DELAYED RECOVERY OF KNEE EXTENSION TORQUE FOLLOWING MAXIMAL ECCENTRIC CONTRACTIONS MAY BE DUE TO CENTRAL FATIGUE

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This study compared 1) The isometric strength, and 2) Peripheral and central fatigue assessed by resting twitch and voluntary activation, following maximal eccentric contractions of knee extensors in young men and women. Nine healthy participants performed 150 maximal eccentric contractions at 60 deg/s of the knee extensor muscles while on a dynamometer. Maximal voluntary isometric contractions (MVIC) were assessed before, immediately, 1 day, 2 days, and 14 days after the eccentric contractions. Electrical stimulation was applied over the skin of knee extensor muscles to elicit twitch torque responses during and immediately following each MVIC. The MVIC torque, rate of torque development (RTD), resting twitch torque (RT), voluntary activation (VA), and time to peak decreased from the baseline after the eccentric fatiguing contractions ($P < 0.05$). RT and time to peak increased and fully recovered after 1 day ($P > 0.05$; compared with baseline). However, MVIC, RTD, and VA increased during the recovery but did not fully recover after 14 days ($P < 0.05$; compared with baseline). These results suggest that the delayed recovery of torque production is mainly due to decrements in central nervous system.

KEY WORDS: Fatigability, Lengthening contraction, Muscle fatigue, Sex, Voluntary activation

INTRODUCTION: Eccentric exercise has demonstrated to be a useful training and rehabilitation method to increase muscle strength, power, and balance, at a relatively low metabolic cost (LaStayo et al., 2003). However repetitive high-intensity eccentric contractions can increase muscle fatigue and damage so that risk of injury increases. Therefore it is important to understand the time course of neuromuscular fatigue during eccentric exercise and recovery as well. Mechanisms within the muscle (peripheral fatigue) and the central nervous system (central fatigue) contribute to muscle fatigue (Gandevia, 2001). However there is minimal understanding of the relative role of each mechanism contributing to neuromuscular fatigability during and in recovery from lengthening contractions. In addition, limited numbers of studies have shown inconclusive results in fatigability from lengthening contractions in men and women. For example, Sewright and colleagues (Sewright, Hubal, Kearns, Holbrook, & Clarkson, 2008) observed a greater loss of isometric strength in women compared to men, whereas other studies found no sex differences (Hubal, Rubinstein, & Clarkson, 2008; Sayers & Clarkson, 2001). Therefore, the purpose of this study was to compare 1) isometric strength 2) peripheral and central fatigue assessed by resting twitch and voluntary activation respectively following maximal eccentric contractions of knee extensors in young men and women.

METHOD: Nine healthy young adults (5 women; Mean ± SD; age 23.9 ± 2.8 years, weight 72.5 ± 21 kg, height 1.73 ± 0.1 m) were volunteered to participate in this study. Participants were excluded from the study if they were injured or had a surgical procedure to their lower extremity within the last six months. This study was approved by the Michigan Technological University's Institutional Review Board for the Protection of Human Subjects.

Each participant performed 150 maximal eccentric contractions at 60 deg/s with the knee extensor muscles while on a dynamometer (Biodex 4, Biodex Medical Systems, NY, US) seated at 85° of hip flexion and 90° knee flexion. Before, immediately, 1 day, 2 days, and 14 days after the task, maximal voluntary isometric contractions (MVIC) were assessed. Electrical stimulation (D185, Digitimer, Welwyn Garden City, UK) was applied via a pair of self-adhesive surface electrodes (6.98 x 12.7 cm, Dura-Stick plus DJO Brands) over the skin of knee extensor muscles to elicit twitch torque responses during and

immediately following each MVIC. The exact electrode positions were determined based on the previous study (Pietrosimone, Selkow, Ingersoll, Hart, & Saliba, 2011) and marked with a permanent pen, which allowed the investigator to replicate positioning of electrode pads for subsequent trials. Peripheral fatigue was assessed by resting twitch torque (RT) and central fatigue was assessed by the relative amplitude of superimposed twitch torque (SIT) to RT i.e. voluntary activation [VA=100 × (1-SIT/RT)] (Merton, 1954). To examine the effect of fatigue, the MVIC, RT, VA, and rate of torque development (RTD) during MVICs were compared before and after the task. Contractile properties including time to peak and half relaxation time for resting twitch torque were also compared.
Data were reported as means ± SD within the text and displayed as means ± SE in the figures. Two-way ANOVAs with repeated measures were used to determine the effect of sex and fatigue on all variables above. SPSS software (ver. 21, SPSS Inc., Chicago, Illinois, USA) was used for all statistical analysis. A significance level of $p < 0.05$ was used to identify statistical significance.

