Eur J Appl Physiol (1996) 74: 375–383

ORIGINAL ARTICLE

Mona Esbjörnsson Liljedahl · Ingemar Holm
Christer Sylvén · Eva Jansson

Different responses of skeletal muscle following sprint training in men and women

Accepted: 26 February 1996

Abstract Six male and ten female physically active students performed 30-s sprint training on a cycle ergometer three times a week for 4 weeks, to investigate the training responses of skeletal muscle and to evaluate possible sex differences in this respect. Three repeated sprint tests with a 20-min rest in between were performed and muscle biopsies from the vastus lateralis muscle were taken before and after the training period. Mean power (average of sprint I–III) and type IIB cross-sectional fibre area increased only in the women (7% and 25% respectively) following sprint training, resulting in a decreased sex difference. There was an increase in total lactate dehydrogenase (LD) activity following sprint training in both sexes, although the levels were lower in the women both before and after training. Glycogen content increased and the activity of LD iso-enzyme 1 decreased in the women, but not in men. It was hypothesised that both the smaller areas of type II fibres and lower activity of LD generally seen in women may be due in part to less frequent activation of type II fibres in women than in men. If this were the case, the women should respond to sprint training (a type of training that activates type II fibres) to a relatively greater extent than men. That the observed increase in type IIB fibre area in response to sprint training was greater in the women than in men supported the hypothesis of the study. However, the results for LD activity, which showed a similar response in the men and the women, did not support the hypothesis.

Key words Human · Sex · Physical exercise · Lactate dehydrogenase · Anaerobic metabolism

M. Esbjörnsson Liljedahl (✉) · E. Jansson
Karolinska Institute, Department of Medical Laboratory Sciences and Technology, Division of Clinical Physiology, Huddinge University Hospital, s-141 86 Huddinge, Sweden

C. Sylvén
Department of Medicine, Huddinge University Hospital, Huddinge, Sweden

I. Holm
Lillsveds Folkhögskola, Värmdö, Sweden

Introduction

Sprint training has been shown to induce an increase in the activities of glycolytic enzymes in the leg musculature (Costill et al. 1979; Roberts et al. 1982; Sharp et al. 1986; Jacobs et al. 1987; Cadefau et al. 1990; Linossier et al. 1993). Those studies were mainly performed on male subjects. Earlier studies on muscle characteristics have demonstrated that women have lower activities of muscle glycolytic enzymes, especially lactate dehydrogenase (LD), and also smaller cross-sectional fibre areas, especially for type II fibres, than men (Komi and Karlsson 1978; Nygaard 1981; Green et al. 1984; Simoneau et al. 1985; Ryushi et al. 1988; Glenmark et al. 1992). Such sex differences have also been found in data on physical education students, where the female and male subjects had very similar levels of physical activity (Esbjörnsson et al. 1993). It is still possible, however, that the lower *anaerobic potential* in the skeletal musculature of those women has been due not to an inherent sex difference, but to less frequent participation in high intensity activities, which recruit type II as well as type I fibres.

The aim of the present study was, therefore, to investigate the response of skeletal muscle to sprint training and to evaluate possible sex differences. It was hypothesised that the smaller areas of type II fibres and lower activities of LD in women than in men may in part be due to less frequent activation of type II fibres. If this were the case, it was considered women should respond to sprint training (a type of training that activates type II fibres) to a relatively greater extent than men.

Methods

Subjects

A group of 11 male and 15 female students at a College for Sports and Recreation Instructors volunteered to participate in the study. The subjects were divided into a training group (6 men and 10 women) and a control group (5 men and 5 women). None of the subjects were at an elite or competition level, but they did participate in leisure-time sports such as various ballgames and running (no sprint running) for the men, and mainly callisthenics, aerobics and running (no sprint running) for the women. During the day time all the subjects participated in the same classes: theoretical and physical education. Mean age, body mass and height for the training group were 26 (range 23–30) years, 76 (range 64–94) kg, and 180 (168–186) cm for the men and 25 (range 21–29) years, 60 (range 47–70) kg, and 165 (range 158–172) cm for the women. Mean age body mass and height for the control group were 24 (range 23–26) years, 76 (range 67–83) kg, and 177 (range 173–181) cm for the men and 24 (range 22–27) years, 62 (range 58–66) kg, and 171 (range 167–171) cm for the women, respectively. The subjects were fully informed about the procedures and the risks. The study was approved by the Ethics Committee of the Karolinska Institute.

Physical activity questionnaire

A physical activity questionnaire was used to estimate the level of physical activity of the subjects during their leisure time. The subjects answered nine different questions from which an activity index (minimal value 5.5 and maximal value 20.5) was calculated (for details see Jansson and Hedberg 1991). Mean activity index for the training group was 14.4 (range 8.5–18.5) for the men and 14.8 (range 12.5–16.5) for the women. Corresponding figures in the control group were 17.2 (range 14.0–20.0) for the men and 13.9 (range 11.5–17.0) for the women.

