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Effects of age and sex on fatigability and recovery from a sustained maximal isometric voluntary contraction

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ABSTRACT

The aim was to assess the effects of sex and age on fatigability and recovery from sustained maximal voluntary contraction (MVC) of the knee extensor muscles. The central (central activation ratio (CAR) and electrical activity amplitude) and peripheral (electrically evoked torque and muscle contractile properties) factors contributing to fatigue and recovery of 24 young adults (12 males) aged 23.2 ± 3.6 years and 20 older adults (12 males) aged 70.6 ± 4.4 years were compared. The increase in central and peripheral fatigue was greater ($p \leqslant 0.01$) in the young adults vs the older adults. Sex differences ($p = 0.002$) regarding MVC were attributed to the greater ($p < 0.01$) peripheral fatigue of males vs females. The recovery rate of MVC was greater ($p < 0.001$) in the young adults vs the older adults, with no sex effect. The recovery of MVC was correlated with the CAR in older adults ($p = 0.001$). Thus, the greater endurance observed with age is caused by differences in central and peripheral mechanisms, whereas the greater endurance in females is caused by a difference in a mechanism located within the muscle. The impaired recovery from fatigue in older adults relied more on the recovery of central factors.

1. Introduction

Neuromuscular fatigue can be defined as an exercise-induced fall in the maximal voluntary contraction (MVC) force (Allman and Rice, 2002; Boyas and Guével, 2011; Enoka and Duchateau, 2008; Gandevia, 2001). Most studies have indicated that young females are less fatigable than young males when performing specific similar-intensity isometric-fatiguing tasks (Enoka and Duchateau, 2008; Hunter, 2014). However, the studies of sex differences in fatigue induced by isometric contractions among older adults are limited and may conflict with observed young adults' results (e.g., Hunter et al., 2004). Based on previous studies (Hunter et al., 2004; Mcphee et al., 2014), it can be suggested that sex- and age-dependent fatigue differences depend on the muscle group tested. Sex differences were observed during elbow flexion at submaximal intensity exercise among young but not older adults (Hunter et al., 2004); in contrast, during knee extension, lower fatigability of females was observed in both age groups (Mcphee et al., 2014). Moreover, it can be suggested that sex- and age-dependent fatigue differences depend on the contraction intensity. In contrast to submaximal intensity exercise (Hunter et al., 2004), for elbow flexors at maximal intensity exercise, older females exhibit lower fatigability compared with age-matched males (Bilodeau et al., 2001). Nevertheless, we have not found any studies showing whether different age and sex elicit differences in fatigability for knee extension at maximal intensity.

It is well established that fatigue may arise due to failure at one or more sites along the pathway of force production from the central nervous system (i.e. causing central fatigue) to the contractile apparatus (i.e. causing peripheral fatigue) (Allman and Rice, 2002; Boyas and Guével, 2011; Enoka and Duchateau, 2008; Gandevia, 2001). Along with the lack of clarity regarding the effects of age and sex on the neuromuscular fatigue, the mechanisms of these differences have not been well established. We found only one study that assessed age and sex effect on fatigue evoked by a sustained isometric maximum contraction. Bilodeau et al. (2001) found similar peripheral fatigue degree (excitation-contraction coupling, neuromuscular propagation and metabolite build-up) for young and older age groups, with greater males' peripheral fatigue (metabolite build-up). However, in this study fatiguing exercise did not evoke central fatigue (failure of voluntary activation) in young adults and about half of older adults, thus we are not aware if greater degree of fatigue causing failure in both sites of force production (central and peripheral) would lead to similar conclusions. Therefore, we applied a 2-min MVC of the knee extensors protocol, which showed the increased central (central

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activation ratio (CAR)) and peripheral (involuntary evoked torque and its contractile properties) fatigues in previous studies of young and middle aged adults (Brazaitis et al., 2012; Skurvydas et al., 2011).

Recovery after fatiguing exercise remains a largely unexplored aspect of fatigue in advanced age (Thompson et al., 2015; Yoon et al., 2012). A previous study by Hunter et al. (2008) showed that older adults have a slower recovery compared with young adults after sustained isometric MVC because of greater central fatigue. In contrast, Bilodeau et al. (2001) found no age differences in recovery. Because both studies were performed on the elbow flexors (Bilodeau et al., 2001; Hunter et al., 2008), understanding of the behavior of other muscle groups, such as whether these effects are also observed on knee extensors after sustained isometric MVC, remains limited (Thompson et al., 2015). It is suggested that MVC recovery relies more on central fatigue, especially among older adults (Bilodeau et al., 2001; Hunter et al., 2008; Yoon et al., 2012). We are not aware of any age-related differences regarding central fatigue caused by maximal-effort isometric knee extensor contraction; however, in accordance with the responses of other muscle groups to isometric sustained MVC, a greater central fatigue can be expected among older adults (Bilodeau et al., 2001; Hunter et al., 2008). Therefore, we predicted that recovery would be impeded by a greater central fatigue, i.e., greater fatigue and lower recovery, in older adults. Moreover, for the knee extensors, the greater fatigability observed among males compared with females during maximal sustained contraction is associated with a larger loss of voluntary activation among young adults (Martin and Rattey, 2007). If this sex difference were to remain among older adults, we would expect a slower recovery in males compared with females.

