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Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women

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Abstract The purpose of this study was to investigate the time course of skeletal muscle adaptations resulting from high-intensity, upper and lower body dynamic resistance training (WT). A group of 17 men and 20 women were recruited for WT, and 6 men and 7 women served as a control group. The WT group performed six dynamic resistance exercises to fatigue using 8–12 repetition maximum (RM). The subjects trained 3 days a week for 12 weeks. One-RM knee extension (KE) and chest press (CP) exercises were measured at baseline and at weeks 2, 4, 6, 8, and 12 for the WT group. Muscle thickness (MTH) was measured by ultrasound at eight anatomical sites. One-RM CP and KE strength had increased significantly at week 4 for the female WT group. For the men in the WT group, 1 RM had increased significantly at week 2 for KE and at week 6 for CP. The mean relative increases in KE and CP strength were 19% and 19% for the men and 19% and 27% for the women, respectively, after 12 weeks of WT. Resistance training elicited a significant increase in MTH of the chest and triceps muscles at week 6 in both sexes. There were non-significant trends for increases in quadriceps MTH for the WT groups. The relative increases in upper and lower body MTH were 12%–21% and 7%–9% in the men and 10%–31% and 7%–8% in the women respectively, after 12 weeks of WT. These results would suggest that increases in MTH in the upper body are greater and occur earlier compared to the lower extremity, during the first 12 weeks of a total body WT programme. The time-course and proportions of the increase in strength and MTH were similar for both the men and the women.

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Introduction

It has been demonstrated many times that heavy resistance training increases skeletal muscle size in men and women regardless of age (Frontera et al. 1988; Fiatarone et al. 1990; McCall et al. 1996; McCartney et al. 1996). Muscle fibre cross-sectional area (CSA) in highly trained male and female body builders have been found to be 147% and 54% greater, respectively, compared with untrained age matched controls (Alway et al. 1992). It has been reported that the percentage increase in muscle hypertrophy in response to high intensity resistance training is similar for men and women (Cureton et al. 1988; Davies et al. 1988; O'Hagen et al. 1995), although absolute increase in muscle CSA tends to be greater in men. A greater hypertrophic response to resistance training has been observed in upper extremity muscles compared to the lower extremity when the relative intensity and amount of training of the arms and legs were similar (Cureton et al. 1988; Wilmore 1974). These studies have only evaluated muscle hypertrophy at the beginning and end of the training, giving no inference as to the time-course of change.

Previous time-course studies have demonstrated the important role of the nervous system in facilitating the strength gains during the early phase of resistance training (Ikai and Fukunaga 1970; Moritani and de Vries 1979; Narici et al. 1989). But even so, the rate of synthesis of muscle protein has been found to increase rapidly following a single period of vigorous exercise (50% increase at 4 h, 109% increase at 24 h and a return to control levels at 36 h; MacDougall et al. 1995, or after 2 weeks of heavy resistance training; Yarasheski et al. 1993). Although a hypertrophic response has been found in the vastus lateralis muscle during the early phase of muscle-building exercise training (8 weeks; Staron et al. 1994), it is not clear when the appearance (time-course) of significant muscle hypertrophy occurs during total body resistance training in men and women in either the upper or lower body muscle groups.

Therefore, the purpose of this study was to investigate the time course of adaptations in skeletal muscle in response to high-intensity, upper and lower body dynamic resistance training in both men and women.

Methods

Subjects

The subjects were 50 young and middle-aged men and women, aged 25–50 years who volunteered to participate in a resistance training programme. The 17 men and 20 women were randomized into a resistance/weight training (WT) group, and 6 men and 7 women to a non-exercising wait-listed control group. The subjects were recruited from the greater Gainesville, Fla., area through newspaper advertisements and by word of mouth. Any of the subjects who suffered from a chronic disease such as cardiovascular disease, hypertension, diabetes, or orthopaedic disorders, as well as pregnant women, were excluded from the study. None of the subjects had participated in WT for a minimum of 12 months prior to the start of the programme. All the participants gave their informed consent prior to enrolment in the study. The methods and procedures were approved by the Institutional Review Board of the University of Florida College of Medicine.

