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# Factors Relating to Gender Specificity of Unloading-induced Declines in Strength

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## Abstract

**BACKGROUND—**This investigation aimed to: 1) confirm whether women were more vulnerable to the negative neuromuscular adaptations elicited by muscle unloading and if so, 2) determine which physiological mechanism(s) explain those gender-related differences.

**METHODS—**Healthy young men (20.7 ± 0.3 yrs) and women (20.3 ± 0.3 yrs) - (N=12/group) - participated by completing neuromuscular functional tests before and after 7 d of unloading.

**RESULTS—**During isokinetic testing of peak torque, work performed, and power, women displayed significantly ($P \leq 0.05$) greater declines in performance than men at 1.05 and 2.09, but not 0.53 rads/s. During maximal isometric contractions, women experienced greater strength decrements. Similar gender-specific adaptations to unloading were found in EMG activity, but not muscle mass, neuromuscular transmission, or force relative to EMG.

**CONCLUSIONS—**Women are more susceptible to the adaptations of muscle unloading, and disturbances in neural drive from the central nervous system are probably responsible.

### Keywords

atrophy; disuse; gender; unweighting; neuromuscular

## INTRODUCTION

The deleterious adaptations brought about by muscle unloading in humans are well known and have been established by an impressive body of literature. They include reductions in muscle strength and power,[1–5] along with atrophic responses of whole muscles and their constituent muscle fibers.[6–9] Moreover, electromyography (EMG) has been utilized to demonstrate that the capacity of the nervous system to stimulate maximally contracting skeletal muscle is attenuated following muscle unloading.[4, 10–12] In sum then, the outcomes of muscle unloading have been well elucidated and have been reported in several excellent reviews.[13–15]

Far less studied, however, are factors that might influence the magnitude or rate at which these unloading-induced adaptations occur. Of further concern is the fact that what is known regarding these factors has been gathered from a few seemingly isolated investigations, rather than by a larger, conclusive body of evidence. Nevertheless, from those few studies it has been reported that aging influences the consequences of muscle unloading among

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humans in that aged men suffer greater losses of strength at faster, but not slower velocities of maximal effort isokinetic muscle contractions compared to younger individuals.[10] It has also been reported that, among young men, pre-habilitative conditioning (i.e., resistance training performed prior to a period of muscle unloading) does not significantly mitigate unloading related decrements in neuromuscular function.[16] More recently it has been reported that, when they are subjected to the same protocol of muscle unloading, women lose significantly more strength than men.[17] That study was limited, however, in its ability to identify what mechanism(s) may account for the more severe decrements in strength experienced by women than men (29% vs. 16%) as a result of a 7 d muscle unloading intervention. Accordingly, the aim of this investigation was twofold: 1) to determine if gender-specific adaptations to muscle unloading would be replicated in a different cohort of young men and women, and 2) if so, to reveal what physiological mechanism(s) are involved in rendering women more vulnerable to the negative effects of muscle unloading.

## MATERIALS AND METHODS

### Subjects

12 healthy young men (20.7 ± 0.3 yrs, 176.5 ± 2.0 cm, 72.4 ± 2.5 kg; mean ± SE), and 12 healthy young women (20.3 ± 0.3 yrs, 167.1 ± 2.3 cm, 62.9 ± 1.3 kg) volunteered to participate in the study. As indicated by completing a written questionnaire,[18] men and women demonstrated similar moderate levels of habitual physical activity. All subjects were verbally apprised of the purpose of the study and of its potential risks before they 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 an isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY) that were separated by 3–5 days. After a 5–7 day recovery period, subjects returned to the laboratory to perform their pre-intervention data collection session. They were instructed to fast for 4–8 hours before arriving and to avoid heavy physical exertion for 24 hours prior to the appointment. To account for circadian variation, all subjects conducted their pre- and post-intervention tests at 15:30 hours. Since it has been previously determined that muscle performance is unaffected by phase of the menstrual cycle,[19–21] it was not necessary to take that variable into account when planning pre- to post-unloading testing in female subjects.