Performance test

A 30-s cycle sprint with maximal voluntary pedalling rate (Wingate test, Bar-Or et al. 1980) was repeated three times (sprints I–III) on a mechanically braked cycle ergometer (Cardionics, Bredäng, Sweden) with a 20-min rest between the sprints. A familiarisation session took place at least 24 h before the actual test. Each subject performed the sprint test before and after a 4-week training period. The post training test was performed 2 days after the last training session. A sensor-microprocessor assembly counted flywheel revolutions. The braking force (individually set at $0.75\ N \cdot kg^{-1}$ body mass), the flywheel progression per pedal revolution (6 m), and the elapsed time, were used to calculate the average power output, which was printed automatically each 5 s for the duration of the 30-s test. The following performance variables were calculated for each of three tests: peak power (i.e. the highest 5-s power output), and mean power (the average power during the 30-s duration).

Training

Each training session consisted of three cycle sprints with maximal voluntary pedalling rate and an individual braking force set at $0.75\ N \cdot kg^{-1}$ body mass on a mechanically braked cycle ergometer (Cardionics, Bredäng, Sweden) with 20-min rest between each sprint. The subjects performed three training sessions each week for 4 weeks.

The training intensity

The training intensity, expressed as the actual mean power output during training related to the average of the mean power output before and after training, was for the men 99(SD 3)%, 102(SD 3)%, 100(SD 2)%, and 100(SD 2)%, and for the women 98(SD 3)%, 101(SD 4)%, 102(SD 5)%, and 103(SD 2)%, for weeks 1, 2, 3 and 4 respectively. There was no significant difference between the sexes in relative training intensity.

Muscle biopsies and analyses

The needle biopsy technique that has been described by Bergström (1962) was used to obtain muscle biopsy samples from the quadriceps femoris vastus lateralis muscle, 1 or 2 days before the start of training. The pretraining sprint test was done 1 or 2 days before the biopsies, and the post-training biopsies were performed 1 or 2 days after the post-training sprint test. In the control group, muscle biopsies were performed at corresponding times. Two biopsy samples were taken on each occasion. All biopsies were obtained from the same leg in each subject. One portion of the first biopsy was weighed and homogenised in a $0.1\ mol \cdot l^{-1}$ phosphate buffer, pH 7.7, and used for the analysis of citrate synthase (CS; Lin et al. 1988), phosphofructokinase (PFK; Lowry et al. 1978), 3-hydroxyacyl CoA dehydrogenase (HAD; Essén et al. 1975) and for total activity of LD (The Committee on Enzymes of the Scandinavian Society for Clinical Chemistry and Clinical Physiology 1974) and its iso-enzymes (LD1–LD5; Rosalki 1974; Lin et al. 1989). In addition, the absolute and the relative amount of the two LD subunits, H and M, were calculated. Creatine and creatine phosphate were analysed, after addition of perchloric acid (PCA) to an aliquot of the homogenate, by an enzymatic fluorometric technique (Lowry and Passonneau 1972). Another portion of the first biopsy was used for analysis of glycogen by fluorometric enzymatic analysis after acid hydrolysis (Lowry and Passonneau 1972).

The second biopsy was mounted in an embedding medium, frozen in isopentane precooled with liquid nitrogen and analysed histochemically for the fibre types (I, IIA, IIB and IIC) with a myofibrillar adenosine triphosphatase (ATPase) stain (Schantz et al. 1982) and examined morphologically for cross-sectional fibre area by planimetry from a nicotinamide adenine dinucleotide, reduced (NADH)-dehydrogenase stain (Novikoff et al. 1961) as described by Jansson and Hedberg (1991). Fibre types were expressed as the relative number of the different fibre types (type I%, type IIA%, type IIB% and type IIC%), and as the relative area of the different fibre types (fibre type area; Jansson and Hedberg 1991).

Statistics

Two or three factor (repeated measurements) analysis of variance was applied to verify differences in training response between the sexes. The factors were sprint (sprints I–III; only performance data), training (before and after sprint training) and sex. If an interaction term between sex and training at the level of $P < 0.1$ was found, the data were separated into women and men. General effects of sex, sprint or training were accepted as statistically significant at the level of $P < 0.05$. Student's t-test for paired observations or groups was applied, where the P-values were corrected according to Holm (1979) and the level of statistical significance was accepted at $P < 0.05$. Control and training groups were analysed separately, due to the low number of controls. Sex difference was calculated as men − women/women × 100.

Results

In the control group no differences were found between men and women for any of the variables studied with regard to changes over the 4-week sprint training period. Therefore, men and women were considered as one group in further statistical analyses. There were no changes in performance or in the muscle biopsy characteristics studied, except that the LD3% and subunit H of LD, increased by 25% and 14%, respectively. Some training from cross-country skiing during schooltime may explain these changes. The cross-country skiing occurred in both the control and the sprint training group. If anything, the changes found in the sprint training group might have been somewhat underestimated, as the skiing could have counteracted the sprint training effects.

