Age and sex affect human muscle fibre adaptations to heavy-resistance strength training

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This study assessed age and sex effects on muscle fibre adaptations to heavy-resistance strength training (ST). Twenty-two young men and women (20–30 years old) and 18 older men and women (65–75 years old) completed 9 weeks of heavy-resistance knee extension exercises with the dominant leg 3 days week–1; the non-dominant leg served as a within-subject, untrained control. Bilateral vastus lateralis muscle biopsies were obtained before and after ST for analysis of type I, IIa and IIx muscle fibre cross-sectional area (CSA) and fibre type distribution. One-repetition maximum (1-RM) strength was also assessed before and after ST. ST resulted in increased CSA of type I, IIa and IIx muscle fibres in the trained leg of young men, type I and IIa fibres in young women, type IIa fibres in older men, and type IIx fibres in older women (all $P < 0.05$). Analysis of fibre type distribution revealed a significant increase in the percentage of type I fibres ($P < 0.05$) along with a decrease in type IIx fibres ($P = 0.054$) after ST only in young women. There were no significant changes in muscle fibre CSA or fibre type distribution in the untrained leg for any group. All groups displayed significant increases in 1-RM (27–39%; all $P < 0.01$). In summary, ST led to significant increases in 1-RM and type II fibre CSA in all groups; however, age and sex influence specific muscle fibre subtype responses to ST.

Age-related declines in muscle mass (sarcopenia) and strength lead to an increased risk of falls and reduced functional mobility (Campbell et al. 1989; Rantanen et al. 1999). Thus, strength training (ST) is an intervention of choice for addressing these risks. Although study of the effects of ST on older individuals initially suggested that strength gains were primarily due to neurological adaptations (Moritani & De Vries, 1980), it is now understood that heavy-resistance ST can induce hypertrophy of whole skeletal muscle (Tracy et al. 1999; Ivey et al. 2000) as well as individual muscle fibres (Häkkinen et al. 1998; Hikida et al. 1998; Fiatarone-Singh et al. 1999) in the elderly. In this regard, previous work has shown that ST can induce relative hypertrophy of skeletal muscle fibres in older individuals that is comparable to that observed in younger individuals (Häkkinen et al. 1998; Hikida et al. 1998); however, these adaptations may take longer in older individuals (Moritani & De Vries, 1980). Furthermore, a large proportion of the muscle mass and strength lost with ageing involves preferential reductions in the number and cross-sectional area (CSA) of fast-twitch (type II) muscle fibres (Lexell et al. 1988; Lexell & Downham, 1992; Fiatarone-Singh et al. 1999; Trappe et al. 2003). Thus, assessment of age and sex effects on muscle fibre responses to heavy-resistance ST could aid in the development of ST protocols that favourably recruit type II muscle fibres (Fiatarone-Singh et al. 1999).

Previous investigations have examined the effects of ST on skeletal muscle morphology in young men (Kraemer et al. 1995; McCall et al. 1996), young women (Staron et al. 1989, 1994), older men (Brown et al. 1990; Hikida et al. 2000; Trappe et al. 2000) and older women (Charette et al. 2000). ST is an intervention of choice for addressing these risks. Although study of the effects of ST on older individuals initially suggested that strength gains were primarily due to neurological adaptations (Moritani & De Vries, 1980), it is now understood that heavy-resistance ST can induce hypertrophy of whole skeletal muscle (Tracy et al. 1999; Ivey et al. 2000) as well as individual muscle fibres (Häkkinen et al. 1998; Hikida et al. 1998; Fiatarone-Singh et al. 1999) in the elderly. In this regard, previous work has shown that ST can induce relative hypertrophy of skeletal muscle fibres in older individuals that is comparable to that observed in younger individuals (Häkkinen et al. 1998; Hikida et al. 1998); however, these adaptations may take longer in older individuals (Moritani & De Vries, 1980). Furthermore, a large proportion of the muscle mass and strength lost with ageing involves preferential reductions in the number and cross-sectional area (CSA) of fast-twitch (type II) muscle fibres (Lexell et al. 1988; Lexell & Downham, 1992; Fiatarone-Singh et al. 1999; Trappe et al. 2003). Thus, assessment of age and sex effects on muscle fibre responses to heavy-resistance ST could aid in the development of ST protocols that favourably recruit type II muscle fibres (Fiatarone-Singh et al. 1999).
and sex on muscle fibre hypertrophic responses to ST by including comparisons of men with women, or younger with older individuals. However, because these studies used varying ST intensities, durations and volumes, it is difficult to draw consistent conclusions regarding responses of specific muscle fibre subtypes to ST in individuals of different age and/or sex. In both previous studies that directly examined the effects of age and sex on muscle fibre hypertrophic responses to ST by comparing muscle samples obtained from men and women of different ages before and after ST (Häkkinen et al. 2001; Kim et al. 2005b), the investigators did not report inclusion of control muscle samples; thus, an impact of factors such as non-study-related physical activity (Lexell et al. 1985) or differences in genotype (Roth et al. 2003; Schrager et al. 2004) on muscle fibre adaptations cannot be ruled out.