Upon the subjects' arrival for the pre-intervention data collection session, a dual energy X-ray absorptiometry (DEXA) scan was collected (GE LUNAR Prodigy, Waukesha, WI) to quantify lean body mass (i.e. skeletal muscle) of the right thigh. After this, height and weight were measured on a conventional scale. 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 (testing was done consistently on knee extensors of the right leg) was aligned at a 95° angle on the dynamometer. In preparation for the collection of surface EMG data, one inch square areas over both the right vastus lateralis (VL) and vastus medialis (VM) were 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 inter-electrode distance of 2 cm and traced with indelible ink. Consistent with previous reports of alterations in EMG with changes in strength,[22–24] these tracings enabled the replication of electrode placement for the post-intervention test one week later. EMG data were collected during a one second interval of a 3 second maximal effort isometric contraction of the right knee extensors while receiving forceful verbal encouragement. This allowed EMG recordings to be collected while muscles were fully activated rather than during the "ramping up" phase to maximal effort.

Recording electrodes were then removed, and two large (2.75 in by 5 in) stimulating electrodes (Dura-Stick, Chattanooga Group, Hixson, TN) were placed parallel in position and diagonal in orientation to maximally cover the knee extensor muscles. To allow accurate repositioning of stimulating electrodes for post-testing, the corners of the electrodes were traced with indelible ink. The knee remained fixed at a 95° angle, and upon command the subject executed a maximal effort isometric contraction of the knee extensors while receiving forceful verbal encouragement from the tester. The force produced during this effort was visualized in real time by the tester but not the subject on the dynamometer's computer monitor, and when force had reached a plateau, an electrical stimulation (Grass S48 stimulator, with Grass SIU8T stimulus isolation unit, W. Warwick, RI) was delivered that was of proper intensity (135 volts), duration (0.6 ms), and rate (100 Hz) to stimulate the nerve terminal endings lying atop muscle fibers, resulting in indirect, or neural, stimulation of the contracting muscle.[25–27]

Subsequent to the isometric contractions, subjects were tested for maximal isokinetic muscle function of the knee extensors at movement velocities of 0.53, 1.05, and 2.09 rads/s. At each of those isokinetic velocities, a set of five repetitions was conducted to assess peak torque, total work performed and average power. 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 post-intervention testing and at each isokinetic movement velocity. It should be noted that, because the main objective of the study was to examine unloading-induced alterations in muscle function, strength was not normalized to body mass in men and women. Upon completion of this initial data collection session, subjects were instructed in the proper use of crutches and began their period of muscle unloading.

## 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.,[28] that has been used previously.[4, 10, 16] In this modification, the right leg is placed in a light weight orthopedic knee brace (Donjoy, djOrthopedics, Chicago, IL, USA) set at a 70° angle, effectively shortening the leg and preventing it from weight bearing activity. To be assured that no weight bearing activity occurred, a tubular elastic bandage (stockinette) was placed over the subject's right foot extending from the ball of the foot to the base of the calf muscles. An empty aluminum juice can was then inserted beneath the stockinette, i.e. between the skin and stockinette, and placed comfortably within the arch of the foot in an orientation that was perpendicular to the heel to toe vector. Using stretchable athletic tape, the can was secured in that position, and the tape was marked with a unique code using invisible ink. Thus, if the subject engaged in weight bearing activity on the involved leg it would be revealed by a deformation of the aluminum can, and tampering with the setup would not be possible without disturbing the positioning of the tape along with the code written on it in invisible ink.

During the 7 d unloading intervention, subjects were required to use crutches during all ambulatory activity. As done previously,[29] the knee brace was removed upon retiring to bed for the evening - bed rest also presents muscle unloading – and subjects were asked to perform very light intensity range of motion activities while lying in bed to promote circulation and to defend against loss of range of motion/muscle stiffness.[4, 12, 16] As an additional precautionary measure taken to minimize any circulatory impairment, women who were taking oral contraceptives were precluded from participating in the study. No 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 conditions impart a state of unloading, or non-weight bearing, on the affected musculature.

### Quantification

Muscle performance variables of interest (peak torque, total work, and average power) were calculated by the software package accompanying the Biodex dynamometer. During EMG recordings, signals were amplified by a factor of 1,000 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 1,000 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, USA).