Power output in the training group

Power output during the first 30-s sprint test and absolute values for calculated peak and mean power in the men and women before and after training are presented in Fig. 1 and Table 1, respectively.

The relative changes following sprint training in peak and mean power in the men and women are presented in Fig. 2. The peak power in sprint I increased by 6% ($P < 0.01$) in the women, whereas in the men it did not change significantly following sprint training. In sprints II and III there were no significant changes in peak power in either the men or women. The mean power increased in sprint I, II and III by 10% ($P < 0.01$), 6% ($P < 0.05$) and 4% ($P < 0.05$) in the women, the increase being significantly higher in sprint I than in II and III. There were no significant changes in mean power in the men.

The sex difference in respect of relative change in peak power was at the level of $P < 0.06$ in sprint I and for mean power it was significant at the level of $P < 0.05$ in both sprint I and II. The sex difference in mean power (average of sprints I–III) decreased with sprint training from 47% to 38%, ($P < 0.03$ for the interaction term sex × training independent of sprints I–III; Table 1).

Cross-sectional fibre areas in training group

Figure 2 and Table 2 show that the type II cross-sectional fibre area increased by 17% following sprint training in the women ($P < 0.05$). The training response was more marked in type IIB than in type IIA fibres. There was no change in the area of any of the fibre types following sprint training in the male subjects. Thus, the sex difference in type IIB fibre area decreased with sprint training from 39% to 11% ($P < 0.05$ for the interaction term sex × training; Table 2).

Fibre types in training group

Table 2 shows that there were no statistically significant changes in relative fibre type composition following sprint training in either the men or women, although the proportion of type II fibres tended to increase in the men ($P < 0.1$).

Table 1 Peak and mean power in absolute values in six men and ten women during three sprint tests repeated before and after sprint training

Sprint		Peak power (W)			Mean power (W)		
		I	II	III	I	II	III
Men							
Before	Mean	933	933	913	660	681	668
	SD	101	86	89	83	74	71
		NS	NS	NS	NS	NS	NS
After	Mean	946	915	898	669	678	674
	SD	95	87	102	63	63	79
Women							
Before	Mean	646	667	668	445	467	461
	SD	93	105	98	51	48	50
		b			b	a	a
After	Mean	682	676	649	490	489	481
	SD	76	82	72	64	64	56
ANOVA (interactions) ($P <$)							
Training × sex				NS			0.03
Sprint × sex				NS			NS
Training × sprint				0.001			0.1
Sex × training × sprint				NS			NS

a, *b* between values (effect of sprint training) indicates $P < 0.05$ and $P < 0.01$, respectively
NS not significant

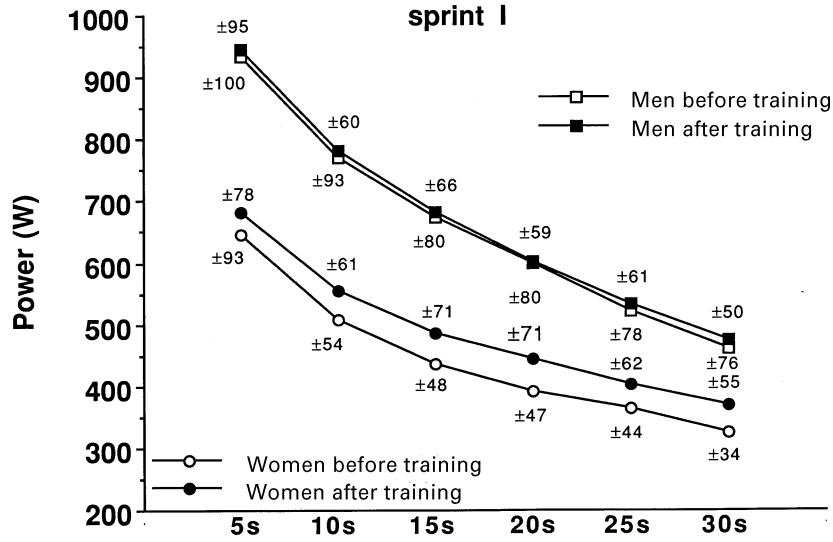

Fig. 1 Power output in absolute values (± *indicates SD*) every 5th s during the first 30-s cycle sprint before and after sprint training in six men and ten women