Other factors that may influence the interpretation of morphological adaptation to ST involve methodology. For example, current studies involving the effects of ST on muscle fibre characteristics tend to use immunocytochemistry to analyse subtle changes in myosin heavy chain (MHC); however, much of our present understanding regarding the effects of ST, age and sex on muscle morphology is derived from studies that used techniques involving myofibrillar ATPase activity (Lexell et al. 1983, 1985, 1988; Staron et al. 1989; Brown et al. 1990; Charette et al. 1991; Lexell & Downham, 1992; Kraemer et al. 1995; McCall et al. 1996; Taaffe et al. 1996; Häkkinen et al. 1998, 2001; Hikida et al. 1998). In addition, Lexell et al. (1983, 1985) reported that a single muscle sample obtained via needle biopsy, the technique most often used in studies of muscle morphology, can provide a poor estimation of whole muscle fibre type distribution and that sampling error can be significantly reduced in biopsy samples by obtaining larger samples (>450 fibres).

Another method of reducing the impact of muscle sample variation on study findings involves the inclusion of appropriately matched control muscle samples. In this regard, Young et al. (1982) reported a strong correlation between muscle fibre distributions in bilateral muscle samples obtained from within the same individual, but substantial variation exists when comparing muscle samples obtained from separate individuals. Despite this, the recruitment of separate control groups for comparison purposes is a technique frequently employed by investigators. Blomstrand et al. (1984) also examined the issue of muscle sample variability involved with biopsy techniques, reporting standard deviations for type I, IIA and IIX fibre CSA in bilateral muscle samples that were ~24–47% lower than repeat samples obtained from the same biopsy site within these individuals. Similar to Lexell et al. (1985), the authors emphasized the importance of analysing all viable muscle fibres within a muscle sample region and having the same investigator perform all measurements within a study. Collectively, these studies suggest that a superior method of controlling for inherent muscle sample variability and the potential confounding effects of age, sex, genotype and physical activity (Young et al. 1982; Lexell et al. 1983, 1985; Blomstrand et al. 1984; Roth et al. 2003; Schrager et al. 2004) would be to obtain experimental and control muscle samples from within a group of subjects (bilateral samples) rather than comparing samples obtained from two separate groups.

Although unilateral ST models have been used for years, we are aware of only a single study that compared muscle samples from ‘strength-trained’ limbs to ‘untrained’ limbs within the same group of individuals (Brown et al. 1990). However, although Brown et al. (1990) compared muscle fibre responses to ST between trained and untrained arms, the biceps brachii musculature of both arms may have been indirectly involved in additional ST exercises, since the authors reported hypertrophy of type I and type II fibres in both arms. Furthermore, Brown et al. (1990) included only older men, since examining the effects of age or sex on muscle fibre responses to ST was not their objective.