Excitation-contraction coupling efficiency, viewed here as muscle force produced relative to excitation of the sarcolemma, 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.

As used previously,[30–32] superimposed electrical stimulation procedures applied during maximal isometric contractions assessed neuromuscular transmission failure (recall that the impulse applied stimulated the nerve endings rather than the muscle itself). The maximal amount of force generated voluntarily was divided by the total amount of force produced when external electrical stimulation of nerve endings was coupled with that effort and multiplying by 100. Three such efforts were performed, separated by 3 min rest intervals. The two best efforts, in terms of neuromuscular transmission efficiency and assuming a voluntary effort that produced force that was at least 90% as great as that during the initial effort during EMG recordings, were averaged together to arrive at a figure for that testing session.

### Statistical analysis

All data are reported as means ± SE. A 2-way (main effects of time and gender) repeated measures analysis of variance (ANOVA) was performed on each variable of interest. In the event of a significant F ratio, *post-hoc* procedures were employed to identify between-group differences (independent *t*-test) and/or pre- to post-intervention differences (dependent *t*-test). Independent *t*-tests were used to compare ULLS-induced declines (% difference from pre- to post-ULLS) in isometric strength, EMG, and neuromuscular efficiency between men and women. Pearson Product correlations were used to relate changes in isometric strength with those of EMG, thigh muscle mass, and neuromuscular transmission failure. In all cases, $P \leq 0.05$ was used to establish significance.

## RESULTS

### Body mass

Prior to the 7 d unloading intervention, men were significantly heavier than women, and this difference was also evident at the post-intervention interval. Moreover, it was established that the ULLS protocol did not alter the body mass of either men or women.

### Peak torque

Factorial ANOVA results for peak torque at 0 rads/s (i.e. isometric contraction) showed significant main effects for gender and unloading. *Post-hoc* analysis revealed that men had significantly greater strength of the knee extensors before and after unloading (Table 1). It was also found that, although both men and women experienced significant declines in isometric strength as a result of unloading, the magnitude of that loss was significantly more pronounced in women than men (22% vs. 13%).

At the contractile velocity of 0.53 rads/s, the initial ANOVA performed again revealed significant main effects for gender and unloading. Follow-up *post-hoc* procedures indicated that peak torque at this isokinetic velocity was more impressive in men than women at both pre- and post-ULLS testing sessions. It was also noted that both men and women exhibited significant strength decrements as a result of unloading, but unlike at 0 rads/s the losses detected at 0.53 rads/s did not differ between men and women.

Results of isokinetic strength testing performed at 1.05 rads/s once again displayed significant main effects for gender and unloading. Gender-related *post-hoc* analysis showed that both before and following 7 d of ULLS, men were significantly stronger than women. But in examining the effects of muscle unloading on the two genders, it was shown that women, but not men, displayed significant unloading-induced strength decreases.

At the final and fastest isokinetic velocity at which peak torque was assessed − 2.09 rads/s – significant main effects for gender and unloading were again noted. Follow-up *post-hoc* procedures revealed that prior to, as well as following the ULLS intervention, men demonstrated higher peak torque values than women. But importantly, and consistent with what was observed at the contractile velocity of 1.05 rads/s, peak torque at 2.09 rads/s significantly declined only in women as a result of muscle unloading. Data for peak torque are shown in Table 1.

### Total work

Unlike peak torque, total work was quantified exclusively during isokinetic muscle actions since, by definition, the calculation of work requires dynamic movement within a known range of motion. At the slowest isokinetic velocity used, our initial ANOVA results indicated that there were significant main effects for gender and unloading. Follow-up procedures showed that work performed by men during five repetitions at 0.53 rads/s was significantly greater than that of women both before, and following the ULLS intervention. *Post-hoc* analysis for the unloading effect revealed that both men and women exhibited significant, but similar, decreases in total work performed at 0.53 rads/s.

At the contractile velocity of 1.05 rads/s, ANOVA results once again identified significant main effects for gender and unloading. *Post-hoc* results showed that during both pre-and post-ULLS testing, the total work completed during five maximal effort contractions was significantly more impressive among men compared to women. However, when examining the impact of unloading on men as opposed to women, it was found that only women suffered significant pre- to post-ULLS decrements in work performed.

