6·9	5·0	5·8	5·8	5·4
21	10·3	10·1	12·0	11·6	6·6	6·2	6·0	6·1
22	9·3	10·6	9·8	11·4	6·1	6·9	6·5	6·5
23	7·0	5·6	7·6	7·5	5·8	5·8	5·3	5·3
Median	9·1	9·0	8·7	9·5	6·1	6·2	6·0	5·8
Range	4·3	5·0	5·5	6·3	1·6	1·1	1·5	1·2

Median value was significantly different from pretraining value (Wilcoxon signed-rank): * $P < 0{\cdot}05$.

smaller than 1 ppm. CO_2 production was converted to ADMR using an energy equivalent of 531 kJ/mol and a respiratory quotient (RQ) value of 0·85 based on the average food quotient (FQ) calculated from the macronutrient composition of the diet as measured with the dietary records, and assuming FQ = RQ.

Body composition. This was calculated from BM, body volume and total body water. BM was measured using a digital balance (240C; Mettler). Volume was measured by means of underwater weighing using the same balance type and simultaneous measurement of lung volume (He-dilution; Mijnhardt Volugraph). Total body water was calculated from isotope dilution according to the formula:

$$\frac{({}^{2}\text{H dilution space}/1{\cdot}04) + ({}^{18}\text{O dilution space}/1{\cdot}01)}{2}$$

(Schoeller *et al.* 1980).

FM and FFM were calculated from weight and volume using the Siri (1956) equation,

Table 3. *Energy expenditure and physical activity index (energy expenditure/sleeping metabolic rate) before (0), and 8, 20, and 40 weeks after the start of the training period in male and female subjects*

	Energy expenditure (MJ/d)				Physical activity index			
Week ... Subject no.	0	8	20	40	0	8	20	40
Men								
5	11·8	—	—	15·0	1·5	—	—	2·2
7	12·3	—	—	14·8	1·9	—	—	2·6
8	15·6	—	—	16·8	2·2	—	—	2·3
12	10·4	—	—	14·2	1·6	—	—	2·3
Median	12·1			14·9*	1·7			2·3*
Range	5·2			2·6	0·6			0·4
6	10·9	13·7	12·6	13·4	1·6	1·9	1·8	2·1
9	10·5	13·3	13·3	13·5	1·6	2·1	2·0	2·2
10	13·2	16·4	15·8	14·3	1·8	2·4	2·3	2·0
11	11·3	13·5	16·0	14·6	1·6	1·9	2·3	2·1
Median	11·1	13·6*	14·6*	13·9*	1·6	2·0*	2·2*	2·1*
Range	2·7	3·1	3·4	1·2	0·3	0·5	0·6	0·2
Median (5–12)	11·6			14·5**	1·6			2·2**
Range	5·2			3·4	0·6			0·6
Women								
19	9·9	—	—	11·7	1·6	—	—	2·1
21	10·0	—	—	11·7	1·5	—	—	1·9
Median	10·0			11·7	1·6			2·0
Range	0·1			0·0	0·1			0·2
20	7·9	11·4	10·4	10·2	1·6	2·0	1·8	1·9
22	10·1	13·5	12·2	12·9	1·7	2·0	1·9	2·0
23	9·7	11·1	9·9	10·2	1·7	1·9	1·9	1·9
Median	9·7	11·4	10·4	10·2	1·7	2·0	1·9	1·9
Range	2·2	2·4	2·3	2·7	0·1	0·1	0·1	0·1
Median (19 23)	9·9			11·7*	1·6			1·9*
Range	2·2			2·7	0·2			0·3

Median value was significantly different from pretraining value (Wilcoxon signed-rank): * $P < 0·05$, ** $P < 0·01$.

and from weight and total body water assuming a hydration coefficient of the FFM of 0·73 (Pace & Rothburn, 1945). Changes in FM and protein mass (PM) within subjects from one study to another were calculated using the equations from Murgatroyd & Coward (1989).

EI, SMR and body composition were determined by hydrostatic weighing in all subjects in all four studies. For measurement of ADMR with doubly-labelled water and consequently body composition using isotope dilution, eight women and eight men were selected randomly and a subgroup of four women and four men in study 2 and 3 also (Table 1).