Because a number of previous studies examined the role of age or sex on muscle fibre hypertrophy after various ST protocols via analysis of myofibrillar ATPase activity, but without inclusion of within-subject control samples, we attempted to replicate previous findings while addressing these issues. Thus, the purpose of our study was to compare bilateral skeletal muscle samples from trained and untrained legs of young and older men and women before and after completing an identical single-leg, heavy-resistance ST protocol.

**Methods**

**Subjects**

The 13 young men, nine young women (young being 20–30 years old), 11 older men and seven older women (older being 65–75 years old) that participated in the study were a subset of subjects from a larger study conducted in our laboratory (Tracy et al. 1999; Lemmer et al. 2000; Ivey et al. 2000). All aspects of this study complied with the Declaration of Helsinki and were approved by the Institutional Review Boards at the University of Maryland College Park and at the Veterans Affairs and the Johns Hopkins Bayview Medical Centers in Baltimore, MD, USA. Following thorough written and verbal explanations of all methods and procedures, subjects provided written informed consent. All subjects were healthy non-smokers who had not participated in regular exercise for at least 6 months prior to the study. A medical history,
maximal graded exercise test with measurement of oxygen consumption, and physical examination were performed by a physician on all older subjects to screen for musculoskeletal and cardiovascular disease. Subjects were excluded if there were any musculoskeletal problems preventing them from successfully completing the ST programme, if the exercise test provided evidence of cardiovascular disease, or if they were taking medications known to affect cardiovascular or metabolic function. Dual energy X-ray absorptiometry was used to assess body composition before and after the study using methods previously described (Tracy et al. 1999); this, along with weekly measurement of body mass, was used to assess whether significant changes in physical activity or dietary habits had occurred during the course of the study.

**Strength testing**

Strength testing of the quadriceps femoris muscle groups was conducted in a unilateral manner on both legs before and after the study as previously described (Lemmer et al. 2000). Briefly, following three familiarization sessions in which the participants completed the training programme protocol with little resistance, one-repetition (1-RM) and five-repetition maximum (5-RM) tests were performed on an air-powered leg extension machine that provided both concentric and eccentric actions. The 1-RM resistance was recorded as a measure of baseline muscular strength, while the 5-RM was used as the initial resistance for the ST programme. All strength tests were conducted by the same investigator before and after the study, paying special attention to consistency with seat adjustment, body position, amount of stabilization, and level of vocal encouragement.

**ST programme**

The unilateral ST programme, as previously described (Tracy et al. 1999; Lemmer et al. 2000), was designed to require near-maximal effort on all repetitions, while maintaining a high training volume to optimize muscle fibre hypertrophy. Briefly, the ST programme consisted of five sets of unilateral leg extension exercise, performed 3 days week−1 for 9 weeks. The dominant leg of each individual was used as the training leg, while the non-dominant leg served as the untrained, within-subject control. All subjects completed each ST session under the direct supervision of one of the investigators. For each ST session, all subjects completed a 10 min warm-up period consisting of light stationary cycling and stretching, followed by a warm-up set consisting of five repetitions at 50% of the predetermined 1-RM resistance. The second set consisted of five repetitions using a predetermined 5-RM resistance. If an individual was able to lift the 5-RM resistance more than five times, the resistance was increased for the subsequent ST session. The third set required subjects to lift the 5-RM resistance until failure. The subjects then quickly pressed an air ‘release’ button near their thumb (to gradually reduce the resistance) just enough to perform one or two more repetitions without interruption. This process was repeated (usually one or two slight reductions in resistance during the third set) until a total of 10 repetitions could be completed. The fourth set also required the subjects to perform as many repetitions as possible at the 5-RM resistance, at which time they were allowed to gradually reduce the resistance (as described above) until a total of 15 repetitions were completed. The fifth and final set followed the same procedure, except that a total of 20 repetitions were completed. The number of reductions in resistance required for the fourth and fifth sets varied by individual, but ranged from roughly four to seven. This training protocol required each individual to perform 50 repetitions at near-maximal effort on every repetition after the warm-up set. Rest periods of 30, 90, 150 and 180 s were allowed between each of the five sets, respectively.