In assessing the work performed at 2.09 rads/s, ANOVA results identified significant effects of gender and unloading. *Post-hoc* analysis demonstrated that men completed more total work than women both before and after unloading. And in examining the effect of the ULLS intervention separately among men and women, it was once again revealed that although unloading significantly impaired muscle performance among women, no such effect was observed among men. Results gathered from the analysis of total work performed can be viewed more completely in Table 2.

### Average power

Similar to total work, quantification of average power produced by the knee extensors was determined only during sets of isokinetic, dynamic contractions. ANOVA results showed that at the contractile velocity of 0.53 rads/s, significant main effects of gender, as well as unloading were apparent. Upon closer examination it was revealed that both prior to, and subsequent to the ULLS intervention the muscular power expressed by men was significantly greater than that of women. *Post-hoc* analysis also demonstrated that both men and women exhibited significant, and similar, reductions in power as a result of 7 d of muscle unloading.

At the faster contractile velocity of 1.05 rads/s, results from the initial ANOVA identified, again, significant main effects for gender and unloading. *Post-hoc* procedures for the effect of gender indicated that men generated significantly more power than women both before and after unloading. At this movement velocity, however, it was found that women, but not men, experienced a significant loss of muscle power due to unloading.

During contractions at 2.09 rads/s, ANOVA results again showed significant main effects for gender and unloading. And as with the slower contractile velocities examined, men displayed significantly higher power values relative to women during both the pre- and post-ULLS testing sessions. And as at the contractile velocity of 1.09, but not 0.53 rads/s, only women experienced significant unloading-induced reductions in muscle power. Data regarding the impact of unloading on power expressed by men and women can be found in Table 3.

### EMG and excitation-contraction coupling

Our ANOVA analysis of EMG recordings taken during maximal effort isometric contractions again revealed significant main effects for gender and unloading. Concerning the main effect for gender, *post-hoc* procedures demonstrated that, although there was no difference in EMG between men and women during pre-ULLS testing, a significant difference did exist during post-ULLS testing (men > women). And in the follow-up analysis for the main effect of unloading, it was noted that men did not experience significant pre- to post-ULLS differences in EMG. But in contrast, women did, in fact, exhibit a significant unloading-related decrease in EMG.

During maximal effort isometric contractions in which EMG activity was recorded, peak torque produced was also quantified. This allowed us to express the amount of force generated relative to EMG activity (torque/EMG) to yield a measure of the excitation (EMG) to contraction (torque) relationship. Statistical analysis of this excitation to contraction coupling indicated that there was no difference between men and women and that unloading did not alter this relationship in either men or women. Table 4 displays data for EMG and excitation to contraction coupling.

### Neuromuscular transmission

The superimposed electrical stimulation technique was used to provide insight into the efficacy of neuromuscular transmission, i.e. the ability of an electrical stimulus arriving at the nerve terminals to carry over to the sarcolemma and produce muscular force. Our ANOVA results failed to detect any significant differences between men and women before or after ULLS or any significant alteration of this variable as a result of the unloading protocol. These findings are shown in Table 5.

### Thigh muscle mass

DEXA scans were use to evaluate the effect of 7 d of unloading on lean body tissue, i.e. skeletal muscle, mass of the affected right thigh region of the body. ANOVA procedures identified a statistically significant main effect of gender, but only a trend (P=0.08) for a main effect of unloading. *Post-hoc* analysis for the effect of gender indicated that men had significantly greater muscle mass of the right thigh than women both before and after the ULLS intervention. Data regarding right thigh muscle mass can be found in Table 6.

## Correlations

In an attempt to gain greater insight as to what mechanism(s) contribute most powerfully to unloading-induced declines in strength, Pearson correlations between decrements in peak isometric force over the 7 d period of ULLS and unloading-induced changes in EMG, excitation to contraction coupling, neuromuscular transmission efficiency, and thigh muscle mass were determined. The sole statistically significant correlation ($r = 0.52$; P=0.01) was between decrements in strength resulting from unloading with those of EMG activity.

