Adaptations to Short-Term Muscle Unloading in Young and Aged Men

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ABSTRACT

DESCHENES, M. R., A. N. HOLDREN, and R. W. MCCOY. Adaptations to Short-Term Muscle Unloading in Young and Aged Men. Med. Sci. Sports Exerc., Vol. 40, No. 5, pp. 856–863, 2008. Introduction: The purpose of this investigation was to determine whether young (21.7 yr) and aged (68.5 yr) men experienced similar responses to 7 d of muscle unloading (N = 10 per group). Methods: Unilateral lower limb suspension (ULLS) was used to impose muscle unloading of the knee extensors. To compare the effects of unloading on aged and young men, a repeated-measures factorial ANOVA was used to assess those effects on isometric strength, as well as strength, total work, and average power during isokinetic contractions conducted at 0.53, 1.05, and 2.09 rad·s−1. Results: Data showed that at slower speeds of movement, only a main effect of unloading was identified with young and aged men displaying similar and significant (P < 0.05) ULLS-induced decrements in strength, as well as strength, total work, and average power. The decrease in isometric strength correlated well with loss of electromyographic activity of contracting muscles (r = 0.79, P = 0.0002). At higher speeds of isokinetic contractions, not only was a main effect of age detected (young > aged), but it was also revealed that aged men, but not young men, experienced significant unloading-induced declines in muscle performance. Moreover, unloading resulted in a significant increase in plasma cortisol, a potent catabolic hormone, only among aged men. In contrast to other variables assessed, muscle endurance, quantified during 30 repetitions completed at 3.14 rad·s−1, did not differ between age groups, nor was it altered by unloading. Conclusion: These findings suggest that young and aged men respond differently to muscle unloading, but in assessing muscle performance, these differences are manifested only during faster contractile velocities. Key Words: NEUROMUSCULAR, UNWEIGHTING, DISUSE, STRENGTH, CORTISOL, TESTOSTERONE

The deleterious effects that muscle unloading imparts on the neuromuscular system have been well documented. For example, in human muscle, unloading results in decreased strength (1,6,28), muted neural drive to muscle (14,36), and even perturbs the pituitary–adrenal axis, leading to greater concentrations of bloodborne cortisol, a muscle wasting hormone (10). The natural process of aging has been found to result in adaptations of the neuromuscular system that are similar to those induced by unloading. These include decrements in strength (9,17), alterations in the neural activation of muscle (39), atrophy of whole muscles and myofibers comprising those muscles (2,16,30), as well as disturbances in basal concentrations of anabolic and catabolic hormones (13,35). Yet the question of whether the negative effects of unloading are any more, or less, pronounced in the neuromuscular systems of aged humans remains unanswered. The answer to that question is particularly relevant in view of demographic data that indicate a "graying" of most Western societies (8,33) and clinical data that demonstrate a rapid increase in the number of hip and knee replacements, along with other procedures that result in muscle unloading among the aged (27,34). Accordingly, the purpose of the present investigation was to determine whether aged and young adult individuals experience age specific unloading-induced disturbances in neuromuscular function. It was hypothesized that since aging itself promotes some degree of neuromuscular degeneration, the added challenge of muscle unloading would exacerbate that process, resulting in greater neuromuscular decline among the aged than among young adults.

METHODS

Subjects. Ten young adult men (21.7 ± 1.1 yr, 175.8 ± 2.8 cm, 74.4 ± 4.2 kg; means ± SE), and 10 aged men (68.5 ± 1.6 yr, 176.7 ± 1.3 cm, 88.0 ± 2.2 kg) volunteered to participate in this study. Based upon our previous investigation of muscle unloading in humans (10), it was determined that a sample size of 10 per group would provide the desired statistical power (1 − β) of 0.8. None of the subjects were on prescribed medications, and none possessed contraindicated medical conditions as evidenced by their medical history forms. As determined by a questionnaire, the two groups were similarly active on a...
recreational and habitual basis. This instrument, developed and validated by Kohl et al. (22), is appropriate for subjects within a wide range of ages and quantifies total activity—that is, habitual activity and exercise. The two groups also displayed similar sums of skinfold thicknesses measured at the chest, abdomen, and thigh (aged = 46 mm, young = 42 mm).