**Muscle sampling and analyses**

Bilateral muscle samples were obtained from the vastus lateralis muscles approximately 1 week prior to baseline strength testing and within 24–48 h after completing ST using a percutaneous needle biopsy technique with suction (Evans et al. 1982). The initial sampling site was superior to the proximal border of the patella by 14 cm for women and 16 cm for men, and at the mid-line of the quadriceps. All muscle biopsies were performed by the same investigator through an incision 2.5 mm proximal and lateral to the original biopsy scar, with the needle inserted as closely as possible to the site of the original biopsy. Also, all biopsies were taken from approximately the same depth for each subject by using markings engraved on the outside of the biopsy needle. Although this method led to samples being obtained from different muscle depths for individuals with different muscle thicknesses, this technique allowed us to control for the effect muscle depth on fibre type distribution within each subject (i.e. for comparisons between time points and control versus trained leg). After dissecting the muscle samples of all visible blood, adipose and connective tissue, the muscle samples were orientated in embedding medium (OCT; Miles Laboratories, Naperville, IL, USA), frozen in isopentane cooled to the temperature of liquid nitrogen, and stored at −80°C. Frozen muscle samples were subsequently orientated in a cross-sectional fashion onto a microtome cryostat (IEC Microtome, International Equipment Co.), cut into 12 μm thick sections at −20°C, and analysed histochemically to classify fibres as type I, IIa,
IIC and IIX using the method of Brooke & Kaiser (1970). Owing to the extremely low occurrence of type IIC fibres in the samples, they were not included in the final statistical analyses. All samples obtained from a particular subject were stained in the same batch to avoid interassay variation. Estimates of fibre type distribution were calculated using all viable muscle fibres from contiguous regions of the samples, resulting in an average of 774 ± 35 fibres being included per sample.

Muscle fibre CSA was determined by downloading video images of the tissue cross-sections at ×100 magnification from a light microscope interfaced with a video recorder. The CSA of approximately 75 type I, IIA and IIX fibres in artifact-free, contiguous regions of the sample were measured before and after ST using a computer program (Scion Image, Frederick, MD, USA). The same investigator analysed all of the muscle samples (distribution and CSA) in duplicate, in a blind fashion. Intra-individual test–retest reliability showed a correlation of 0.99 (P < 0.001) for muscle fibre CSA measured on different days.

Data analysis

All data are expressed as means ± s.e.m. Unpaired t tests were used to examine group differences in descriptive variables. Analyses of variance (ANOVA) with repeated measures were used for assessing group differences and the effect of ST on muscle fibre distribution and CSA. The independent variables for the ANOVA included time (before versus after ST), leg (trained versus control) and group (young men, young women, older men and older women); thus a 2 × 2 × 4 factorial design was used for each fibre type. Since there were significant group differences at baseline for muscle fibre CSA (e.g., differences in baseline type IIA CSA between young men and young women), factorial analyses of covariance (ANCOVA) with repeated measures were performed using the same independent variables mentioned above. When significant time-by-group (4 separate groups; age and gender groups were not pooled) interactions were present, Tukey post hoc procedures were used for identifying the specific differences. Logistic regression was used to verify the lack of individual cases present that could skew group means. All statistical analyses were conducted using statistical software (SPSS, Inc.; Chicago, IL, USA). Statistical significance was set at P < 0.05 for all tests.

Results

Physical characteristics and muscle strength

The body fat percentages and maximal oxygen uptake (V\textsubscript{O\textsubscript{2max}}) values of the subjects in this study are indicative of relatively sedentary individuals (Table 1). Despite baseline group differences in body mass and body fat percentage, there were no significant changes in either variable for any group after ST, indicating that physical activity levels and dietary intake during the ST programme were not significantly altered. As reported previously (Lemmer et al. 2000), there were significant increases in 1-RM strength in both the trained and untrained legs for all groups following ST, with significantly larger increases occurring in the trained leg versus the untrained leg for all groups (increases of 31, 39, 27 and 29% in the trained legs of young men, young women, older men and older women, respectively; all P < 0.001).