RESULTS

During the study nine subjects withdrew being unable to keep up with the training programme. They all dropped out within 20 weeks of the start of the training. Two women and one man said they did not have enough time to join the training, three men and two women gave up due to injuries and finally one woman had to slow down the training,

Table 4. *Body mass, fat mass, and fat-free mass before (0) and 8, 20, and 40 weeks after the start of the training period in male and female subjects*

	Body mass (kg)				Fat mass (kg)				Fat-free mass (kg)			
Week ... Subject no.	0	8	20	40	0	8	20	40	0	8	20	40
Men												
1	63·2	65·0	64·5	63·0	9·5	10·7	10·8	7·9	53·7	54·3	53·7	55·1
2	79·6	80·6	80·6	79·0	15·9	15·1	14·9	13·2	63·7	65·5	65·7	65·8
3	66·3	67·7	66·6	64·6	13·4	13·2	11·2	8·4	52·9	54·5	55·4	56·2
4	68·0	66·8	67·0	65·7	21·4	17·3	14·8	13·1	46·6	49·5	52·5	52·6
5	75·6	76·6	77·3	75·5	11·4	12·3	11·0	10·1	64·2	64·3	66·3	65·4
6	69·7	71·3	70·4	67·4	12·6	13·6	12·7	9·0	57·1	57·7	57·7	58·4
7	59·4	59·1	59·7	59·4	11·5	11·1	11·1	8·2	47·9	48·0	48·6	51·2
8	72·0	73·7	72·0	72·2	15·7	14·0	10·5	12·3	56·3	59·7	61·5	59·9
9	69·4	69·3	68·3	65·1	17·1	19·4	14·5	10·8	52·3	49·9	53·8	54·3
10	74·2	73·4	71·9	73·9	18·8	15·0	15·3	12·8	55·4	58·4	56·6	61·1
11	77·0	77·5	74·2	74·9	20·4	17·4	11·6	13·3	56·6	60·1	62·6	61·6
12	70·3	70·3	67·9	68·9	18·8	18·5	16·4	14·0	51·5	51·8	51·5	54·9
Median	70·0	70·8	69·4	68·2**	15·8	14·5	12·2**	11·6**	54·5	56·1**	56·0**	57·3**
Range	20·2	21·5	20·9	19·6	11·9	8·7	5·9	6·1	17·6	17·5	17·7	14·6
Women												
13	63·3	66·4	63·4	61·3	15·7	15·2	15·0	10·8	47·6	51·2	48·4	50·5
14	54·0	56·3	55·1	54·4	13·8	15·0	15·0	12·5	40·2	41·3	40·1	41·9
15	66·8	67·5	66·5	65·9	18·8	18·5	17·6	17·3	48·0	49·0	48·9	48·6
16	60·1	62·4	61·5	60·7	17·8	18·0	17·2	14·7	42·3	44·4	44·3	46·0
17	61·0	59·3	60·3	60·6	20·2	18·1	18·1	17·5	40·8	41·2	42·2	43·1
18	61·1	60·3	58·4	56·5	22·0	21·5	21·3	16·4	39·1	38·8	37·1	40·1
19	64·4	63·5	63·3	62·7	17·4	16·3	14·6	13·8	47·0	47·2	48·7	48·9
20	52·6	54·6	54·7	55·0	14·6	14·8	14·0	14·9	38·0	39·8	40·7	40·1
21	70·4	70·8	71·4	69·2	21·5	20·8	20·5	19·6	48·9	50·0	50·9	49·6
22	68·5	68·9	69·4	70·3	22·4	20·9	22·4	20·1	46·1	48·0	47·0	50·2
23	65·8	65·6	63·0	63·4	23·0	22·3	21·0	19·0	42·8	43·3	42·0	44·4
Median	63·3	63·5	63·0	61·3	18·8	18·1*	17·6*	16·4**	42·8	44·4**	44·3*	46·0**
Range	17·8	16·2	16·7	15·9	9·2	7·5	8·4	9·4	10·9	12·4	13·9	10·5

Median value was significantly different from pretraining value (Wilcoxon signed-rank): * $P < 0·05$, ** $P < 0·01$.

finishing with the 15 km contest. Thus, eleven women and twelve men eventually completed the half-marathon competition after 44 weeks preparation from a completely untrained state. The subjects who withdrew all had an initial percentage body fat above the group mean for their sex (Table 1). We present only the results from the remaining twenty-three subjects to allow comparisons in time over all four studies.