After receiving a verbal description of the investigation, its potential risks, and the experimental procedures to be used, the subjects provided written informed consent. All experimental procedures were approved by the Protection of Human Subjects Committee at The College of William & Mary.

Experimental design. Subjects initially performed two familiarization trials on the isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY) that were separated by 3–5 d. Examining a subset of subjects beforehand, it was determined that, as in young men, employing two familiarization trials among the aged was just as effective as three trials in overcoming the early learning curve that is evident with strength testing on an isokinetic dynamometer. Indeed, among the subset of four older subjects, average gains in strength from the second to the third familiarization trial was less than 5%. After a 5- to 7-d recovery period, subjects returned to the laboratory to perform their preintervention data collection session. They were instructed to fast for 4–8 h before arriving and to avoid heavy physical exertion for the 24 h prior to their laboratory appointment. To account for circadian variation, all subjects conducted their pre- and postintervention tests at 15:30 h into the day.

Upon their arrival, height and weight were measured, and skinfold calipers (Lange, Beta Technology, Inc., Cambridge, MD) were used to assess skinfold thickness. After a 5-min equilibration period while seated, a 3-mL blood sample was obtained from an antecubital vein. Whole blood was collected into a heparin-treated tube (Vacutainer, Becton Dickinson, Franklin Lakes, NJ) and centrifuged at 3000g for 10 min at 4°C. The resultant plasma was stored at −80°C until bloodborne variables were analyzed.

Subjects were then seated on the Biodex dynamometer, which was properly adjusted according to limb length, and performed a warm-up set (~66% of perceived maximal effort) of five repetitions at each of the movement velocities that were to be used to quantify muscle function. Following the warm-up, the right knee—all testing was done on the right leg—was aligned at a 95° angle on the dynamometer. In preparation for the collection of surface electromyographic (EMG) data, a one-square-inch area over both the right vastus lateralis (VL) and vastus medialis (VM) was shaved, abraded, and cleansed with an alcohol wipe. Along the longitudinal contour of the muscle, 2-mm diameter electrodes filled with electrolyte gel were secured on the skin with adhesive collars at an interelectrode distance of 2 cm and traced with indelible ink. These tracings enabled the replication of electrode placement for the postintervention test 1 wk later.

EMG data were collected during a 1-s maximal-effort isometric contraction of the right knee extensors. Subsequent to this, subjects were tested for maximal isokinetic muscle function of the knee extensors at the movement velocities of 0.53, 1.05, 2.09, and 3.14 rad·s⁻¹. At all but the fastest velocity, sets of five repetitions were conducted to assess peak torque, total work performed, and average power, but at 3.14 rad·s⁻¹, 30 maximal repetitions were completed to determine muscle endurance. Three-minute rest intervals interspersed sets, and verbal encouragement was provided throughout each set; range of motion was held constant for each set during both pre- and postintervention testing.

Upon completion of this initial data-collection session, subjects were instructed in the proper use of crutches and began their period of muscle unloading. To maximize compliance, the importance of avoiding all weight-bearing activity of the affected leg was forcefully and explicitly conveyed to the subjects. Moreover, subjects were regularly contacted during the 7-d intervention period to be reminded of the importance of maintaining a non–weight-bearing condition. Subjects returned to the laboratory 7 d following the initial testing session, again at 15:30 h, to perform their postintervention data collection session, which replicated procedures used during preintervention testing.

Muscle unloading. The model used to elicit unloading of the thigh muscles of the right leg was a modification of the unilateral lower-limb suspension (ULLS) technique first described by Berg et al. (5), which has been used previously (10). In this modification, the right leg is placed in a lightweight orthopedic knee brace (Donjoy, djOrthopedics, Chicago, IL) set at an angle of 70°, effectively shortening the leg and preventing it from weight-bearing activity. Subjects were required to use crutches during ambulatory activity. Aged and young men were instructed to remove the knee brace upon retiring to bed for the evening, and to perform range-of-motion activities while lying in bed before sleeping, and again upon awaking in the morning. As additional precautionary measures taken to minimize any circulatory impairment, aged men were provided with compression stockings, and, if already doing so, they were encouraged to continue taking daily doses of children’s aspirin. Neither young nor aged subjects reported or displayed circulatory complications during the unloading intervention. It should be noted that this version of ULLS not only results in a continuous (i.e., day and night) state of unloading, but also limb immobilization during the daytime hours. Finally, it must be underscored that ULLS—like bed rest, total immobilization, and microgravity—does not control for neural activation of the affected leg muscles. Rather, all of these models are used to impart a state of unloading, or non–weight bearing, on the affected musculature.