Muscle fibre type distribution

Analysis of muscle fibre type distribution in both legs of all four groups at baseline indicated no significant group differences (Table 2). ANOVA with repeated measures (including all groups) indicated a significant time-by-group interaction (P < 0.05), so we performed a post hoc analysis to examine the source of the interaction. We observed no significant changes in fibre type distribution for young men, older men or older women; however, there was a significant increase in the percentage of type I fibres

| Table 1. Physical characteristics of the subjects before and after ST |
|-------------------------|-------------------|-------------------|-------------------|-------------------|
|                         | Young men (n = 13) | Young women (n = 9) | Older men (n = 11) | Older women (n = 7) |
| Age (years)             | 25 ± 1            | 26 ± 0.4           | 69 ± 1            | 68 ± 1            |
| Height (cm)             | 178 ± 3           | 167 ± 2            | 174 ± 2           | 161 ± 2           |
| Body mass (kg)          |                   |                   |                   |                   |
| Before                  | 82 ± 5            | 62 ± 4             | 80 ± 2            | 68 ± 3            |
| After                   | 83 ± 5            | 62 ± 4             | 81 ± 2            | 68 ± 3            |
| Body fat (%)            |                   |                   |                   |                   |
| Before                  | 24 ± 2            | 31 ± 2             | 30 ± 2            | 39 ± 2            |
| After                   | 23 ± 2            | 31 ± 2             | 29 ± 1            | 38 ± 2            |
| V\textsubscript{O\textsubscript{2max}} (ml kg\textsuperscript{-1} min\textsuperscript{-1}) | 43 ± 1            | 33 ± 2             | 24 ± 2            | 20 ± 1            |

* Significantly different from young and older women (P < 0.05); † significantly different from older men and women (P < 0.05); ‡ significantly different from older women (P < 0.05); and § significantly different from young women (P < 0.05).
(40–51%; \(P < 0.05\)) along with a decrease in type IIx fibres (29–19%; \(P = 0.054\)) in the trained leg of young women. There were no significant group differences or changes in fibre type distribution in muscle samples obtained from the untrained leg for any group.

**Muscle fibre CSA**

Analysis of muscle fibre CSA for all four groups at baseline indicated significant group differences in both the trained and untrained legs for all three fibre types (Table 3). The older men had significantly larger type I, IIa and IIx muscle fibres than young and older women (all \(P < 0.01\)), while young men had significantly larger type IIa and type IIx muscle fibres than both young and older women (all \(P < 0.05\)). Although the young men had larger type I muscle fibres than young women (\(P < 0.05\)), there was no significant difference in type I muscle fibre CSA between young men and older women.

The factorial ANCOVA indicated significant effects of ST on muscle fibre CSA, and significant leg and group interactions for all three fibre types (all \(P < 0.05\)). Post hoc analysis for the leg interactions for each fibre type revealed significant changes in muscle fibre CSA in the trained leg, but no significant changes in muscle fibre CSA in the untrained leg. These findings verify that the increases in muscle fibre CSA that were observed in the trained leg were significantly larger than any variation in the untrained leg. With regard to the significant group interactions, post hoc analysis revealed significant increases in type I fibre CSA in both young men and young women (19 and 20%, respectively; both \(P < 0.05\)), whereas there were no significant increases for older men (6%) or older women (7%). For type IIa muscle fibre CSA, there were significant increases in young men, young women and older men (21, 19 and 24%, respectively; all \(P < 0.05\)), with no significant changes occurring in the trained leg of older women (\(\sim 14\%\)). Finally, there were significant increases in type IIx fibre CSA in young men and older women (41 and 49%, respectively; both \(P < 0.05\)), with no significant changes occurring in the trained leg of young women (21%) or older men (25%).

**Discussion**

Despite the utilization of an identical ST protocol in the present study by young and older men and women, ST led to significant increases in type I muscle fibre CSA only in young men and young women. In addition, there were non-significant increases after ST for type IIx fibre CSA.
in young women (21%) and older men (25%) that were ∼50% smaller than the significant increases observed in young men (41%) and older women (49%). Because these differences in fibre hypertrophy occurred in the trained leg with no significant changes in the untrained leg, our results indicate that there are age and sex effects on muscle fibre responses to ST, and that these dissimilarities are not due to methodological variation, differences in physical activity status or genotype, or differences in ST intensity, volume or duration.