EI did not show significant changes (Table 2), although there was a tendency to an increase in the women after the third study onwards. In the men, EI remained unchanged until a fall in the fourth study period. No changes in the nutrient composition of the diet were detected.

SMR showed a significant decrease in the men from a median value of 6·8 (range 1·7) MJ/d in study 1 to 6·6 (1·5) MJ/d in study 4 ($P < 0·05$; Wilcoxon signed-rank). Median SMR values for men in studies 2 and 3, and for women at all stages after the start of the training period, were no different from the initial median values (Table 2).

ADMR increased between studies 1 and 2, remaining elevated until study 4 (Table 3) while the training intensity increased. Judging from the physical activity index (PAI =

Table 5. *Changes in body composition from before until 40 weeks after the start of the training period in male and female subjects*

Subject no.	Fat mass* (kg)	Fat-free mass* (kg)	Fat mass† (kg)	Body water† (kg)	Protein mass† (kg)
Men					
5	−1·3	+1·2	−0·6	−0·2	+0·8
6	−3·6	+1·3	−3·8	+1·2	+0·4
7	−3·3	+3·3	−1·9	+0·1	+1·8
8	−3·4	+3·6	−3·4	+2·2	+1·4
9	−6·3	+2·0	−5·2	−0·3	+1·2
10	−6·1	+5·8	−5·7	+3·0	+2·4
11	−7·1	+5·0	−6·1	+1·8	+2·2
12	−4·8	+3·4	−3·7	+0·5	+1·8
Median	−4·2	+3·4	−3·8	+0·9	+1·6
Range	5·8	4·6	5·5	3·3	2·0
Women					
19	−3·6	+1·9	−2·3	−0·6	+1·2
20	+0·3	+2·1	+0·0	+1·7	+0·7
21	−1·9	+0·7	−2·0	+0·6	+0·2
22	−2·2	+4·0	−1·8	+1·9	+1·7
23	−4·0	+1·6	−2·5	−0·8	+1·3
Median	−2·2	+1·9	−2·0	+0·6	+1·2
Range	4·3	3·3	2·5	2·7	1·5

* Calculated from body mass and body volume.
† Calculated from body mass, body volume and total body water.

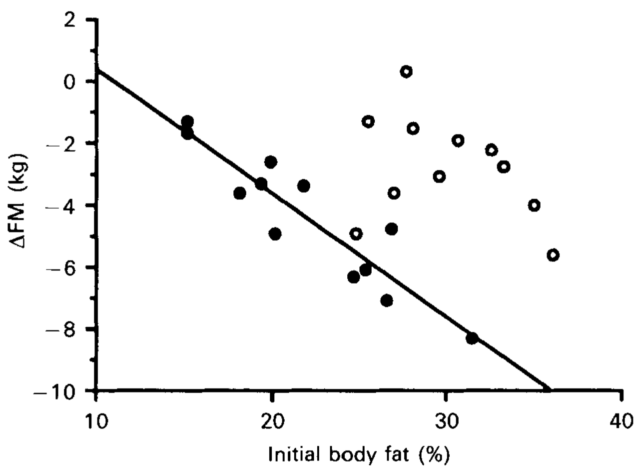

Fig. 1. Fat-mass change (ΔFM) from before until 40 weeks after the start of the training period *v*. the initial body fat percentage in male (●) and female (○) subjects with the calculated linear regression line for men ($P < 0·001$).

ADMR/SMR), the subjects started at a low level of physical activity. The initial median values were 1·6 (0·6) and 1·6 (0·2) in men and women respectively, but these increased to between 1·9 and 2·4 in study 2 (Table 3). In men PAI tended to increase more with training than in women.

BM changed little (Table 4). In women the median value of BM change from study 1 to study 4 of −0·9 (7·0) kg was not significant. In men the change in BM of −1·0 (4·5) kg over the corresponding interval reached significance ($P < 0·01$; Wilcoxon signed-rank).