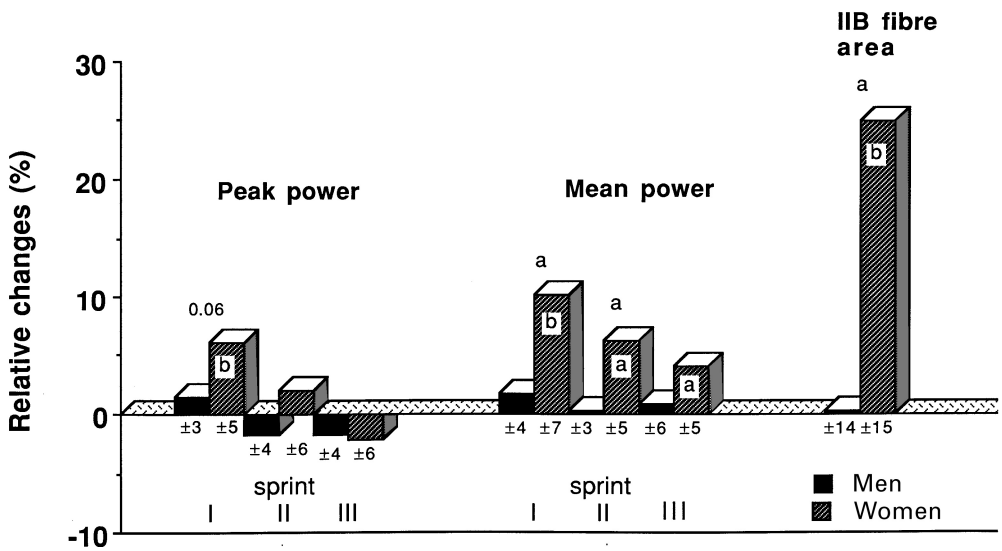

Fig. 2 Relative changes (± *indicates SD*) in peak power in sprints I–III, mean power in sprints I–III and IIB fibre area following sprint training in six men and ten women. *a*, *b within bars* indicate relative change within sex. *a and 0.06 between bars* indicate difference between sex. *a* $P < 0.05$, *b* $P < 0.01$ and *0.06* $= P \leq 0.06$

Enzymes in training group

Table 3 shows that training increased the activity of total LD by 16%, independent of sex ($P < 0.01$). The men had 40% higher activity of total LD than the women, independent of training status ($P < 0.05$). The activities of LD5 and the M subunit followed the same pattern as total LD with regard to training response. The LD1 activity decreased by 66% in the women following sprint training ($P < 0.05$), whereas in the men there was no change ($P < 0.001$ for the interaction term sex × training).

There were no significant changes in the activities of PFK, CS or HAD following training, either for the men or the women. There was no sex difference in activity of PFK, CS or HAD either before or after sprint training.

Substrates in training group

Table 3 shows that muscle glycogen content increased in the women ($P < 0.01$) but not in the men following sprint training ($P < 0.05$ for the interaction term sex × training), resulting in a 31% higher glycogen content in the women than in the men following the training ($P < 0.05$). Total creatine content (the sum of creatine phosphate and creatine), did not differ between the sexes before sprint training. Following

Table 2 Histochemical and morphological muscle characteristics before and after sprint training in six male and ten female subjects

		Fibre type (%)					Fiber type area (%)			Fibre area (μm^2)				
		I	IIA	IIB	IIC	IIA + IIB	I	IIA	IIB	I	IIA	IIB	Mean area	Mean area type II
Men														
Before	Mean	52	34	8	6	42	53	39	8	4570	5025	3950[b]	4675[b]	4843[b]
	SD	14	9	7	6	11	13	10	7	515	615	102	467	543
												NS	NS	NS
After	Mean	47	35	14	4	49	47	41	12	4441	5084	3932[NS]	4610[a]	4794[a]
	SD	12	4	7	2	11	12	7	7	715	672	530	558	506
Δ%	Mean											0[a]	0[0.06]	0[0.06]
	SD											14	19	16
Women														
Before	Mean	51	31	16	2	47	54	33	13	3648	3657	2838	3547	3400
	SD	13	9	11	3	14	15	11	9	505	716	541	502	638
												b	a	a
After	Mean	51	31	17	1	48	51	33	16	3926	4076	3548	3938	3937
	SD	9	6	8	2	9	11	7	8	470	700	772	425	702
Δ%	Mean											25	12	17
	SD											15	11	18
ANOVA ($P <$)														
Sex		NS	NS	NS	NS	NS	NS	NS	NS	0.01	0.01	–	–	–
Training		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	–	–	–
Interaction:														
Sex × training		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.05	0.1	0.1

NS not significant
[a, b, 0.06] Indicate differences at $P < 0.05$, $P < 0.01$ and $P \leqslant 0.06$ between men and women. a, b, 0.06 between values indicate $P < 0.05$, $P < 0.01$ and $P \leq 0.06$ between before and after training. Main effects are not indicated in the case of $P < 0.1$ for the interaction term. Δ% relative changes following sprint training: (after-before) × before^{-1} × 100, only changes with $P \leq 0.06$ are indicated; Equation for mean area: (type I% × mean fibre area of type I + type IIA% × mean fibre area of type IIA + type IIB% × mean fibre area of type IIB) × (100 − type IIC%)$^{-1}$

sprint training total creatine content was 15% higher in the men ($P < 0.05$) than in the women, ($P < 0.05$ for the interaction term sex × training).

Discussion

The major findings in the present study were that 4 weeks of sprint training decreased the sex differences in mean power output, type II fibre cross-sectional area, and LD1 activity, and increased it for glycogen content (women higher after training) and total creatine content (men higher after training). The sex differences in total LD activity did not change following training.