The findings of the present study regarding significant sex effects on hypertrophic responses of skeletal muscle to resistance exercise are supported by recent work involving ST in men and women (Ivey et al. 2000; Häkkinen et al. 2001; Bamman et al. 2003; Kim et al. 2005a,b). For example, Kim et al. (2005a,b) reported significant differences between men and women after resistance exercise for the expression of myostatin (an inhibitor of skeletal muscle hypertrophy), as well as cyclin D1, myogenic gene (MyoD), tissue binding protein, and muscle-specific insulin-like growth factor I, all of which play an important role in muscle fibre hypertrophy and/or regeneration. Although not assessed in the present study, we hypothesize that sex-related hypertrophic dissimilarities are related to underlying differences in the expression of these factors (Kim et al. 2005a,b).

Our finding of a lack of increase in type I CSA in older men and women is also supported by previous work indicating blunted hypertrophic responses of muscle fibres to ST in older individuals (Moritani & De Vries, 1980; Charette et al. 1991; Fiatarone-Singh et al. 1999; Häkkinen et al. 2001). For example, Charette et al. (1991) observed increases in type II fibre CSA after 12 weeks of ST in older women, but no increase for type I fibres. Fiatarone-Singh et al. (1999) and Häkkinen et al. (2001) also reported no significant increases for type I fibre CSA in older individuals after 10 weeks and 6 months of ST, respectively, despite increases in type II fibre CSA. It should also be noted that the findings of Fiatarone-Singh et al. (1999) were a result of analysis of both myofibrillar ATPase activity and immunocytochemistry. Furthermore, Hikida et al. (1998) reported similar increases in type I CSA in young and older men after ST, but the older men in their study trained for 16 weeks, compared to only 8 weeks for young men. Finally, Kim et al. (2005a,b) recently reported significant differences between young and older individuals for the expression of myostatin, myogenin, MyoD, myogenic regulatory factor (myf-5) and muscle-specific insulin-like growth factor I, indicating blunted skeletal muscle responses in older men and women.

In addition to the underlying cellular mechanisms for age and sex differences in muscle hypertrophy described above, we propose that active older individuals who have undergone age-related muscle changes (i.e. motor unit remodelling, age-related loss of type I fibre number and/or CSA) begin to rely more heavily on type I fibres during everyday activities due to the normal pattern of muscle fibre recruitment, thus inducing type I fibre hypertrophy. Therefore, even ST programmes of high intensity could require longer duration to induce further improvements in type I fibre CSA and/or metabolic capacity in older individuals.

In the present study, we observed significant hypertrophy of type IIa and IIx fibres in young men, type IIa fibres in young women and older men, and type IIx fibres in older women after ST. Despite these differences in group responses, the present study indicates that young and older men and women can experience type II muscle fibre hypertrophy in a relatively short period of time (ranging from 19 to 49% depending on group and fibre subtype). This is noteworthy, and may have important clinical implications for addressing the effects of sarcopenia, since a number of research groups (Lexell et al. 1988; Lexell & Downham, 1992; Fiatarone-Singh et al. 1999; Trappe et al. 2003) have reported that most muscle loss due to ageing is attributed to reductions in the number and size of type II muscle fibres. Thus, ST programmes requiring relatively high levels of resistance may be most effective for recruiting type II fibres, helping to address the problems associated with sarcopenia-related conditions.