RESULTS: All participants successfully completed all procedure including maximal eccentric fatiguing contractions. Although men were considerably stronger than women (225.6 ± 28.7 vs. 109.5 ± 26.3 N·m, $P < 0.001$), no sex-related differences in main variables were found. Thus data from men and women were analysed together. MVIC torque decreased after the eccentric fatiguing contractions from control values by 34.8% ± 23.8% (fatigue effect, $P < 0.005$). During the recovery, MVIC increased but was still significantly lower after 14 days (77.9% ± 37.0% of baseline, $P < 0.01$, Fig 1A). Rate of torque development during MVIC decreased after the eccentric fatiguing contractions from control values by 33.9 % ± 11.7 % ($P < 0.05$), but did not fully recover after 14 days (85.2% ± 45.6% of baseline, $P < 0.05$, Fig. 1B).

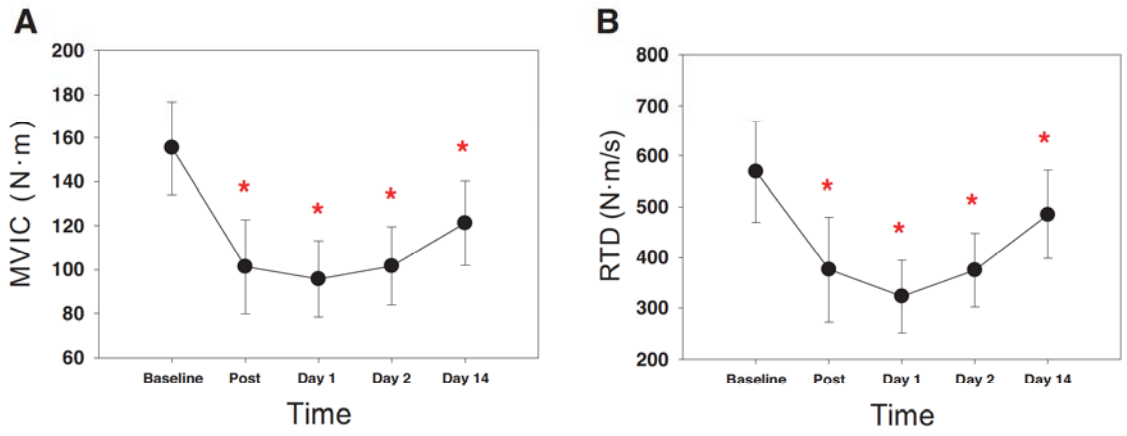

Figure 1. Maximal voluntary contraction (A) and Rate of torque development (B). * Indicates significant difference from the baseline value ($P < 0.05$).

Resting twitch torque amplitude decreased after the eccentric fatiguing contractions from control values by 20.05% ± 38.0% ($P < 0.05$). RT increased and recovered to same level of baseline ($P = 0.584$, Fig 2A). Voluntary activation decreased following the eccentric fatiguing contractions after 1 day from control values by 22.0% ± 58.1% ($P < 0.005$) and increased but did not fully recover after 14 days (86.5% ± 18.0% of baseline, $P < 0.01$, Fig 2B).

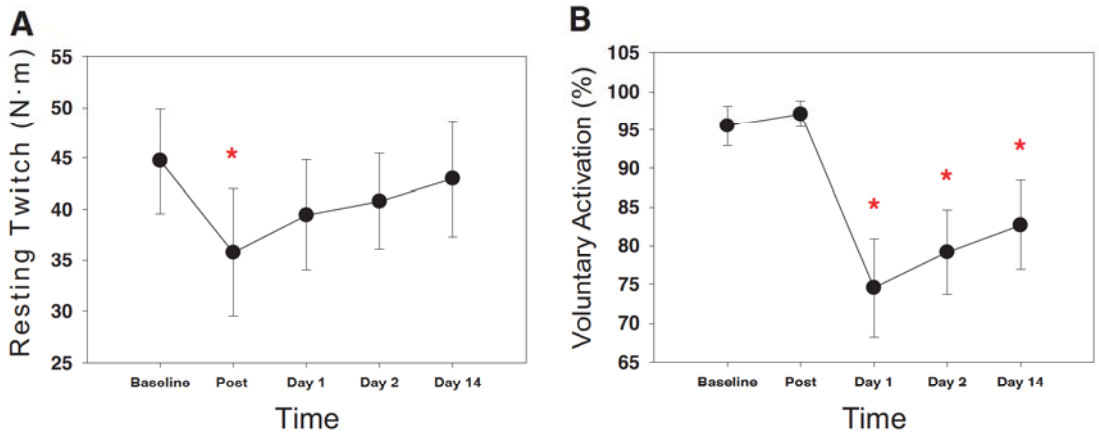

Figure 2. Resting twitch (A) and Voluntary activation (B). * Indicates significant difference from the baseline value (P < 0.05).