Our hypothesis was that the women should show a greater response to sprint training than the men with regard to cross-sectional type II muscle fibre areas and muscle LD activity, since the lower pretraining values in the women for these variables could have been due in part to less frequent daily high intensity muscle activation. The results of the present study supported this hypothesis as far as type II muscle fibre areas are concerned; however, the sex differences in total LD activity did not decrease. Thus, there was no support for the hypothesis that the lower pretraining value of total LD activity in the women than in the men was related to less frequent high intensity muscle activation in the women.

Performance

There are divergent results in the literature with regard to changes in power output following different types of sprint training or short-term high intensity training. Jacobs et al. (1987) and Allemeier et al. (1994) have found that there was no increase of power output after 6 weeks of sprint training. On the other hand Linossier et al. (1993) and Stathis et al. (1994) have found an increase of power output after 8 and 7 weeks of sprint training, respectively.

In the present study increased power output in the women could in part have been due to increased fibre area – especially of type II fibres – increased glycogenolytic rate (suggested by an increase in total LD activity), and increased glycogen storage. In the men there was no significant change in power output in response to sprint training. The lack of hypertrophy of the muscle fibres in the men could have been one possible explanation for the absence of an increase in performance. However, the increased activity of total

Table 3 Metabolic muscle characteristics before and after sprint training in six male and ten female subjects. *NS* not significant, *Glyc* glycogen, *TCP* total creatine content (creatine + creatine phosphate) in mmol · kg^{-1} dry muscle, *PFK* phosphofructokinase, *HAD* 3-hydroxyacyl CoA dehydrogenase, *CS* citrate synthase, *TLD* total lactate dehydrogenase, *LD1-LD5* iso-enzymes 1–5 of LD and H and M subunits of LD in μkat · g^{-1}. Composition of LD iso-enzymes: LD1 = 4H subunits, LD2 = 3H and 1M subunits, LD3 = 2H and 2M subunits, LD4 = 1H and 3M subunits, LD5 = 4 M subunits

		Glyc	TCP	PFK	HAD	CS	TLD	LD1	LD2	LD3	LD4	LD5	H	M	LD1%	LD2%	LD3%	LD4%	LD5%	H%	M%
Men																					
Before	Mean	411^{NS}	126^{NS}	1.4	0.46	0.66	42	0.8^{NS}	2.5	6.4	7.7	24.4	7.8	34.0	2.5^{NS}	7.4	16.6	17.6	55.9	20.6	79.4
	SD	37	16	0.2	0.1	0.1	15	1.2	1.6	2.6	4.0	12.2	3.3	14.8	2.7	5.9	6.9	3.8	13.8	9.5	9.5
		NS	NS					NS							NS						
After	Mean	454^{a}	138^{a}	1.6	0.45	0.68	49	1.2^{NS}	2.4	6.4	9.0	29.9	8.3	40.4	2.7^{NS}	6.3	14.1	18.3	58.6	19.1	80.9
	SD	56	11	0.2	0.1	0.1	18	1.2	1.9	2.8	4.0	15.9	3.9	18.2	3.1	6.4	6.7	3.8	17.5	11.2	11.2
Δ%	Mean	12$^{0.06}$	11^{a}					30^{a}							1^{a}						
	SD	23	17					100							65						
Women																					
Before	Mean	442	128	1.3	0.48	0.62	30	1.5	2.8	4.7	5.2	16.3	7.2	23.2	5.1	10.3	16.4	17.3	51.0	25.3	74.7
	SD	109	16	0.3	0.1	0.1	8	1.0	1.3	1.4	1.8	7.7	1.4	8.1	3.8	5.9	6.1	4.6	11.9	8.1	8.1
		b	NS					a							b						
After	Mean	597	120	1.4	0.47	0.68	35	0.9	2.4	5.2	6.3	19.7	6.8	27.8	3.0	7.8	15.6	16.4	55.5	21.0	79.0
	SD	128	12	0.3	0.1	0.1	9	0.7	1.3	1.1	2.6	7.7	1.4	9.4	2.9	5.0	3.7	6.1	9.1	7.0	7.1
Δ%	Mean	39	− 6					− 48							− 50						
	SD	28	8					28							23						
ANOVA ($P <$)																					
Sex		–	–	NS	NS	NS	0.05	–	NS	NS	NS	NS	NS	NS	–	NS	NS	NS	NS	NS	NS
Training		–	–	NS	NS	NS	0.01	–	NS	NS	0.01	0.05	NS	0.01	–	0.05	NS	NS	NS	0.05	0.05
Interaction:																					
Sex × training		0.05	0.05	NS	NS	NS	NS	0.001	NS	NS	NS	NS	NS	NS	0.001	NS	NS	NS	NS	NS	NS

