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Contraction intensity and sex differences in knee-extensor fatigability

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ABSTRACT

Females are less fatigable than males during isometric contractions across various muscles and intensities. However, sex differences in knee-extensor fatigability remain relatively unexplored. *Purpose:* To determine the sex difference in performance fatigability for intermittent, isometric contractions of the knee-extensor muscles. *Methods:* Eighteen participants (10 males, 8 females) performed intermittent, isometric, knee-extensor contractions at 30% of their maximal voluntary force (MVC) for 30 min and in a separate session at 50% MVC until task-failure. During both fatiguing protocols a MVC was performed every 60 s and electromyography (EMG) was recorded during all contractions. *Results:* At task completion males had a larger reduction in MVC force for the 30% MVC task (−32 ± 15% vs. −15 ± 16%, $P = 0.042$) and the 50% MVC task (−34 ± 8% vs. −24 ± 1%, $P = 0.045$). Furthermore, for the 50% MVC task, females had a longer task duration (937 ± 525 s vs. 397 ± 153 s, $P = 0.007$). The rise in EMG activity and force fluctuations were more rapid for the males than females ($P < 0.05$). When participants were matched for strength *post hoc* ($n = 10$), a sex difference in fatigability for both tasks was still evident. *Conclusions:* Females were less fatigable than males during intermittent, isometric, knee-extensor contractions at moderate relative forces and this difference was independent of strength.

1. Introduction

Fatigue is a disabling symptom characterised by sensations of tiredness and weakness, underpinned by multiple complex mechanisms (Enoka and Duchateau, 2016). The intricacies of fatigue vary depending on circumstances, but during exercise, reductions in physical function [i.e., performance fatigability (Hunter, 2017)] involves impaired force producing capacity of the working muscles. An exercise-induced reduction in force capacity has been termed muscle fatigue (Gandevia, 2001), mechanisms contributing to this reduction in force can occur at various and multiple sites along the motor pathway, between neural activation and the contractile proteins of the working muscles (Enoka and Duchateau, 2016). The contribution of these mechanisms and the magnitude of this fatigability however, are dependent on the demands of the exercise task (Enoka and Stuart, 1992) such as the contraction intensity (Place et al., 2009). When submaximal tasks are performed at lower intensities for a longer duration, impaired activation of the muscles can contribute substantially to fatigability (Smith et al., 2007) whereas contractile failure is often dominant for higher intensity–-shorter duration tasks with modest deficits in activation (Bigland-Ritchie et al., 1986).

Performance fatigability is also modulated by the sex of the individual. Males have typically shown to be more fatigable than females in several muscle groups (Hunter, 2014, 2016) for both continuous, and intermittent tasks (Hunter and Enoka, 2001; Hunter et al., 2009; Yoon et al., 2009). However, the sex difference in fatigability and the contributing mechanisms can be specific to the demands of the task including the contraction intensity and type, and the muscle groups involved. For example, for lower intensity sustained contractions, there were sex differences for the elbow-flexor muscles, but not in the ankle-dorsiflexor muscles (Avin et al., 2010), and no sex differences for the elbow-extensor muscles (Dearth et al., 2010). The sex differences in fatigability are also greater at lower intensities during sustained contractions that are held until task-failure for the elbow-flexor muscles, forearm and the knee-extensor tasks (Maughan et al., 1986; West et al., 1995; Yoon et al., 2007), possibly in part due to perfusion-related differences between sexes, as males produce more absolute force for the same relative intensity (Clark et al., 2005). For intermittent tasks, when perfusion related-differences are minimized, the sex difference is still apparent, even when the sexes are matched for strength in elbow-flexor and forearm muscles (Hunter et al., 2006, 2004). In the *vastus lateralis*, females have been shown to have greater proportion of type-1 oxidative

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fibres (Staron et al., 2000) giving rationale for a more fatigue resistant muscle. Lower limb muscles are important for locomotion and often exercise training regimes but there is less information on any sex-related differences across different tasks. While the sex difference in fatigability is primarily attributable to contractile and metabolic processes for the elbow-flexor muscles, for lower limb muscles (ankle-dorsiflexors and knee-extensors), the sex difference has also been attributed to larger reductions in voluntary activation in men during maximal tasks (Martin and Rattey, 2007; Russ and Kent-Braun, 2003). Thus, the mechanisms of sex differences in performance fatigability are specific to the task and muscle groups involved.

A sex difference in fatigability of the knee-extensor muscles was demonstrated for sustained isometric and isotonic contractions (Clark et al., 2005; Martin and Rattey, 2007; Maughan et al., 1986; Senefeld et al., 2013) but it is unknown if the fatigability of male and female knee-extensor muscles also occurs for submaximal intermittent, isometric contractions across different contraction intensities. Whilst Albert et al. (2006) purported to use this contraction style in the knee extensors and found that females were less fatigable, the protocol used 30 s contractions with a 1:1 duty cycle. Therefore, the long duration of contraction likely led to differential degrees of blood flow occlusion between sexes, which might have been the reason for the sex difference reported (Clark et al., 2005). In order to examine whether the sex difference was still apparent without occlusion difference, the present study used a much shorter duration contraction (3 s), with a duty cycle previously reported to negate the influence of occlusion (Hunter et al., 2004). The aim of this study was to determine sex differences in fatigability for two submaximal intermittent contraction intensities performed with the knee-extensors. It was hypothesised that females would exhibit less fatigability than males following intermittent, isometric contractions.