Resistance training

The subjects in the WT group participated in 12 weeks of individualized progressive heavy-resistance training. During this period the controls did not participate in any such training exercise. Training was conducted 3 days a week for 12 weeks using either one set (8 men and 10 women) or three sets (9 men and 10 women) of six exercises until each individual became fatigued. The training protocol included knee extension (KE), knee flexion (KF), chest press (CP), seated row (SR), elbow flexion (EF), and elbow extension (EE) exercises performed with weight training machines (MedX Corporation, Ocala, Fla.). Each set of exercises required the performance of 8–12 repetitions maximum (RM) of dynamic variable resistance exercise. The initial training weight was 60% 1-RM for the KF, SR, EF and EE and 70% 1-RM for the KE and CP exercises. All training was monitored individually by qualified staff and the participants were instructed and coached to perform each exercise until they felt maximally fatigued.

Strength measurements

A pre-training week was used for subject orientation, and practice and familiarization with testing and training equipment. Each subject sat successively on six selected weight machines, and the joint axes of the knee (KE and KF) and elbow (EF and EE) were aligned with that of the machine by adjusting the position of the seat. Also, the subject's range of motion of CP, and SR was assessed and the position of the seat was determined. Strength of KE and CP was assessed using 1-RM tests. The 1-RM for each test was determined by progressively increasing the weight lifted until the subject failed to lift the weight through a full range of motion using good form. Usually 3–5 trials were required to complete a 1-RM test. Approximately 1.5–2 min of rest was taken, between trials. Testing of the 1-RM was performed at the start and at weeks 2, 4, 6, 8, and 12 for the WT group and at the start and at week 12 for the controls. The coefficient of variation for this test in our laboratory was 9%.

Muscle thickness

Muscle thickness was measured using B-mode ultrasound (Aloka SSD-500, Tokyo, Japan) at eight anatomical sites [chest, anterior and posterior upper arm (at 60% distal between the lateral epicondyle of the humerus and the acromial process of the radius), anterior thigh (at 30%, 50% and 70% thigh length between the lateral condyle of the femur and greater trochanter, starting at the greater trochanter) and posterior thigh (at 50% and 70% of the thigh length)] as has been described previously (Abe et al. 1994, 1998). Briefly, the measurements were carried out while the subjects stood with their elbows and knees extended and relaxed. A 5-MHz scanning head was placed on the skin perpendicular to the tissue interface. The scanning head was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. The subcutaneous adipose tissue-muscle interface and the muscle-bone interface were identified from the ultrasonic image, and the distance from the adipose tissue-muscle interface to the muscle-bone interface was taken as muscle layer thickness (MTH). The MTH was assessed at the start and weeks 2, 4, 6, 8, and 12 for the WT group and at the start and week 12 for the controls. The precision and linearity of the image reconstruction have been described and confirmed elsewhere (Kawakami et al. 1993; Narici et al. 1996). The coefficient of variation for this method was 0.8% (intraclass correlation coefficients: 0.97). The same investigator (TA) made all the ultrasound measurements.

Fat-free mass and percentage body fat

An anterior-posterior view total body scan was performed using dual-energy X-ray absorptiometry (model DPX-L; Lunar Radiation, Madison, Wis.). Fat mass, lean tissue mass, and bone mineral content were determined. Fat-free mass (FFM) was calculated as lean tissue plus bone mineral content. All scans were analysed by the same investigator using the Lunar version 1.3z extended analysis program for body composition. This technique has been previously validated (Mazese et al. 1984).

Statistical analysis

Since there was no statistical difference in the magnitude of training effect between one and three sets in either sex (DeHoyos et al. 1998; Pollock et al. 1998), all data were pooled for further analysis. A repeated-measures two-way analysis of variance (ANOVA) was used to determine the effects of training, sex, and the training-sex interaction. When a statistically significant F value was obtained, a one-way ANOVA was used to examine the training effect for each sex. To evaluate the influences of being overweight on the training-induced changes in strength and MTH, the data were divided into four subgroups; overweight men (> 25% body fat), non-overweight men (< 25% body fat), overweight women (> 30% body fat) and non-overweight women (< 30% body fat). Significance levels were set at $P < 0.05$.

Results

Subject characteristics

At the start of the experiment, there were no significant differences between WT and control groups in either the men or women for age, standing height, body mass, body mass index and waist to hip circumference ratio (Tables 1, 2).