The intervention period of 7 d was selected in large part out of concern for potential circulatory complications (i.e., deep vein thrombosis), particularly among aged subjects who are more susceptible to such maladies (11,38). Pilot
data had indicated that 7 d of unloading was sufficient to induce decreases in strength. Thus, it was determined that 1 wk was an appropriate duration of unloading to evoke a decrement in neuromuscular function while, at the same time, minimizing the risk of venous thromboembolism, especially among older subjects.

Quantification. Resting plasma concentrations of total testosterone and cortisol were assessed in duplicate using enzyme immunoassays (Diagnostic Systems Laboratories, Webster, TX) in conjunction with an automated microparticle reader (Multiskan RC, Labsystems, Helsinki, Finland). For each hormone, all samples were measured on a single microwell plate to avoid interassay variation. Intraassay variation for each hormone was < 10%; sensitivities for testosterone and cortisol were 0.14 and 2.76 nM, respectively.

During EMG recordings, signals were amplified by a factor of 1000 and passed through a bandwidth filter set at 30 and 500 Hz, along with a 60-Hz notch filter. Signals were digitized at a sampling frequency of 1000 Hz and were recorded by an online computer system during the maximal isometric contraction of the right quadriceps. These raw recordings were then full-wave rectified, integrated, and quantified as root mean square (RMS) with the MyoResearch XP software (Noraxon USA, Inc., North Scottsdale, AZ). The same software was used to analyze EMG data.

Muscle performance variables of interest (peak torque, total work, average power, and muscle endurance) were calculated by the software package accompanying the Biodex dynamometer. Muscle endurance was assessed as the difference in work produced during the first 10 repetitions compared with the last 10 repetitions during the 30-repetition set completed at 3.14 rad s−1.

Neuromuscular efficiency, viewed as the responsiveness of muscle to neural excitation, was quantified by dividing the torque generated by knee extensors during the maximal isometric effort by the average EMG activity recorded at the VL and VM muscles during that contraction.

Statistical analysis. All data are reported as means ± SE. Independent t-tests were used to compare descriptive characteristics of the young and aged groups. The effects of aging and muscle unloading were determined with a repeated-measures factorial analysis of variance (ANOVA). In the event of a significant F ratio, post hoc procedures were employed to identify between-group differences (independent t-tests) and/or pre- to postintervention differences (dependent t-tests). In all cases, an alpha level of 0.05 was used to establish significance.

RESULTS

Body Mass

The 7-d period of muscle unloading did not impact the body mass of the subjects. This was true for both young and aged men (data not shown).

Muscle Function

Peak torque. Repeated-measures factorial ANOVA results on peak torque during the isometric contraction (0 rad s−1), as well as the isokinetic set performed at 0.53 rad s−1, identified a significant main effect of unloading (P = 0.0006, 0.0004 at 0 and 0.53 rad s−1), but not a significant main effect of age, or a significant interactive effect. In both the young and the aged subjects, the unloading intervention resulted in significant (P = 0.005 and 0.04, respectively, at 0 rad s−1; P = 0.007 and 0.02, respectively, at 0.53 rad s−1), but similar, decrements in strength (~15% at 0 rad s−1 and ~12% at 0.53 rad s−1). It was also determined that both before and after unloading, young and aged men displayed similar peak torque values at those movement velocities.

At 1.05 rad s−1, a significant (P = 0.002) main effect of unloading was again found, indicating that both young and aged men suffered significant (P = 0.04 and 0.001, respectfully) and similar declines (~6%) in strength following unloading. However, at this faster velocity, the first signs of age-related differences were observed. A statistical trend (P = 0.07, effect size = 0.89) suggested a potential main effect of aging whereby strength was greater in young men than in aged ones before and after muscle unloading.