2. Methods

2.1. Participants

Eighteen recreationally active participants were recruited from University sports teams, 10 males, (age, 21 ± 1 years; stature, 1.78 ± 0.04 m; mass, 78 ± 12 kg) and eight females (age, 21 ± 0 years, stature, 1.64 ± 0.06 m; mass, 61 ± 10 kg) who regularly competed in sport of intermittent nature (hockey, netball, rugby, and soccer) provided written informed consent to volunteer for the study. Participants arrived at the laboratory rested and hydrated, having avoided strenuous exercise in the preceding 48 h, and having refrained from caffeine for 12 h and alcohol for 24 h prior to each experiment. The study received institutional ethical approval and was conducted according to the Declaration of Helsinki.

2.2. Experimental design and exercise protocol

Participants visited the laboratory on three separate sessions over a 10-day period that included one familiarisation session (visit 1) followed by two experimental sessions. All sessions were a minimum of 48 and a maximum of 72 h apart. On visits 2 and 3, participants completed intermittent, isometric, knee-extensor exercise at either 30 or 50% maximal voluntary contraction (MVC) in a randomised, counter-balanced, crossover design. During the familiarisation session participants practiced performing MVCs with their dominant knee-extensors, and two sets of the intermittent contractions (3 s contraction, 2 s rest) at 30% MVC. One set comprised of 12 contractions followed by a MVC (Fig. 1).

Each experimental session began with three ~3–5 s MVCs with 30 s of recovery between each trial to attain maximum MVC force. Participants then performed an intermittent fatiguing task either at 30% or 50% MVC with the order of the tasks randomised across the two experimental days. Target forces, based on the MVC achieved on each day, and real-time force were presented on a computer screen placed in view of the participant. For the 30% MVC task, all participants exercised for 30 min and for the 50% MVC task, each participant performed the intermittent contractions until task-failure. Task-failure was defined as a failure to meet the target force by 5% three times within one set. A metronome (Gymboss interval timer, Gymboss LLC, St Clair MI, USA) ensured the correct timing for the start and end of each contraction during the fatiguing protocols.

2.3. Force and electromyography

Knee-extensor force (N) was recorded using a calibrated load cell (MuscleLab force sensor 300, Ergotest technology, Norway). The load cell was fixed to a custom-built chair and connected to a non-compliant cuff attached around the participant's dominant leg, ~1–2 cm superior to the ankle malleoli. Participants were instructed to sit upright in the chair with the hips and knees at 90° of flexion, this position was maintained for the entire trial. The force signal was amplified (×300) with an isolated pre-amplifier (1902, Cambridge Electronic Design, [CED] UK), digitised at 4 kHz (Power 1401, CED, UK) and analysed offline with Spike2 v7.12 (CED, UK).

Electromyographic (EMG) activity was recorded from the *vastus lateralis* using surface electrodes (Kendall, Ag/AgCl H87PG/F, Covidien, MA, USA). After the skin was cleaned and shaved, electrodes were placed 2 cm apart over the muscle belly with a reference over the ipsilateral patella in accordance with SENIAM guidelines (Hermens et al., 2000). Electrode placement was marked with permanent ink to ensure consistent placement between laboratory visits. From the recorded interference EMG, root mean square EMG (rmsEMG) amplitude was calculated during the submaximal and maximal (rmsMVC) contractions. The EMG signals were amplified (×1000) and band-pass filtered (20–2000 Hz) with an isolated pre-amplifier (1902, CED, UK), digitised (4 kHz; Power 1401, CED, UK), and analysed off line using Spike2 v7.12 (CED, UK).

2.4. Data analysis

Maximal force was determined as the peak force achieved during the greatest of the three MVCs and the rmsMVC was calculated from the corresponding time point centred over a 500 ms window. During the fatiguing task, knee-extensor force, rmsEMG activity, and force fluctuations were measured over a 1.5 s window during each contraction. The rmsEMG during sets of contractions was normalised to the baseline rmsMVC at the beginning of each trial. Force fluctuations were quantified as the coefficient of variation (CV) of force during each submaximal contraction. The same variables were also analysed *post hoc* during the sets of submaximal contractions that were closest in time to the 25, 50 and 75% of task duration. Five males and five females were matched for strength; each pairing had a baseline knee-extensor MVC within ~10% of the matched partner. This was included in the analysis to compare the fatigability of the knee extensors to strength-matched pairs in the elbow flexors (Hunter et al., 2004).

2.5. Statistical analysis

Data are presented as mean ± SD within the text and figures. To detect effects of sex (males, females), time (start and end exercise) and any interactions, the data of the dependent variables were entered into a separate two-way (2 × 2) Analysis of Variance (ANOVA) for each of the fatiguing protocols. Dependent variables included force, rmsEMG, and CV of force. Assumptions of sphericity were explored and controlled for all variables using the Greenhouse-Geisser adjustment, where appropriate. Post-hoc paired sample *t*-tests were used to detect pre- to post-differences within groups (SPSS v21, IBM, Chicago, USA) and effect sizes were calculated for the selected comparisons using Cohen's *d*. Due to the small sample size of strength-matched pairs,

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