Table 1 Physical characteristics of the subjects. *WT* Resistance/weight-training group, *Control* control group, *BMI* body mass index, *WHR* waist hip circumference ratio

Group	*n*	Age (years)		Height (cm)		BMI (kg · m^2)		WHR	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Men									
WT	17	37.7	7.2	178.4	4.9	27.5	4.3	0.94	0.05
Control	6	42.5	7.2	177.6	8.5	27.7	3.9	0.95	0.07
Women									
WT	20	41.0	4.1	164.3	6.9	24.1	4.2	0.83	0.06
Control	7	44.6	5.7	165.4	7.6	23.3	3.1	0.86	0.08

Table 2 Changes in body composition following 12-weeks resistance-training or control period. *WT* Resistance/weight training group, *Control* control group

Group	Body mass (kg)				% Body fat				Fat-free mass (kg)			
	Pre		Post		Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Men												
WT	87.6	12.8	89.2	12.5	28.6	6.7	29.1	6.4	61.1	5.1	62.7	5.3
Control	87.3	13.1	86.4	12.2	28.0	5.5	27.8	5.3	62.4	6.4	62.0	5.7
Women												
WT	64.7	9.3	65.1	9.5	35.6	7.8	35.1	8.1	41.0	3.5	41.7	3.5
Control	63.6	9.6	64.5	9.9	33.1	4.3	34.1	4.7	42.3	5.1	42.3	5.2

Table 3 Chest press and knee extension one-repetition maximum in male and female subjects before, during, and after 12 weeks of resistance training or control period. *WT* Resistance/weight training group, *Control* control group

Group	Pre		2 weeks		4 weeks		6 weeks		8 weeks		12 weeks	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chest press (kg)												
WT men	153	27	165	27	172	28	179	28[a]	184	30[b]	188	26[b]
WT women	61	14	67	15	72	16[a]	74	16[a]	79	16[b]	84	16[c]
Control men	147	36									142	30
Control women	58	13									58	14
Knee extension (kg)												
WT men	171	30	191	25[a]	200	27[a]	208	28[a]	208	29[a]	211	28[a]
WT women	94	23	104	22	107	22[a]	111	22[a]	114	21[a]	116	20[a]
Control men	177	22									186	21
Control women	93	9									91	15

Significantly different from [a]pre-training, [b]pre- and week 2, [c]pre-, weeks 2, 4, and 6

Strength change

The dynamic strength (1-RM) in CP and KE increased progressively in both the men and women. A significant increase in 1-RM strength for CP and KE had occurred by week 4 for the female WT group (Table 3). A significant increase in 1-RM strength had occurred at week 2 for KE and by week 6 for CP for the male WT group (Table 3). The male WT group had significantly greater mean absolute increases in CP (men 37.5 kg compared to women 23.6 kg) and KE (men 42.7 kg compared to women 22.4 kg) strength than the female WT group (Table 3). Relative percentage changes for the male and female WT groups were not significantly different for CP and KE (Fig. 1). Changes for controls were small and non-significant in both CP and KE strength (Table 3).

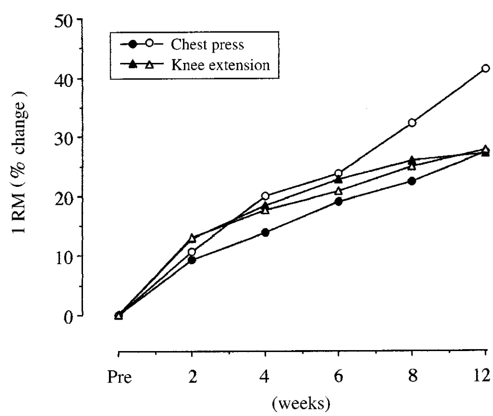

Fig. 1 Relative percentage increases in one repetition maximum (*1-RM*) strength for men (*unfilled symbols*) and women (*filled symbols*) among resistance-trained subjects over 12 weeks

FFM and % fat change

No significant changes in percentage body fat were found between the start of the experiment and after 12 weeks of resistance training for either the WT or control groups. There were no significant trends for increases in FFM for either the men or the women in the WT group. The FFM was similar between the start and week 12 in the controls (Table 2).