At 2.09 rad s−1, clear evidence of age-related differences in strength were detected. And, although a significant main effect of age was noted (P = 0.01), along with a significant interactive effect (P = 0.04), no significant main effect of unloading was observed, unlike results from the slower speeds of movement. Post hoc analysis indicated that while contracting at 2.09 rad s−1, strength was significantly greater in young men than in aged men, both before (P = 0.03) and after (P = 0.006) the unloading intervention. It was also found that the unloading-induced diminution in peak torque at 2.09 rad s−1 was significantly more pronounced among the aged than the young (P = 0.02) subjects (6 vs 0% decline). Data showing the effects of unloading on peak torque generated by young and aged men can be found in Table 1.

Total work. Results from the repeated-measures factorial ANOVA indicated significant main effects for both age (P = 0.02, 0.03, and 0.007) and unloading (P = 0.0002, 0.02, and 0.04) at each of the movement velocities assessed (0.53, 1.05, and 2.09 rad s−1). And, at 2.09 rad s−1, a significant interactive effect (P = 0.045) was also detected. Post hoc procedures for the main effect of age revealed that at each isokinetic velocity, total work performed by young men was significantly greater than that by aged men both before (P = 0.04, 0.04, and 0.03) and after (P = 0.01, 0.02, and 0.001) unloading. Post hoc analysis conducted for the main effect of unloading showed that when contracting at 0.53 rad s−1, both young and aged men experience significant (P = 0.02 and 0.006, respectfully), but similar, declines in work performed following unloading. But at 1.05 and 2.09 rad s−1, only...
TABLE 1. Effects of short-term muscle unloading on peak torque, total work, and average power in young and aged men.

<table>
<thead>
<tr>
<th>Velocity (rad ( \text{s}^{-1} ))</th>
<th>Peak torque (newtons at isometric, newton-meters at isokinetic)</th>
<th>Average power (W)</th>
<th>Total work (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preunloading</td>
<td>Postunloading</td>
<td>Preunloading</td>
</tr>
<tr>
<td>0.53</td>
<td>220.2 ± 14.4</td>
<td>197.2 ± 16.7</td>
<td>561.4 ± 44.2</td>
</tr>
<tr>
<td>1.05</td>
<td>206.0 ± 12.9</td>
<td>184.2 ± 15.1</td>
<td>616.5 ± 40.7</td>
</tr>
<tr>
<td>2.09</td>
<td>171.3 ± 10.3</td>
<td>172.7 ± 13.9</td>
<td>494.9 ± 30.2</td>
</tr>
</tbody>
</table>

Values are means ± SE; N = 10 per group.
* Significant (P < 0.05) pre- to postunloading difference within the same age group; † significant (P < 0.05) difference from the value of aged men at the same time point—that is, before or after unloading.

Aged men displayed significant (P = 0.03 and 0.01, respectively) unloading-induced reductions in total work. Thus, age-related differences in sensitivity to unloading were even more apparent in assessing total work performed than in peak torque, where age-related differential responses to ULLS were noted only at 2.09 rad \( \text{s}^{-1} \). Table 1 presents data on total work produced during isokinetic contractions at 0.53, 1.05, and 2.09 rad \( \text{s}^{-1} \).