[a, b] Indicates $P < 0.05$ and $P < 0.01$ between men and women. *a*, *b*, between values indicates $P < 0.05$ and $P < 0.01$ between before and after training. Δ% Relative changes following sprint training: (after − before) × before^{-1} × 100, only changes with $P \leq 0.06$ are indicated.
μkat = μ mol · s^{-1}

LD (or LD5) should have favoured such an increase. A discrepancy between changes in enzymes involved in anaerobic energy production and increase in performance has also been shown by Costill et al. (1979), who have found that performance was increased after sprint training, but who did not find any change in total LD activity. The complexity of the relationship between changes in performance after sprint training and changes in biochemical and morphological variables has been further demonstrated by Linossier et al. (1993), who have found an increased anaerobic performance after sprint training together with increased type I% and decreased cross-sectional fibre areas. Thus, other factors, e.g. neuronal mechanisms such as fibre recruitment, synchronisation, and co-ordination may have been of importance.

Fibre types

The increase in the proportion of type II fibres in the men was not statistically significant in the present study ($P < 0.1$). However, when the present material was pooled with earlier material from subjects with a similar training protocol, the increase in the proportion of type II fibres became significant (see Jansson et al. 1990). The musculature of the women in the present study did not change in fibre type composition with sprint training. No significant interaction term between sex and training could be demonstrated in the present study, however. Therefore, no safe conclusion could be drawn as to whether or not there is a sex difference in the way fibre type composition is affected by sprint training.

Fibre areas

In general, women have been found to have a lower type II/type I area ratio than men (Simoneau et al. 1985; Glenmark et al. 1992). In the present sprint training study, there was an increase of type II fibre area, especially of type IIB fibres, in the women but not in the men. It has been reported that during sprint cycling, type II fibres are activated to a great extent (Bodin et al. 1994; Esbjörnsson et al. 1994), and this could therefore have been a stimulus for the increased area of type II fibres. To our knowledge, there have been no other sprint training studies in adult women with which to compare these results. There are a few studies, however, on high resistance training in women which have demonstrated increases in fibre areas, especially of type II fibres (Staron et al. 1991).

In our study no increase in type II fibre area was found in the male subjects. One explanation could be that the men were more used to this kind of exercise and therefore that the 4 weeks of training did not give rise to a stimulus strong enough to cause additional hypertrophy. Another possible explanation could be that some factors acting against hypertrophy, for instance, glucocorticoids or catecholamines, were more enhanced during sprint training in the men as has been suggested by Gambert et al. (1981) and Gratas–Delamarche et al. (1994) and thereby induced a greater catabolic response. Some earlier sprint training studies in men have also failed to show any increase of fibre areas (Thorstensson et al. 1975; Jacobs et al. 1987; Linossier et al. 1993).

Enzymes

The activities of enzymes representing glycogenolytic or anaerobic metabolism, such as LD or PFK, have been shown to increase in earlier sprint training studies (Costill et al. 1979; Roberts et al. 1982; Sharp et al. 1986; Jacobs et al. 1987; Linossier et al. 1993). This was also the case in the present study, the effect being independent of sex. Thus, as mentioned earlier, the sex difference in total LD activity did not decrease following sprint training and it is possible that the sex difference in LD may be an inherant one, i.e. one secondary to differences in physical activity. Enzymes involved in oxidative metabolism have been shown in some earlier studies to increase to a lesser, albeit significant extent, following sprint training (Costill et al. 1979; Jacobs et al. 1987).

The LD iso-enzymes showed a sex difference with regard to the response of LD1: the activity did not change in the men, whereas it decreased in the women, resulting in similar LD1 levels after the training period in both sexes. It is not known whether this has any significance for sprint performance. In an earlier study it has been, shown that sprint performance was inversely related to the activity of LD2 (Esbjörnsson et al. 1993), an iso-enzyme with similarities to LD1 with regard to subunit composition: LD2 contains three H and one M subunit and LD1 contains four H subunits. Thus, it could be speculated that a high LD1 activity also has a negative effect on sprint performance, and that the decrease in LD1 activity in the women favoured their sprint performance.

Substrates

Glycogen content was increased following sprint training in the women but not in the men. A possible reason for this may be that the women were using their glycogen at a lower rate than the men during the 30-s cycle sprints, as has been suggested by the work of Esbjörnsson et al. (1994). It is also possible that the rate of resynthesis of glycogen was higher in the women during the 20-min rest periods between sprints. The lower concentrations of catecholamines in women during recovery may have favoured resynthesis of glycogen

(unpublished data). Another possibility is that the women were consuming a diet richer in carbohydrates than the men. It has been shown that during a 3-month training period, women, but not men, compensated for increased energy expenditure by increasing energy intake (Andersson et al. 1991).

The training-induced alteration in total creatine content (different in men and women) resulted in a higher total creatine content in the men than in the women after training. As has been found previously, this change would have favoured improved performance in the men (Balsom et al. 1993), but no relationship was found between changes in the total creatine content and changes in performance in the present study. It is possible that other factors counteracted the effects of changed total creatine content on performance.