## DISCUSSION

There were two main objectives of this investigation. The first was to ascertain whether women truly are more susceptible to the negative effects of short-term muscle unloading, as indicated in a recently reported study,[17] and the second was to gain insight as to which physiological factor(s) may account for gender-specific adaptations to unloading should they, in fact, exist. We assert that the data presented here provide firm, conclusive answers to both these questions.

As in our earlier study using an entirely different cohort of participants,[17] this investigation consistently demonstrated that women experience more pronounced diminutions in muscle function than men following short term muscle unloading. This was evident in each of the parameters of muscle function examined, namely peak torque (strength), total work performed during sets of five maximal effort repetitions, and average power expressed during those repetitions. This, despite the fact that in neither of our studies of the effects of unloading in men and women, did either gender experience significant alterations in body or thigh mass over the 7 day period of unloading.

And while the gender-specific adaptations reported here were in response to 7 d of unloading, recently reported findings from another laboratory showed that the increased vulnerability of women to muscle unloading is also evident following 14 d of unloading.[8]

An important and revealing feature of this investigation was the fact that it quantified muscle function during a range of different contractile velocities and examined the effects of gender and unloading on more than just muscle strength. We also evaluated the additional muscle function parameters of power, and total work performed. The data reported here consistently documented that women experienced significantly greater unloading-induced decrements in muscle function regardless of whether function was defined as strength, power, or total work performed. Also consistently demonstrated in every measure of muscle function was the fact that the gender-related differences in unloading-induced decrements were most severe at the faster contractile velocities of 1.05 and 2.09 rads/s relative to the slowest isokinetic velocity used, i.e., 0.53 rads/s. Although it is known that the area occupied by type II (fast-twitch) muscle fibers in knee extensors is significantly greater in men than women,[8, 33, 34] it is difficult to see how this could explain why women lose more muscle function than men at faster movement velocities. Recall that our assessment of DEXA scans before and after 7 d of unloading failed to identify significant changes in thigh muscle mass, and that this was found in both men and women. Moreover, while examining muscle fiber profiles from biopsies taken from knee extensor muscles prior to, and following 14 d of unloading, Yasuda et al.[8] found that although both men and women displayed fiber atrophy, gender-related differences were not evident, even when examining only type II fibers. Thus, it is unlikely that the explanation for women experiencing more severe declines in isokinetic muscle function during rapid contractile velocities resides in the contractile apparatus itself.

In our second objective of defining the physiological mechanism(s) for gender-specific adaptations to muscle unloading, we focused our experiments on isometric contractile strength. This was mainly due to the fact that static contractions are most conducive to EMG recording techniques and the procedures used to apply superimposed electrical stimulation. These techniques allowed us to assess the roles of neuromuscular transmission (superimposed electrical stimulation), excitation- contraction relationship (force produced relative to EMG), and neural impulses generated by the central nervous system (EMG), in accounting for gender-specific strength declines following muscle unloading. These techniques were particularly informative, since it was already established both here and previously[8] that changes in muscle size or mass did not explain the exacerbated strength losses noted in women following unloading.

In examining our data on the coupling of excitation to contraction, we observed that the responsiveness of the contractile filaments of muscle to a given amount of electrical stimulation of the sarcolemma remains unaffected by a brief period of muscle unloading. This was found to be the case in both men and women. In effect, the relationship between electrical stimulation of the sarcolemma and the contractile force it triggers is not disturbed by 7 d of unloading and cannot explain the fact that women lose more strength than men as a result of short-term unloading.

We next turned our attention to the efficiency of neuromuscular transmission. Here, as in previous works,[30–32, 35] any blockage of the neural impulse from motor nerve endings to their muscle fibers was determined by applying an externally generated electrical impulse to motor neurons while the muscle was undergoing a maximal voluntary contraction to assess whether the added impulse could amplify muscle force. As was characteristic of this technique,[36] it was found that, by itself, voluntary contraction of the leg extensors could produce 93–95% of the total force generating capacity of those muscles that was demonstrated when supplementing that voluntary effort with a supramaximal external electrical stimulus. But perhaps more germane to the present study's objectives, we established that 7 d of muscle unloading did not alter this measure of neuromuscular transmission, and this was evident in both men and women. Thus, gender-specific declines in muscle strength following unloading are not attributable to disturbances in neuromuscular transmission.