**Average power.** In assessing average power generated during isokinetic contractions, repeated-measures factorial ANOVA revealed significant main effects for age (P = 0.03, 0.04, and 0.02) and unloading (P = 0.001, 0.005, and 0.04) at each velocity used (0.53, 1.05, and 2.09 rad \( \text{s}^{-1} \)). And, at 2.09 rad \( \text{s}^{-1} \), a significant interactive effect (P = 0.04) was identified. Post hoc procedures for the main effect of age indicated that young men demonstrated significantly greater power than aged ones at each isokinetic velocity tested both before (P = 0.03, 0.04, and 0.03 at 0.53, 1.05, and 2.09 rad \( \text{s}^{-1} \)) and after (P = 0.04, 0.03, and 0.008 at 0.53, 1.05, and 2.09 rad \( \text{s}^{-1} \)) the ULLS intervention. In assessing the main effect of unloading, post hoc analysis revealed that both young (P = 0.006) and aged (P = 0.02) men experienced unloading-induced declines in power at 0.53 rad \( \text{s}^{-1} \), but at the faster speeds of movement only aged men exhibited diminished power following ULLS (P = 0.02 and 0.02, at 1.05 and 2.09 rad \( \text{s}^{-1} \)). These results mimic those of total work presented above and, again, suggest that measuring peak strength may not be the most sensitive method for evaluating the influence of aging on sensitivity to unloading-related neuromuscular disturbance. Data concerning average power generated during isokinetic contractions at 0.53, 1.05, and 2.09 rad \( \text{s}^{-1} \) are displayed in Table 1.

**Muscle endurance.** Repeated-measures factorial ANOVA results failed to identify a significant main effect for either age or unloading. Moreover, no significant interactive effect was noted. Thus, when evaluating muscle endurance as resistance to muscle fatigue during a 30-repetition set of maximal effort contractions completed at 3.14 rad \( \text{s}^{-1} \), the decrement in total work performed during that test did not differ between young and aged men either before or after 7 d of unloading. Moreover, neither age group experienced a significant alteration in muscle endurance as a result of the unloading intervention (data not shown).

**EMG and neuromuscular efficiency.** Repeated-measures factorial ANOVA results for EMG data did not identify a significant main effect for unloading. That is, neither young nor aged men experienced a significant decline in EMG activity over the course of the 7-d unloading intervention (~2% and ~14%, respectfully). Similarly, no significant interactive effect was observed. However, a significant (P = 0.01) main effect of age was detected, which showed that both before (P = 0.01) and after unloading (P = 0.01), the EMG activity generated during maximal muscle effort was greater in the young than in the aged subjects (pre-ULLS = 43%, post-ULLS = 50%).

When analyzing the neuromuscular efficiency data, ANOVA results indicated a trend (P = 0.08, effect size = 0.22) for a main effect of unloading, and a significant (P = 0.04) main effect of age. No significant interactive effect was identified. Post hoc analysis for the main effect of age revealed that before ULLS there was only a trend (P = 0.08, effect size = 0.94) for the neuromuscular efficiency of aged men to exceed that of young ones, but unloading amplified that difference, such that during postintervention testing, the
neuromuscular efficiency of aged men was significantly greater than that of young men ($P = 0.02$). Table 2 presents EMG and neuromuscular efficiency data.

**Plasma Hormones**

The statistical analysis of testosterone concentrations showed a significant ($P = 0.0006$) main effect for aging, whereby levels of this anabolic hormone were significantly higher in young men than in aged ones both before ($P = 0.002$) and after muscle unloading ($P = 0.0006$), as indicated by post hoc analysis. Neither group, however, experienced a significant alteration in bloodborne testosterone values as a result of the 7-d period of unloading, nor was a significant interactive effect established.

Concentrations of the catabolic hormone cortisol also demonstrated a trend ($P = 0.09$, effect size = 0.97) for being higher in young men than in aged men, but following the unloading intervention, this trend for an age-related difference was no longer evident. This was coupled with a significant ($P = 0.04$) unloading-induced increase in plasma cortisol among aged but not young men.

To provide an indication of the general anabolic endocrine milieu (23), testosterone:cortisol ratios were also calculated. Two-way repeated-measures ANOVA indicated a significant ($P = 0.02$) main effect of age. Post hoc procedures showed that compared with aged subjects, this ratio was significantly elevated in young men both before ($P = 0.046$) and after muscle unloading ($P = 0.02$). In neither group was the ratio of plasma testosterone to cortisol modified by short-term unloading, and no significant interactive effect was identified. Results from the analysis of circulating hormones can be found in Table 3.