In the only other study to our knowledge that has directly compared muscle morphology in men and women of different age groups before and after ST, Häkkinen et al. (2001) reported no significant baseline group differences in muscle fibre type distribution, and no significant changes in distribution as a result of 6 months of ST. These findings are consistent with those of the present study, but are in contrast to previous work reporting significant alterations in type II muscle fibre subtype distributions after ST, usually a decrease in the percentage of type IIx fibres and an increase in Ila or Iib fibres (Staron et al. 1989, 1994; Kraemer et al. 1995; Häkkinen et al. 1998; Hikida et al. 1998, 2000). For example, Hikida et al. (1998) observed a significant reduction in the percentage of type Ix fibres for older men (9%) along with a significant increase in the percentage of type IIx fibres and an increase in Ila or Iib fibres (Staron et al. 1989, 1994; Kraemer et al. 1995; Häkkinen et al. 1998; Hikida et al. 1998, 2000). For example, Hikida et al. (1998) observed a significant reduction in the percentage of type Ix fibres for older men (9%) along with a significant increase in the percentage of type Ia fibres (4%) following 16 weeks of ST. In addition, Häkkinen et al. (1998) previously reported significant decreases in the percentage of type Ix fibres for young and older men (∼9% for both groups) and an increase in the percentage of type Ia fibres (4%) in young men after 10 weeks of ST. Although our analysis of muscle fibre type distribution revealed no significant main effects of ST for any group, there was a significant time-by-group interaction; post hoc analysis revealed significant changes only in the fibre type distribution of young women. Despite our observation of a reduction in the percentage of type Ix fibres after ST in young women being consistent with previous literature, our observance of an increase in type I fibre percentage is not. We believe that this increase in type I fibres after
ST in young women may be due to our collapsing of fibre types into only four major categories for reporting, similar to previous investigators (Kraemer et al. 1995; Hakkinen et al. 1998, 2001); however, this method may not allow for the detection of subtle changes in other fibre subtypes. For example, the work of Staron et al. (1989, 1994) involved assessment of six muscle fibre subtypes (I, Ic, IIc, Ila, IIB and IIX) for their muscle fibre distributions. Thus, we recommend that future studies examining muscle fibre type distribution continue to use methods that allow for examination of all six detectable muscle fibre subtypes to avoid the limitations presented by assessing only type I, IIc, Ila and IIX fibres.

As can be seen, the available literature regarding the effects of ST on muscle morphology is quite extensive, with research groups using an array of laboratory techniques and ST protocols to assess changes in muscle fibre characteristics. Although the present study, as well as others (Hakkinen et al. 2001; Bamman et al. 2003; Kim et al. 2005a, b), indicate inherent differences in how muscle fibres of young and older men and women respond to ST, the potential impact of ST protocols of varying frequency, duration, intensity and volume on muscle fibre responses cannot be ignored, since these factors may affect the degree and rate of response. For example, the present study examined vastus lateralis muscle fibre responses to a rather short, but very intense ST protocol (~150 near-maximal lifts per week for ~9 weeks) in young and older men and women. In addition, our ST protocol involved only a single ST exercise, seated leg extensions. On the contrary, Hakkinen et al. (2001) examined vastus lateralis muscle samples obtained from middle-aged and older men and women after performing multiset combinations of heavy resistance and explosive leg extension and leg press exercises; also, these subjects trained only twice weekly for 6 months with a gradually increasing load (~50% 1-RM to ~80% 1-RM by the end of the study). Thus, it seems logical to assume that some of the differences between our findings and those of previous investigators could be partly due to the use of such a vast array of ST programmes.

In summary, our study indicates the presence of significant age and sex effects on muscle fibre hypertrophic responses to ST, since older individuals appear to develop hypertrophy of type I muscle fibres more slowly than young individuals, while young men appear to have greater hypertrophic capacity than young women as well as older men and women. By evaluating bilateral muscle biopsy samples from young and older men and women before and after completion of the same ST protocol, the impact of confounding factors such as differences in ST frequency, intensity and duration, as well as biological and genetic variation on our data were minimized. Furthermore, when comparing our findings to recent work in this area, it appears that age- and sex-related differences in muscle hypertrophy may be due to varying expression of cellular components known to impact muscle fibre hypertrophy. However, despite potential age and sex differences, young and older men and women appear to display type II fibre hypertrophy after heavy-resistance ST. Thus, we strongly encourage the use of heavy-resistance ST to help reduce risks associated with sarcopenia.

References


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