Thus, with this study we aimed to assess the effects of sex and age regarding fatigue and recovery from sustained maximal-effort isometric contraction of the knee extensors. There is also a need to elucidate the specific mechanisms within the central and/or peripheral nervous system that contribute to evoked changes so that rehabilitation or training interventions can be targeted to the appropriate source(s) based on age and gender. Therefore, we considered that it was important to compare central (CAR and electrical activity amplitude, as an indicator of neural drive (Allman and Rice, 2002; Enoka and Duchateau, 2008; Gandevia, 2001; Kent-Braun and Le Blanc, 1996; Wang et al., 2015)) and peripheral factors (electrically evoked forces and their contractile properties (Allman and Rice, 2002; Enoka and Duchateau, 2008)) that contribute to fatigue and recovery.

2. Methods

2.1. Participants

Twenty four young adults (18–29 years, 12 males and 12 females) and twenty older adults (65–75 years, 12 males and 8 females) volunteered to participate in two experimental trials that involved fatiguing contraction with the knee extensor muscles. Their physical characteristics are presented in Table 1. Volunteers with chronic disease or those taking medications that might affect experimental variables were excluded. All participants were relatively sedentary in that they participated in two or less periods of continuous (>20 min) activity per week. Prior to participation, written informed consent was obtained from all participants after explanation of all details of the experimental procedures and the associated discomforts and risks. All procedures were approved by the Kaunas Regional Research Ethics Committee (2011-11-05 No. BE-2-38) and were conducted according to the guidelines of the Declaration of Helsinki.

2.2. Procedures

Subjects reported to the laboratory on two occasions, once for a familiarization session and once for experimental sessions, during which they performed the fatiguing protocol. To attain a stable level of performance, 4 days before the experiment, subjects attended a familiarization session, during which they were introduced to the experimental procedures. On arrival at the laboratory, anthropometric variables were measured, and each subject learned to achieve and maintain maximal-effort knee extension for 3–4 s with a 250-ms stimulation train test at 100 (TT-100) Hz superimposed on an MVC. The tolerance to electrical stimulation was then assessed.

The experimental procedures (Fig. 1) were performed in the early evening (16h00 to 18h00). The subjects refrained from consuming any food for at least 3 h, and from ingesting alcohol or caffeine and performing heavy exercise for at least 24 h before the experiment. They were also instructed to sleep at least 8 h the night before the experiment. Each session was preceded by a 7–8 min nonintensive warm-up on a cycle ergometer with a load of 25–35 W that allowed the maintenance of a speed of up to 70 rep/min and corresponded to a heart rate of 110–130 beats/min. Upon completion of the warm-up, subjects were positioned in the dynamometer chair, stimulating and surface electromyographic (EMG) electrodes were placed over the quadriceps muscle, and the peak torque-generating capacity of the right knee extensor muscles was assessed using 1-s trains of electrical stimuli at 20 and 100 Hz. About 3 s were needed to change the stimulation frequency. After a 30-s resting period, two attempts of a 3–4-s MVC interspaced with a 1-min resting interval were performed with a TT-100 Hz superimposed on the voluntary contraction. Subsequently, TT100 Hz was repeated at rest immediately after each MVC. The better of the two MVCs and TT100s attempted were recorded. After a 5-min resting period, a 120-s isometric MVC was tested. The TT100 Hz stimulus was superimposed on the 120-s contraction at about 3, 15, 30, 45, 60, 75, 90, 105, and 120 s. An involuntary force generating capacity assessment was performed after 3 s via 1-s trains of electrical stimuli at TT100, 20, and 100 Hz. The recovery of involuntary and voluntary force was assessed after 5 min. Electrical stimuli at 20 and 100 Hz were applied. Thirty seconds later, one attempt of a 3–4-s MVC was performed with a TT100 Hz stimulus superimposed on the contraction. The TT100 Hz was repeated 3 s after the MVC.

2.3. Measurements

2.3.1. Anthropometric measurements

The subject‘s height and weight (TBF-300 body composition scale; Tanita, UK Ltd., West Drayton, UK) were estimated during the familiarization session.

2.3.2. Force-generating capacity measurement

The torque of knee extensor muscles was measured using an isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY, USA). The sensitivity of the Biodex System 3 in torque measurements is ±1.36 N m. The subjects sat upright in the dynamometer chair with the knee joint positioned at 120 angle (full knee extension = 180). For brief and sustained MVC measurement, the subject was instructed to achieve and maintain maximal effort of knee extension for 3–4 and 120 s, respectively. The equipment and procedure for electrically stimulated torque have been described previously (Brazaitis et al., 2012; Solianik et al., 2015). Muscle stimulation was applied using two carbonized flexible surface rubber electrodes (MARP Electronic, Krakow, Poland), covered with a thin layer of electrode gel (ECG-EEG Gel; Medigel, Modi'in, Israel) with one electrode (6×11 cm) placed transversely across