**DISCUSSION**

Research has confirmed that unloading and aging bring about similar negative adaptations of the neuromuscular system. These include a loss of strength (1,7,9,26), atrophy of whole muscles and myofibers (2,6,16,19), changes in the capacity of the nervous system to stimulate muscles (10,39), and even alterations in the concentrations of circulating hormones (10,40). But it is unknown how the interaction of these two conditions—that is, unloading and aging—impact the neuromuscular system. More specifically, it has yet to be determined whether the preexisting degenerative pro-

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**TABLE 3. Effects of short-term muscle unloading on resting plasma hormone levels in young and aged men.**

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Aged</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preunloading</td>
<td>Postunloading</td>
</tr>
<tr>
<td>Testosterone (nM)</td>
<td>23.7 ± 3.3†</td>
<td>24.8 ± 2.9†</td>
</tr>
<tr>
<td>Cortisol (nM)</td>
<td>699.0 ± 147.8</td>
<td>735.2 ± 163.1</td>
</tr>
<tr>
<td>Testosterone:cortisol</td>
<td>33.7 ± 5.8†</td>
<td>33.9 ± 5.1†</td>
</tr>
</tbody>
</table>

Values are means ± SE; $N = 10$ per group.
* Significant ($P \leq 0.05$) pre- to postunloading difference within the same age group; † significant ($P \leq 0.05$) difference from the value of aged men at the same time point—that is, before or after unloading.
were demonstrated not only at 2.09 rad·s⁻¹, but also at the slower isokinetic velocities of 1.05 and 0.53 rad·s⁻¹. These findings suggest that strength may not be the most sensitive parameter that can be assessed to detect the effects of aging on muscle function.

In addition to preexisting age-related differences in muscle function, the present investigation confirmed that aged and young men respond differently to brief periods of unloading. These differences, however, are revealed in a manner that is specific to contractile velocity. That is, ULLS-induced loss of strength was similar among aged and young men at 0, 0.53, and 1.05 rad·s⁻¹, but at 2.09 rad·s⁻¹ it was found that only aged men exhibited declines in strength following unloading. This age-related difference in susceptibility to muscle unloading was also manifested, and even amplified, when muscle function was assessed either as total work performed, or average power generated during brief sets of isokinetic contractions. More specifically, while age-related differences in the sensitivity to unloading-induced decrements in strength were observed only at 2.09 rad·s⁻¹, it was determined that aged men, but not young men, experienced significant pre- to postunloading declines in total work and average power at both 1.05 and 2.09 rad·s⁻¹. (At the slower velocity of 0.53 rad·s⁻¹, young men displayed similar and significant decreases in work and power produced.) These results, combined with those of peak torque, indicate not only that aging exacerbates one's sensitivity to the detrimental effects of unloading, but also that this age-specific sensitivity is evident only when muscle function is quantified at faster contractile velocities. Thus, it appears that unloading amplifies the degenerative processes already present among aged muscles and further degrades the functional capacity of fast-twitch muscle tissue. Unfortunately, muscle biopsies were not performed in the present study, so it is not possible to definitively ascertain whether unloading among the aged men elicited atrophy specific to fast-twitch myofibers. More likely, the unloading intervention hastened aging-related neurodegenerative processes that preferentially affect fast motor neurons and precede the loss of fast-twitch muscle tissue (3,29) and, thus, inhibited the capacity of aged subjects to voluntarily activate fast-twitch muscle during faster contractile velocities. However, this age-related remodeling of motor units apparently does not affect baseline muscle endurance, at least as measured here, or susceptibility to unloading-induced alterations in that parameter. In the present study, fatigability during the completion of 30 maximal-effort repetitions at 3.24 rad·s⁻¹ was similar in young and aged men before and after ULLS.

EMG activity generated by the VL and VM muscles during the 1-s isometric contractions completed before and after the 1-wk unloading intervention was also recorded. It was determined that young men produced more EMG activity during those maximal efforts than older men did before, and after, muscle unloading. This age-related difference in EMG activity is probably best explained by the denervation and reinnervation process noted among aged muscle that results in the loss of some fast-twitch fibers and conversion of others to slow-twitch. As reported by Larsson (25) and others (12,29), as the degeneration of fast motor axons proceeds during aging, some of the newly abandoned (denervated) fast-twitch myofibers atrophy and eventually die (apoptosis), while others are reinnervated by neighboring slower motor axons, resulting in a remodeling of the muscle's motor units—that is, a smaller number of units that are larger in size and slower in contractile characteristics. And because a greater proportion of whole muscle mass comprises slow-twitch muscle, EMG activity generated by aged, contracting muscle declines, because slow-twitch muscle produces less electrical activity than fast-twitch tissue (21).