Finally, our EMG data were more closely examined to find whether they might provide meaningful insight as to the physiological mechanism leading to gender-specific adaptations to muscle unloading. EMG recordings were collected from maximally contracting muscle fibers. But since skeletal muscle is not capable of self-excitation, the electrical activity detected with EMG is by necessity generated by the nervous system. And because our analysis of superimposed electrical stimulation procedures demonstrated that the peripheral nervous system, i.e., neuromuscular transmission, was unaffected by muscle unloading, it is reasonable to surmise that the observed changes in EMG activity originate from decreased central nervous system drive. Indeed, it is understood that changes in central drive are principally responsible for any modifications in peripherally recorded EMG activity.[35, 37, 38] The data presented here clearly reveal that women, but not men, experienced a significant decline in EMG activity as a result of short-term muscle unloading, and this suggests that the central nervous system is the main locus of unloading-induced gender-specific adaptations in muscle strength. It is not possible with the techniques used here, however, to determine whether the muted central drive produced by women following muscle unloading is due to alterations within the spinal cord, supraspinal centers, or a combination of those domains. Perhaps techniques such as transcranial magnetic stimulation or functional magnetic resonance imaging will be useful for revealing the exact source of decreased central drive that is evident in women following muscle unloading.

Our data indicating that the greater loss of isometric strength suffered by women following a brief period of unloading principally resides within the central nervous system also provides some explanation for the fact that, during isokinetic contractions, gender-specific declines in muscle function are manifested only during faster rates of movement. With the attenuation of the neural impulses generated by women after unloading, it is likely that the ability to recruit high threshold motor units is compromised. And it is the fast-twitch muscle fibers comprising those high threshold motor units that fail to produce force during higher velocity contractions, thus accounting for the fact that it is during more rapid dynamic contractions that women demonstrate decreases in muscle function. In essence then, it is the decreased capacity of the central nervous system to initiate powerful impulses during maximal effort contractions that explains why women experience greater declines in peak isometric torque, as well as more pronounced strength, power, and work decrements during higher velocity dynamic contractions following a brief period of muscle unloading. Unfortunately, the surface electrode EMG techniques used in this study only indicate general changes in electrical activation and are not able to directly determine changes in the electrical activation of specific motor units (i.e., fast vs. slow ones).

In summary, the results presented here confirm that women experience more marked impairments to muscle function than men following brief periods of muscle unloading. Our findings also indicate that gender-specific (women > men) decreases in peak torque developed during isometric contractions can also be attributed to greater disturbances in the capacity of the central nervous system of women to generate neural drive following muscle unloading. It is this impairment in the excitability of the central nervous system of women that accounts for gender-specific strength declines resulting from 7 d, and presumably 14 d of unloading - recall that Yasuda et al.,[8] reported that men and women suffered similar degrees of muscle atrophy following 14 d of unloading. Yet it is unknown whether this difference in neural function persists during longer periods of unloading, or even whether women continue to display a greater vulnerability to muscle unloading beyond that time frame. These important questions require further investigation. Nonetheless, the unequal susceptibility of men and women to the deleterious effects of muscle unloading, even if it exists only during short-term unloading, must be taken into account when designing post-unloading rehabilitative strategies.

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## Abbreviations

| | |
|---|---|
| **E-C** | excitation-contraction |
| **EMG** | electromyography |
| **ULLS** | unilateral lower limb suspension |

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## Table 1

Effects of gender and unloading on peak torque.

| | Men (N=12) | | Women (N=12) | |
|---|---|---|---|---|
| ***Movement velocity*** | **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| 0 rads/s | 150.5 ± 13.5 | 131.1 ± 14.1 * | 104.0 ± 7.5 † | 80.8 ± 5.0 *† |
| 0.53 rads/s | 157.5 ± 11.9 | 143.7 ± 12.0 * | 103.0 ± 5.9 † | 89.3 ± 5.2 *† |
| 1.05 rads/s | 144.6 ± 8.9 | 140.2 ± 9.2 | 98.7 ± 4.4 † | 88.9 ± 4.3 *† |
| 2.09 rads/s | 134.5 ± 8.3 | 127.8 ± 7.4 | 83.2 ± 3.1 † | 77.2 ± 3.6 *† |

Values are means ± SE. Units are Newtons at 0 rads/s, and Newton meters during dynamic contractions.