Muscle thickness change

There were apparent gradual increases in MTH in all the muscles selected in both the men and women in the WT group (Tables 4, 5). Progressive resistance training had elicited a significant increase in MTH of the chest, triceps, and 70% hamstrings muscles by week 6 for both the men and women. The biceps MTH had significantly increased by week 4 for the men and by week 8 for the

Table 4 Upper body muscle thickness in male and female subjects before, during, and after 12 weeks of resistance training or control period. *WT* Resistance/weight training group, *Control* control group

Group	Pre		2 weeks		4 weeks		6 weeks		8 weeks		12 weeks	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Biceps muscle (cm)												
WT men	2.98	0.36	3.15	0.28	3.22	0.35[a]	3.33	0.28[a]	3.41	0.26[b]	3.45	0.27[b]
WT women	1.78	0.31	1.83	0.28	1.87	0.30	1.96	0.33	2.00	0.32[a]	2.10	0.32[c]
Control men	3.27	0.28									3.22	0.26
Control women	1.80	0.29									1.77	0.24
Triceps muscle (cm)												
WT men	4.55	0.47	4.63	0.45	4.83	0.46	4.94	0.38[a]	5.01	0.41[b]	5.07	0.45[b]
WT women	3.26	0.35	3.34	0.39	3.41	0.36	3.52	0.39[a]	3.52	0.38[a]	3.56	0.34[a]
Control men	4.33	0.41									4.32	0.49
Control women	3.27	0.44									3.37	0.39
Chest muscle (cm)												
WT men	3.01	0.59	3.03	0.47	3.22	0.51	3.41	0.48[b]	3.46	0.49[b]	3.57	0.44[c]
WT women	1.58	0.34	1.64	0.33	1.74	0.33	1.79	0.32[a]	1.88	0.34[b]	2.03	0.34[d]
Control men	2.82	0.56									2.72	0.47
Control women	1.39	0.27									1.46	0.32

Significantly different from [a] pre-training, [b] pre- and week 2, [c] pre-, weeks 2 and 4, [d] pre-, weeks 2, 4, and 6

Table 5 Lower body muscle thickness in male and female subjects before, during, and after 12 weeks of resistance training or control period. *WT* Resistance/weight training group, *Control* control group

Group	Pre		2 weeks		4 weeks		6 weeks		8 weeks		12 weeks	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Quadriceps muscle 30% (cm)												
WT men	6.12	0.61	6.29	0.60	6.29	0.55	6.39	0.56	6.42	0.59	6.40	0.63
WT women	5.15	0.68	5.24	0.59	5.24	0.59	5.24	0.57	5.30	0.58	5.28	0.57
Control men	6.27	0.52									6.18	0.53
Control women	5.10	0.37									5.10	0.28
Quadriceps muscle 50% (cm)												
WT men	5.28	0.52	5.49	0.58	5.49	0.55	5.56	0.60	5.62	0.59	5.64	0.58
WT women	4.30	0.55	4.46	0.45	4.57	0.53	4.53	0.52	4.57	0.53	4.61	0.57
Control men	5.53	0.71									5.48	0.74
Control women	4.30	0.22									4.34	0.29
Quadriceps muscle 70% (cm)												
WT men	3.84	0.56	4.01	0.65	4.07	0.62	4.14	0.66	4.18	0.65	4.19	0.65
WT women	3.18	0.59	3.32	0.54	3.44	0.55	3.42	0.53	3.41	0.55	3.49	0.59
Control men	3.95	0.50									3.87	0.63
Control women	3.01	0.35									3.03	0.39
Hamstrings muscle 50% (cm)												
WT men	6.09	0.51	6.21	0.37	6.28	0.48	6.48	0.54[a]	6.54	0.53[a]	6.62	0.52[b]
WT women	5.25	0.55	5.27	0.61	5.31	0.63	5.36	0.60	5.40	0.59	5.61	0.55
Control men	6.02	0.61									6.05	0.54
Control women	5.44	0.48									5.34	0.51
Hamstrings muscle 70% (cm)												
WT men	5.68	0.40	5.84	0.47	5.89	0.52	6.06	0.57[a]	6.06	0.50[a]	6.11	0.59[a]
WT women	5.17	0.35	5.25	0.30	5.28	0.30	5.37	0.31[a]	5.37	0.34[a]	5.47	0.33[b]
Control men	5.63	0.50									5.67	0.40
Control women	5.30	0.55									5.29	0.61

Significantly different from [a] pre-training, [b] pre- and week 2 women. There were non-significant trends for increases in 30%, 50% and 70% quadriceps MTH for both sexes and in 50% hamstrings MTH for the women. Increases of 12%–21% and 7%–9%, respectively, for upper- and lower-body MTH in the WT men and 10%–31% and 7%–8%, respectively, in the WT women were observed after 12 weeks of resistance training (Fig. 2). Although the mean relative increase in MTH of the upper body was greater than that of the lower body, the mean percentage change in MTH was not significantly different between the men and women in the WT group. No changes in MTH were found in the control group ($P > 0.05$).