Changes in body composition were more pronounced. Hydrodensitometry alone indicated an almost linear decrease in FM and a corresponding increase in FFM in both sexes (Table 4). Median values of differences were −2·8 (5·9) kg FM in women and −4·2 (7·0) kg FM in men between study 1 and study 4, 40 weeks later. The difference in FFM over the corresponding interval was +1·9 (3·5) kg in women and +3·2 (4·8) kg in men. Based on changes of BM, body volume and total body water, in women the median value of the change in FM was −2·0 (2·5) kg ($P < 0{\cdot}05$; Wilcoxon signed-rank) and for PM +1·2 (1·5) kg ($P < 0{\cdot}05$; Wilcoxon signed-rank; Table 5). The corresponding changes in men were −3·8 (5·5) kg FM ($P < 0{\cdot}001$; Wilcoxon signed-rank) and +1·6 (2·0) kg PM ($P < 0{\cdot}01$; Wilcoxon signed-rank).

In men the change in FM was significantly correlated with the initial percentage body fat of the subject ($n = 12$, Pearson r 0·92, $P < 0{\cdot}001$). That is, subjects with a higher initial percentage body fat lost more fat than those who were leaner at the start. This was not so in women (Fig. 1).

DISCUSSION

The dropout rate was fairly high in the present study. Nine of thirty-two (28%) of the subjects withdrew, mainly because of injuries or inability to maintain the timetable of the training schedule. The preponderance of these subjects in the higher FM range is in agreement with earlier observations (Gwinup, 1975). Although manifestly obese subjects were excluded by the selection criteria, most subjects with a BMI over 24 could not cope with the programme in practice.

We chose the average FQ of 0·85 to calculate the energy equivalent of CO_2 because changes in the nutrient composition of the diet were not detected. Although subjects were not in nutrient balance over the 40-week observation period, losing FM and gaining PM, the correction for increased fat combustion and decreased protein combustion is negligible. For example, a loss of 4 kg fat over 40 weeks is equivalent to 0·5 MJ/d which would change the energy equivalent of CO_2 in a subject expending 12 MJ/d by less than 1%.

The selection of sedentary subjects based on an inventory of leisure activities seemed to be justified. The initial median PAI value of 1·6 in men and women was between the values of 1·5 and 1·8 for light and moderate activity respectively (World Health Organization, 1985). However, PAI would have been overestimated in our subjects because it is normally based on ADMR/basal metabolic rate (BMR) while we were using ADMR/SMR, and SMR is supposed to be on average 5% lower than BMR (Goldberg *et al.* 1988). The training programme raised PAI to levels between moderate activity (1·8) and high activity (2·1).

EI did not show a significant change in response to the training programme, although EE increased. Thus, the men's energy balance was negative in study 2 ($P < 0{\cdot}05$; Wilcoxon signed-rank), 3 ($P < 0{\cdot}05$; Wilcoxon signed-rank) and 4 ($P < 0{\cdot}01$; Wilcoxon signed-rank). In the women, differences between EI and EE did not reach significance at any stage of the training programme.

Despite the increase in FFM, SMR remained remarkably stable throughout the training period, although there was a significant decrease between the initial and final value in men. This contrasts with previous observations of Westerterp *et al.* (1991) and of Tremblay *et al.* (1988) in endurance athletes.

Changes in BM were not great. Men showed a significant loss of 1·0 kg ($P < 0{\cdot}01$; Wilcoxon signed-rank) over the 40-week period. Changes in body composition on the other hand were very pronounced. Hydrodensitometry indicated that men lost significantly more FM and gained more FFM than women ($P < 0{\cdot}05$; Wilcoxon signed-rank). However, these estimates were higher than those calculated from density and total body water together.

Using this approach, the median value (range) of the change in FM was −3·5 (5·5) and −2·0 (2·5) in men and women respectively. The respective changes in FFM, calculated as the sum of the change in PM and total body water, were +2·1 (4·8) and +0·8 (3·0).

The observed effect of the increase in physical activity on energy balance and body composition corresponds with earlier observations (Tremblay *et al.* 1984). Women tend to preserve their energy balance more strongly than men, and loss of FM is significantly less. Whether the sex difference is attributable to decreased intake in men or an increased intake in women cannot be stated although the latter appears more likely. The exercise was not within the capability of the subjects with a higher FM and the changes we observed in BM and FM support the earlier view (Segal & Pi-Sunyer, 1989) that exercise is not the therapy of first choice to reduce weight. Women especially do not lose much FM, even when a high exercise level can be maintained.

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