* indicates significant (P ≤ 0.05) pre- to post-unloading difference within same gender.

† indicates significant (P ≤ 0.05) difference from men at the same time point, i.e., pre- or post-unloading.

## Table 2

Effects of gender and unloading on total work performed.

| | Men (N=12) | | Women (N=12) | |
|---|---|---|---|---|
| **Movement velocity** | **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| 0.53 rads/s | 495.2 ± 38.7 | 432.4 ± 39.2 * | 314.8 ± 20.6 † | 278.3 ± 21.5 *† |
| 1.05 rads/s | 453.9 ± 31.3 | 435.9 ± 29.9 | 314.1 ± 20.6 † | 277.1 ± 18.5 *† |
| 2.09 rads/s | 390.3 ± 27.4 | 376.8 ± 21.0 | 268.2 ± 17.0 † | 246.8 ± 14.8 *† |

Values are means ± SE. Units are Joules.

* indicates significant ($P \leq 0.05$) pre- to post-unloading difference within same gender.

† indicates significant ($P \leq 0.05$) difference from men at the same time point, i.e., pre- or post-unloading.

**Table 3**

Effects of gender and unloading on average power.

| | **Men (N=12)** | | **Women (N=12)** | |
|---|---|---|---|---|
| **Movement velocity** | **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| 0.53 rads/s | 75.4 ± 5.4 | 65.6 ± 5.2 * | 47.5 ± 2.4 † | 40.6 ± 2.5 *† |
| 1.05 rads/s | 127.1 ± 8.4 | 122.5 ± 7.4 | 84.9 ± 4.5 † | 74.2 ± 3.8 *† |
| 2.09 rads/s | 184.4 ± 10.7 | 177.1 ± 10.7 | 123.9 ± 6.2 † | 110.3 ± 5.8 *† |

Values are means ± SE. Units are Watts.

* indicates significant ($P \leq 0.05$) pre- to post-unloading difference within same gender.

† indicates significant ($P \leq 0.05$) difference from men at the same time point, i.e., pre- or post-unloading.

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**Table 4**

Effects of gender and unloading on EMG (root mean squares), and excitation-contraction (E-C) coupling.

| | **Men (N=12)** | | **Women (N=12)** | |
|---|---|---|---|---|
| **Variable** | **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| EMG (mV * s) | 365 ± 48.4 | 337.8 ± 41.5 | 285.2 ± 34.0 | 207.0 ± 29.3*† |
| E-C relationship | 0.480 ± 0.071 | 0.477 ± 0.097 | 0.370 ± 0.039 | 0.440 ± 0.044 |

Values are means ± SE. EMG values are averages from vastus lateralis and vastus medialis muscles. E-C coupling calculated by dividing peak torque by EMG.

*indicates significant (P ≤ 0.05) pre- to post-unloading difference within same gender.

†indicates significant (P ≤ 0.05) difference from men at the same time point, i.e., pre- or post-unloading.

**Table 5**

Effects of gender and unloading on neuromuscular transmission efficiency.

| Men (N=12) | | Women (N=12) | |
|---|---|---|---|
| **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| 93.1 ± 1.5 | 93.0 ± 1.4 | 95.1 ± 1.1 | 93.5 ± 1.8 |

Values are means ± SE. Units are percentages. Neuromuscular transmission efficiency determined by dividing force produced with maximal voluntary contraction by force produced upon superimposing electrical stimulation during voluntary contraction, and multiplying by 100.

## Table 6

Effects of gender and unloading on lean mass (muscle) of the right thigh.

| Men (N=12) | | Women (N=12) | |
|---|---|---|---|
| **Pre-unloading** | **Post-unloading** | **Pre-unloading** | **Post-unloading** |
| 6,410 ± 248.7 | 6,229.7 ± 219.5 | 4,715.9 ± 204.1 † | 4,641.8 ± 181.8 † |

Values are means ± SE. Units are grams.

† indicates significant ($P \leq 0.05$) difference from men at the same time point, i.e., pre- or post-unloading.