Influences of overweight on hypertrophy and strength gain

Changes in 1-RM strength (KE and CP) and MTH (quadriceps, hamstrings, chest, triceps and biceps muscles, etc.) were similar between overweight and non-overweight groups in both the men and the women.

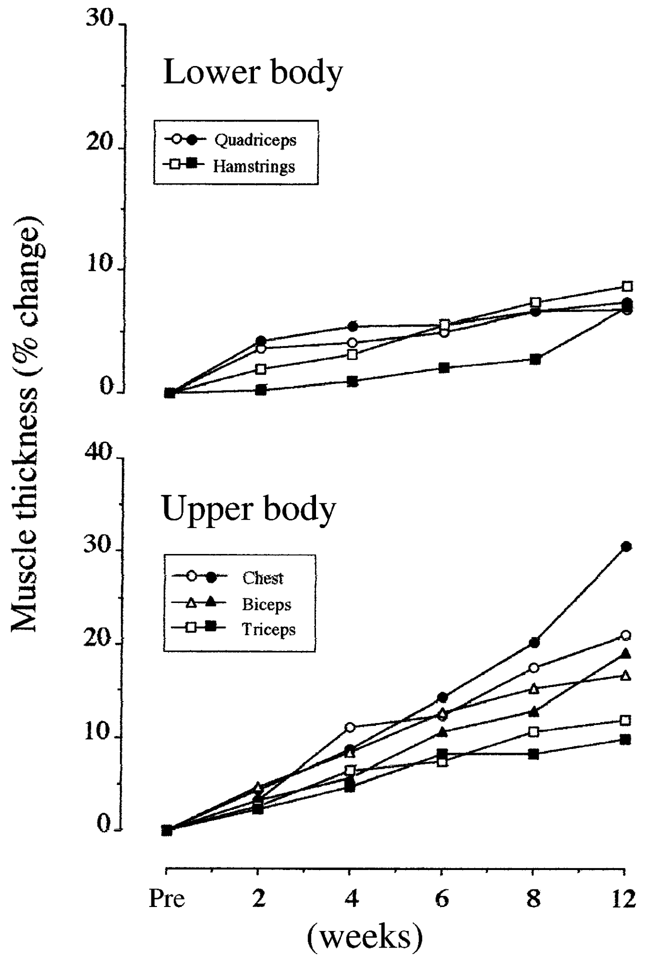

Fig. 2 Relative percentage increases in skeletal muscle thickness over 12 weeks in men (*unfilled symbols*) and women (*filled symbols*) among resistance-trained subjects

Discussion

It has been demonstrated that increases in strength occur before hypertrophy is apparent in training by elbow flexion (Davies et al. 1988; Ikai and Fukunaga 1970; Moritani and de Vries 1979; O'Hagen et al. 1995) or knee extension (Fiatarone et al. 1990; Frontera et al. 1988; Narici et al. 1989; Starkey et al. 1996; Young et al. 1983). For example, Ikai and Fukunaga (1970) have evaluated the effect of isometric training on CSA of the elbow flexor muscle in young men. They have found that a significant increase in muscle CSA had occurred after 6 weeks of training, but not after 3 weeks. Staron et al. (1991) have reported that CSA of the vastus lateralis muscle fibres had significantly increased after 6 weeks of high-intensity resistance training, although this increase in fibre CSA was not confirmed in a later study, (Staron et al. 1994). Recently, Akima et al. (1999) have reported a nonsignificant increase in quadriceps muscle CSA after 2 weeks of resistance training. When the relative intensity and amount of training of the arms and legs were similar, a greater hypertrophic response to resistance training has been observed in muscles of the upper extremity compared to those of the lower extremity (Cureton et al. 1988; Wilmore 1974).

Our results demonstrated that a significant increase in upper body MTH had occurred by 4–6 weeks following the initiation of total body resistance training. While there had been no significant changes in muscle size after 2 weeks of resistance training, there were non-significant trends for increases in knee extensor MTH. Therefore, the results from our present total body resistance training programme together with previous studies of single joints, help confirm that significant increases in muscle size in response to high-intensity resistance training do not appear within the first 4 weeks of training. However, the time course of muscle hypertrophy is not clear, especially with total body resistance training.