Objections to the hypothesis

There are several possible explanations for the lack of a decrease in the difference between total LD activity in the men and women. Firstly, the acute metabolic response to a 30-s sprint and thereby the training stimulus may differ between men and women. We have shown that the decrease in glycogen content after a single 30-s sprint was greater in men than women (Esbjörnsson et al. 1994). At the same time, blood lactate and plasma catecholamine concentrations have been found to be higher in the men (unpublished data). Thus, there might have been a sex difference in some metabolic stimuli for enzyme synthesis, a difference related to glycogenolytic rate, lactate or catecholamines. This may have favoured the synthesis of LD in the men, even though their pretraining level was higher than that of the women. A second possibility is that the training response in women is different from that in men, even though the acute metabolic response is similar.

Methodological considerations

One special problem with the Wingate test is the necessity for giving each subject a braking force that ensures that the individual optimal power output is attained. Of special importance in this kind of study is to have similar loading conditions for both sexes. It has been shown that by giving both women and men $0.75\ N \cdot kg^{-1}$ body mass, the power output is, on average, within 95% of the optimal power output (Dotan and Bar-Or 1983).

Our previous study has demonstrated, that the decrease in adenosine triphospate (by 22% in type I and by 50% in type II) and in creatine phosphate content (by 67% in type I and by 75% in type II fibres) during a 30-s cycle sprint (braking force $0.75\ N \cdot kg^{-1}$ body mass) was not different in men and women (Bodin et al. 1994). These data indicate that there is an extreme and similar metabolic stress during a 30-s cycle sprint in both sexes. This suggests that the loading conditions were similar for women and men during the sprint training in the present study.

Conclusion

The greater sprint training response in the type IIB fibre area in the women than in the men supported the hypothesis of the study. It is suggested that the smaller area of type II fibres generally found in muscle of women may in part be due to less frequent activation of their type II fibres, especially type IIB. It could be expected that less well-trained subjects (the women) would show a greater training response than subjects closer to their upper limit of performance (the men).

The results for LD, which showed a similar response in the men and women, did not support the hypothesis. Thus the lower local anaerobic potential (as estimated by enzyme activities), which is generally found in women, may be more tightly coupled to the female sex and the typical responses of women during sprint exercise, such as the lower peak lactate concentrations and lower concentrations of catecholamines which have been described by Jacobs et al. (1983) and Gratas–Delamarche et al. (1994).

Acknowledgements This study was supported by grants from the Swedish Centre for Research in Sports and the Swedish Medical Research Council (no. 4494).

References

Allemeier CA, Fry AC, Johnson P, Hikida RS, Hagerman FC, Staron RS (1994) Effects of sprint cycle training on human skeletal muscle. J Appl Physiol 77:2385–2390

Andersson B, Xu X, Rebuffé-Scrive M, Terning K, Krotkiewski M, Björntorp P (1991) The effects of exercise training on body composition and metabolism in men and women. Int J Obes 15:75–81

Balsom PD, Ekblom B, Söderlund K, Sjödin B, Hultman E (1993) Creatine supplementation and dynamic high-intensity intermittent exercise. Scand J Med Sci Sports 3:143–149

Bar-Or O, Dotan R, Inbar O, Rothstein A, Karlsson J, Tesch PA (1980) Anaerobic capacity and muscle fibre type distribution in man. Int J Sports Med 1:82–85

Bergström J (1962) Muscle electrolytes in man. Scand J Clin Lab Invest 14 [Suppl 68]:1–110

Bodin K, Esbjörnsson M, Jansson E (1994) Alactic ATP turnover rate during a 30-s cycle sprint in females and males Clin Sci [Suppl] 87:205

Cadefau J, Casademont J, Grau JM, Fernandéz J, Balaguer A, Vernet M, Cussó R, Urbano-Marquez A (1990) Biochemical and histochemical adaptation to sprint training in young athletes. Acta Physiol Scand 140:341–351

Costill DL, Coyle EF, Fink WF, Lesmes GR, Witzman FA (1979) Adaptation in skeletal muscle following strength training. J Appl Physiol 46:96–99

