observed fatigue. Central fatigue can be defined as a decline in the ability to activate the muscle during exercise whereas peripheral fatigue can be defined as the impairment of any process distal to the neuromuscular junction [2].

Muscle fatigue is most commonly assessed through the loss of force production [4] since maximum voluntary contractions (MVC) quantify the end result of both central and peripheral processes resulting in generating a muscular contraction [1]. It has also been assessed by changes in frequency measures of electromyography (EMG) signals [5,6], the reduction in electrically evocable forces [7], changes in metabolic factors [8,9], or with ratings of perceived exertion [6]. Females have been shown to have a significant advantage in relative fatigability due to reduced absolute force loss [4], but no significant differences have been found with respect to both metabolic factors [9] and ratings of perceived exertion [6]. Unrelated to fatigue, sex differences in EMG frequency measures have been difficult to determine [5].

The majority of workplace musculoskeletal injuries are related to repetitive strain [10], however, the individual effects of peripheral and central fatigue have not isolated. In manual materials handling work for example, the fatigue related changes in lifting technique has been a key focus [11-15]. due to the perceived injury risk of fatigued muscles being less capable of reacting to any perturbations that may occur during a lift [12,14]. The changes in lifting technique resulting from muscular strength and fatigability differences may also influence trunk motion and spinal loading [16], although it has been difficult to make this link empirically [6,17,18].

Although recent studies have shown that women have greater muscular endurance [9,19], there is a lack of information on sex differences in fatigue patterns considering the amount of information documenting strength differences [4]. The mechanisms for these differences are largely unknown, but there are two widely proposed hypotheses; 1) differences in muscle mass, and 2) differences in activation pattern [19]. Recent research [9,19] appears to indicate that the first hypothesis is most likely related to the sex differences in muscular fatigue due to similar findings that differences in endurance times during a fatiguing task were not related to differences in the neuromuscular recruitment strategy when both men and women were assessed. Therefore, it is most likely that the increased absolute force generated by men causes a greater demand for muscle oxygen with more occlusion of blood flow due to increased compression of tissues [19]. Current physiological guidelines for work to rest ratios and level of activity such as lifting are based on the metabolic demand of the activity [20] and do not consider sex differences in fatigue development or recovery.

The absolute levels of muscular force production and fatigability disparity between genders may be a predisposition to a greater risk of injury when required to work in a fatigued state. To address this fundamental issue a protocol for inducing muscular fatigue must be used to assess the nature of fatigue induced (peripheral versus central), the extent of the fatigue, rate of fatigue development, rate of recovery, and whether there are sex differences for all of these measures across multiple muscle groups. Therefore, the purpose of this study was to quantify the sex differences in fatigue development and recovery rate of lower and upper body musculature after repeated bouts of sustained isometric contractions. It is hypothesized that sex differences in the rates of fatigue accumulation and recovery of different muscle groups will lead to gender specific limiting neuromuscular factors for occupational tasks.

Methods

Participants

Twelve healthy males (age: 24.5 ± 2.5 years.; weight: 81.5 ± 9.3 kg; height: 177.6 ± 6.1 cm; Body Mass Index: 25.8 ± 2.0 kg/m^2) and 15 healthy females (age: 23.5 ± 2.4 years.; weight: 64.0 ± 6.9 kg; height: 169.8 ± 4.8 cm; Body Mass Index: 22.3 ± 3.1 kg/m^2) underwent bilateral localized fatigue of either the knee extensors (male: n = 8; female: n = 8), elbow flexors (male: n = 8; female: n = 10), or both muscle groups. All physical characteristics were measured in accordance with the Canadian Physical Activity Fitness and Lifestyle guidelines [21] using a wall mounted metric tape (Seca Body Meter) and a beam scale to obtain height and weight, respectively. Due to difficulties in retaining participants, only four males and three females participated in both conditions. All participants provided written informed consent in accordance with guidelines set by the university Ethics Review Board.

Determination of maximum voluntary contraction

All force recordings were performed while the participants were secured to custom-built isometric knee extensor and elbow flexor myographs (Figure 1) fitted with two independent PT4000-500lb force transducers (Precision Transducers, Auckland, New Zealand) that were amplified (MM50, Micron Meters, Simi Valley, CA) and analogue to digital converted through a NI-6036E Multifunction DAQ board (National Instruments, Austin, TX) housed on a Pentium II desktop PC at 1024 Hz. The force transducers were secured to the limbs using canvas straps with heavy duty Velcro, and allowed for simultaneous recording of the amplified raw net reaction force acting through the transducer at the site of attachment required to balance the torque generated by the muscular contractions. For the isometric knee extensions, the straps were placed