Time to peak decreased with fatigue (P < 0.001) and fully recovered after 1 day (P = 0.422, Fig 3A). Half relaxation time of resting twitch torque did not change significantly with fatigue (P > 0.05, Fig 3B).

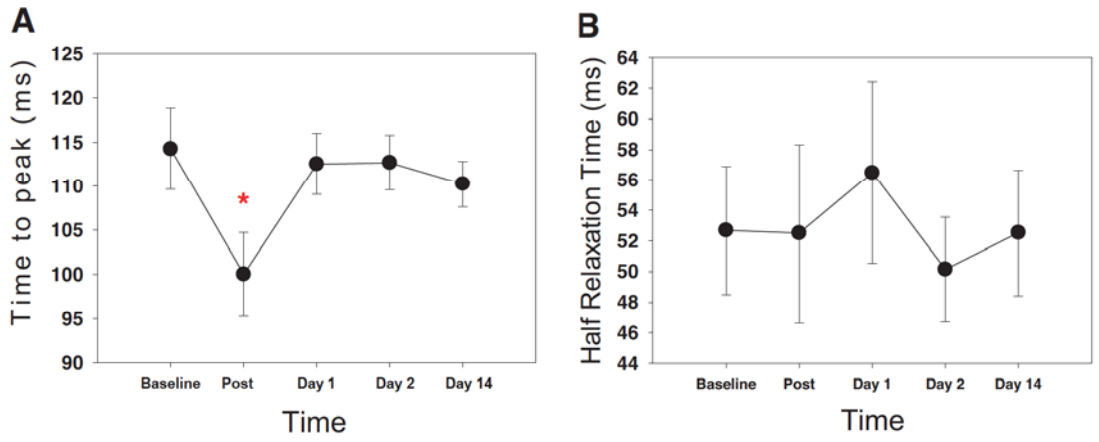

Figure 3. Time to peak (A) and Half relaxation time (B). * Indicates significan difference from the baseline value (P < 0.05).

DISCUSSION: This study compared fatigability of the knee extensors from maximal eccentric contractions in young men and women. The relative roles of peripheral and central mechanisms of fatigability were examined as well. MVIC and Rate of torque development decreased following the maximal eccentric contractions, and the relative declines were similar in men and women, which is similar to other studies (Hubal et al., 2008; Sayers & Clarkson, 2001). Many studied have shown that women are less fatigable than men during sustained isometric contractions, which is generally due to the larger muscle mass, less blood flow and muscle perfusion, faster contractile properties, and relatively less area of type I fibers in men compared to women (Hunter, 2014). The sex difference in muscle fatigability is task dependent. For example, the magnitude of sex difference decreased as contraction intensity increased during isometric contractions (Yoon, Schlinder Delap, Griffith, & Hunter, 2007). Similar to isometric contraction, women are less fatigable than men for lower velocity contractions, but not for high velocity contractions during concentric dynamic tasks (Senefeld, Yoon,

Bement, & Hunter, 2013; Yoon, Doyel, Widule, & Hunter, 2015). No sex difference were found in this study, and it is likely that physiological mechanisms for the sex differences in muscle fatigability observed in other studies did not affect enough during high intensity eccentric contractions but requiring low metabolic costs. After 14 days of recovery, men and women showed similar increase in isometric torque production, but both sexes did not fully recover. This incomplete recovery in torque production was likely due to decrements in central nervous system, because resting twitch recovered fully but voluntary activation did not. In addition, voluntary activation did not change immediately after 150 maximal eccentric contractions but it showed the lowest value after 24 hours of recovery, which is interesting because this time course is similar to muscle damage. Further study is warranted.

CONCLUSION: The new findings of this study are 1) The time courses of the isometric strength were similar in men and women 2) Despite the 14 days of recovery, baseline isometric strength did not fully recover 3) The depressed isometric strength is mainly due to decrements in central nervous system. These new findings will contribute to understanding differences in neuromuscular fatigue induced by eccentric exercise. This is key to the proper design and implementation of training and rehabilitations protocols that are sex specific and suited uniquely to an individual's needs.

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