Dotan R, Bar-Or O (1983) Load optimization for the Wingate anaerobic test. Eur J Appl Physiol 51:409–417
Esbjörnsson M, Sylvén C, Holm I, Jansson E (1993) Fast twitch fibres may predict anaerobic performance in both females and males. Int J Sports Med 14:257–263
Esbjörnsson M, Bodin K, Jansson E (1994) Females have lower glycogenolytic rate in type I muscle fibres than males during a 30-s Wingate test. Clin Sci [Suppl] 87:116
Essén B, Jansson E, Henriksson J, Taylor AW, Saltin B (1975) Metabolic characteristics of fibre types in human skeletal muscle. Acta Physiol Scand 95:153–165
Gambert SR, Garthwaite TL, Pontzer CH, Cook EE, Tristani FE, Duthie EH, Martinson DR, Hagen TC, McCarty DJ (1981) Running elevates plasma beta-endorphin immunoreactivity and ACTH in untrained human subjects. Proc Soc Exp Biol Med 168:1–4
Glenmark B, Hedberg G, Jansson E (1992) Change in muscle fibre type from adolescence to adulthood in women and men. Acta Physiol Scand 146:251–259
Gratas-Delamarche A, Le Cam R, Delamarche P, Monnier M, Koubi H (1994) Lactate and catecholamine responses in male and female sprinters during a Wingate test. Eur J Appl Physiol 68:362–366
Green HJ, Fraser IG, Ranney DA (1984) Male and female differences in enzyme activities of energy metabolism in vastus lateralis muscle. J Neurol Sci 65:323–331
Holm SA (1979) A simple sequentially rejective multiple test procedure. Scand J Stat 6:63–70
Jacobs I, Tesch PA, Bar-Or O, Karlsson J, Dotan R (1983) Lactate in human muscle after 10 and 30 s of supramaximal exercise. J Appl Physiol 55:365–367
Jacobs I, Esbjörnsson M, Sylvén C, Holm I, Jansson E (1987) Sprint training effects on muscle myoglobin, enzymes, fibre types and blood lactate. Med Sci Sports Exerc 19:368–374
Jansson E, Hedberg G (1991) Skeletal muscle fibre types in teenagers: relation to physical performance and physical activity. Scand J Med Sci Sports 1:31–44
Jansson E, Esbjörnsson M, Holm I, Jacobs I (1990) Increase in the proportion of fast-twitch muscle fibres by sprint training in males. Acta Physiol Scand 140:359–363
Komi PV, Karlsson J (1978) Skeletal muscle fibre types, enzyme activities and physical performance in young males and females. Acta Physiol Scand 103:210–218
Lin L, Sotonyi P, Somogyi E, Karlsson J, Folkers K, Nara Y, Sylvén C, Kaijser L, Jansson E (1988) Coenzyme Q10 content in different parts of the normal heart. Clin Physiol 8:391–398
Lin L, Sylvén C, Sotonyi P, Somogyi E, Kaijser L, Jansson E (1989) Lactate dehydrogenase and its isoenzyme activities in different parts of the normal human heart. Cardiovasc Res 23:601–606
Linossier M-T, Denis C, Dormois D, Geyssant A, Lacour JR (1993) Ergometric and metabolic adaptation to a 5-s sprint training programme. Eur J Appl Physiol 67:408–414
Lowry C, Kimmey J, Fleder S, Chi M, Kaiser K, Passonneau P, Kirk K, Lowry O (1978) Enzyme patterns in single human muscle fibres. J Biol Chem 253:8269–8277
Lowry OH, Passonneau JV (1972) A flexible system of enzymatic analysis. Academic Press, New York
Novikoff AB, Shin W, Drucker J (1961) Mitochondrial localization of enzymes: staining results with two tetrazolium salts. J Biophys Biochem Cytol 9:47–61
Nygaard E (1981) Skeletal muscle fibre characteristics in young women. Acta Physiol Scand 112:299–304
Roberts AD, Billeter R, Howald H (1982) Anaerobic muscle enzyme changes after interval training. Int J Sports Med 3:18–21
Rosalki SB (1974) Standardisation of isoenzyme assays with special reference to lactate dehydrogenase isoenzyme electrophoresis. Clin Biochem 7:29–40
Ryushi T, Häkkinen K, Kauhanen H, Komi P (1988) Muscle fibre characteristics, muscle cross-sectional area and force production in strength athletes, physically active males and females. Scand J Sports Sci 10:7–15
Schantz P, Henriksson J, Jansson E (1982) Training-induced increase in myofibrillar ATPase intermediate fibers in human skeletal muscle. Muscle Nerve 5:628–636
Sharp RL, Costill DL, Fink WJ, King DS (1986) Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. Int J Sports Med 7:13–17
Simoneau J-A, Lortie G, Boulay MR, Thibault M-C, Thériault G, Bouchard C (1985) Skeletal muscle histochemical and biochemical characteristics in sedentary male and female subjects. Can J Physiol Pharmacol 63:30–35
Staron RS, Leonardi MJ, Karapondo DL, Malicky ES, Falkel JE, Hagerman FC, Hikida RS (1991) Strength and skeletal muscle adaptation in heavy-resistance-trained women after detraining and retraining. J Appl Physiol 70:631–640
Stathis CGA, Febraio MA, Carey MF, Snow RJ (1994) Influence of sprint training on human skeletal muscle purine nucleotide metabolism. J Appl Physiol 76:1802–1809
The Committee on Enzymes of Scandinavian Society for Clinical Chemistry and Clinical Physiology (1974) Recommended methods for the determination of four enzymes in blood. Scand J Clin Lab Invest 33:291–306
Thorstensson A, Sjödin B, Karlsson J (1975) Enzyme activities and muscle strength after sprint training in man. Acta Physiol Scand 94:313–318