A Pearson product–moment correlation run between ULLS-induced changes in EMG activity and peak torque revealed a strong (r = 0.79) and significant (P < 0.0002) relationship between the decrease in strength and neural activation of unloaded muscles, suggesting that in both age groups, neural factors mainly accounted for the loss of peak torque during static contractions. A correlation was also run between habitual activity values reported by subjects and their alterations in strength as a result of unloading. This analysis revealed a very weak (r = 0.14) and nonsignificant relationship between those two variables. It appears that at least among untrained, and only moderately active individuals, initial levels of physical activity do not influence how much strength is lost during a brief period of muscle unloading.

As with EMG, data reported here suggest that aging influences neuromuscular efficiency both before and after unloading. Yet, it was interesting to find that at least for this one variable of interest, aging had a favorable effect. That is, relative to EMG activity recorded, aged men produced more force than young men did. This, too, can probably be explained by the preferential loss of fast-twitch muscle mass among the aged. Since fast-twitch muscle generates more EMG activity than does slow-twitch muscle (21), it is reasonable that the ratio of force to EMG would be higher among aged subjects, due to their preferential loss of fast-twitch muscle mass. Also considered was the possibility that differences in skinfold thickness of the thigh could have insulated aged muscles, thereby blunting the amplitude of their EMG recordings, but skinfold thickness was similar in young and aged men (12.3 and 12.0 mm, respectively).

Although the EMG data presented here suggest that aging does not alter one's sensitivity to unloading-induced adaptations, the fact that neuromuscular efficiency (force relative to EMG) was significantly greater among aged than young men only after the ULLS intervention supports the previously expressed contention that unloading hastens the neurodegeneration of fast motor neurons that naturally occurs among the aged, and that a decreased ability to recruit fast-twitch myofibers precedes atrophy of those fibers. Accordingly, it is postulated that this ULLS-related...
acceleration of the neurodegeneration of fast axons is primarily responsible for unloading-induced decrements in muscle function that was revealed only among aged men at faster contractile velocities.

In addition to age-related differences in neural drive, it is likely that the greater strength produced by young compared with aged men, both before and after the ULLS intervention, can be linked to similar differences in muscle size. As previously alluded to, significant reductions in muscle size occur after 50 yr of age (16,30). Accordingly, it is reasonable to expect that the size of the quadriceps was greater in young men than in the aged men participating in the present investigation.

At least in part, the age-related loss of muscle mass has been attributed to changes in the anabolic status of the endocrine environment (31). The data reported here are consistent with previous studies documenting diminished levels of circulating testosterone among aged men (13,24,32). The young men of the present study had higher concentrations of that potent anabolic steroid than aged men did, both before and after the unloading intervention. And, although cortisol levels were also elevated in young men compared with aged ones, they were not increased enough to counter the higher testosterone values noted among the young males. As a result, testosterone to cortisol ratios were higher among young men, suggesting the presence of a more positive bloodbome anabolic environment for skeletal muscle. This, too, has been previously reported (15). A novel finding presented here was that aged men, but not young men, experienced similar declines in muscle function following a brief period of muscle unloading. But at faster speeds of contraction, not only were age-related differences in muscle function apparent before unloading (young > aged), but it was also revealed that—with the exception of resistance to fatigue-aged men suffered greater unloading-induced declines in muscle function. Moreover, in addition to preexisting differences in EMG activity produced during isometric contractions (young > aged), unloading-induced decrements in isometric strength were well coupled with pre- to postunloading declines in the neural activation of contracting muscles. Finally, the overall anabolic status of circulating hormones was not only initially lower among aged men, but unloading elicited an increase in bloodborne cortisol levels exclusively among aged subjects. The results of this investigation present a troubling scenario in that the aged—that rapidly growing demographic segment of Western society that is most likely to experience imposed muscle unloading—are more severely impacted by the deleterious effects of that condition.

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