The reasons why muscle hypertrophy does not appear within the first 4 weeks of resistance training are unclear, but isotope studies would suggest a faster time course of muscle hypertrophy than was seen with the previous single joint and the present studies. MacDougall et al. (1995) have reported that the synthesis rate of muscle protein increased rapidly following a single period of vigorous resistance exercise and was 50% higher at 4 h and 109% higher at 24 h. Furthermore, a marked increase in the synthesis rate of muscle protein has been shown to occur in both young and elderly men and women after 2 weeks of resistance training while myofibrillar protein breakdown has remained unchanged (Yarasheski et al. 1993). The possibility exists that the sensitivity of current measurement techniques might be too low to detect small significant changes in muscle growth and therefore be the limiting factor in the determination of the time course for MTH changes.

In the present study, KE 1-RM strength had increased significantly by week 2 for the men and by week 4 for the women who performed WT. However, quadriceps MTH did not increase significantly during the 12-week training period for either the men or the women in the WT group. We also found that a significant increase in CP 1-RM had occurred by week 4 for the women who performed WT, although MTH of the chest and triceps muscle had not increased significantly until week 6. For the men who performed WT, however, both CP 1-RM and chest and triceps muscle MTH had increased significantly by week 6. This would be expected since neuromuscular adaptations have been found to occur before hypertrophy (Ikai and Fukunaga 1970; Moritani and de Vries 1979; Narici et al. 1989), but at the same time, it would support the notion that significant increases in MTH in the upper body occur earlier compared with the lower extremity.

Our findings showed that no significant hypertrophic response occurred in the quadriceps MTH of either the men or the women during the first 12 weeks of training. This finding is consistent with other investigations that have examined the effects of resistance training on quadriceps muscle (Cureton et al. 1988; Fiatarone et al. 1990) and vastus lateralis muscle fibre CSA (Staron et al. 1994). We found a mean 7% increase in 50% quadriceps MTH for both the men and the women who performed WT. Even though the increases were not statistically significant, our findings were consistent with other studies (Jones and Rutherford 1987; Luthi et al. 1986; Narici et al. 1989; Young et al. 1983) which have reported a 5%–8% increase in quadriceps muscle CSA following 5–12 weeks of resistance training. In contrast to the quadriceps MTH results, there was a statistically significant increase in the 70% hamstrings MTH for both the men and the women and in the 50% MTH for the men. Starkey et al. (1996) have found that 40% and 60% hamstrings MTH increased significantly in both men and women after 14 weeks of heavy-resistance training. Fiatarone et al. (1990) have also reported that 8 weeks of high-intensity resistance training significantly increased computed tomography (CT)-measured hamstring and adductor muscle CSA in frail elderly people.

Previous studies have reported on the sex responses to resistance training evaluated by CT. Cureton et al. (1988) have reported that the relative changes in strength and muscle hypertrophy after 16 weeks of resistance training were similar in both men and women. In a similar study which evaluated the effect of 20 weeks of resistance training on male and female students, muscle size increased similarly in both men and women (O'Hagen et al. 1995). In the present study we also observed a similar relative increase in strength and MTH in the men and the women after 12 weeks of training. In addition, we observed a similar time-course for change in MTH for both the men and the women. Our findings were consistent with the observation of others that resistance training promotes hypertrophy similarly in young and middle-aged adult men and women.

The present study indicated that FFM increased by a mean of 1.6 kg for the men in the WT group and 0.7 kg for the women in the WT group over 12 weeks of resistance training. Although these changes did not reach statistical significance ($P > 0.05$) the magnitude of the increase was consistent with previous studies (Cureton et al. 1988; Hagberg et al. 1989; Ryan et al. 1995; Wilmore 1974) which have reported increases of approximately 2 kg in FFM following 10–26 weeks of total body resistance training. It is probable that a longer period of WT would have produced a significant increase in total body FFM.

It was concluded from our findings that significant increases in MTH in the upper body and hamstrings can occur by 6 weeks of WT and, furthermore, that the increases in MTH of the upper body are of greater magnitude compared with the lower extremity during the first 12 weeks of total body WT. Finally, the time-course and relative increases in strength and MTH would appear to be similar for both men and women.

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