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Sex-specific reliability and multidimensional stability of responses to tests assessing neuromuscular function

V. Bernecke[a,b], K. Pukenas[a], L. Daniuseviciute[c], N. Baranauskiene[a], H. Paulauskas[a,*], N. Eimantas[a], M. Brazaitis[a]

[a] Institute of Sport Science and Innovations, Lithuanian Sports University, Sporto st. 6, LT-44221 Kaunas, Lithuania
[b] Department of Rehabilitation, Siauliai State College, M. K. Ciurlionio St. 16A, LT-76228 Siauliai, Lithuania
[c] Department of Educational Studies, Kaunas University of Technology, K. Donelaicio str. 73, LT-44029 Kaunas, Lithuania

A B S T R A C T

The objective of this study was to estimate sex-specific effects in the test–retest cross-reliability of peripheral and central changes in nonlinear and linear measures of a surface electromyography signal during a brief (5 second) and sustained (2 minute) isometric maximal voluntary contraction, combined with superimposed electrical stimulation involving the ankle plantar flexors over five identical trials. In this study, we repeated the testing protocol used in our previous study of 10 women (age 20.9, SD = 0.3 years) (Bernecke et al., 2015) in a group of 10 men (age 21.2, SD = 0.4 years). Despite the central (sex effect; $p < 0.05$, $\eta_p^2 > 0.71$, SP > 70%) and peripheral fatigability (sex effect; $p < 0.01$, $\eta_p^2 > 0.8$, SP > 90%) during sustained isometric maximal voluntary contraction, and lower reliability for central activation ratio during brief (intraclass correlation coefficient [ICC] = 0.95 for men and ICC = 0.82 for women) and sustained maximal voluntary contraction (ICC > 0.82 for men and ICC > 0.66 for women) over ankle plantar flexors expressed in women more than in men, all the ICCs of all indices measured by tests assessing neuromuscular function across the five identical test–retest trials were found as meaningful (correlation significance of $p < 0.05$ was reached) and no significant differences were found between trials for any of the measured variables. In conclusion, the present study demonstrated greater central and peripheral fatigue for female participants following sustained (2 minute) isometric maximal voluntary contraction of the plantar flexor muscles for all repeated trials and indicated an acceptable agreement between measurements of the characteristic variables made using the three different devices (dynamometry, electrical stimulation, and surface electromyography) over time for both sexes.

Introduction

The output of complex systems, for example, neuromuscular fatigue after repeated exercise, becomes increasingly complex and unpredictable as complexity increases, because of the sensitivity of the systems to initial conditions and nonlinear interactions between their structural components (Burggren and Monticino, 2005). Multiple mechanisms contribute to the force and power decrements seen in neuromuscular fatigue and range from inadequate activation of the motor cortex to impairment of the contractile proteins within skeletal muscle fibers; however, the predominant impairment is specific to the process that is stressed the most (Gandevia, 2001). The existence of anatomical and physiological differences between men and women results in marked sex-specific

* Corresponding author. Tel.: +370 66 223283; fax: +370 37 204 515.
E-mail address: henrikas.paulauskas@lsu.lt (H. Paulauskas).

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differences in neuromuscular performance and fatigability (Hunter, 2014). For example, in general, the skeletal muscles of men are larger and some muscles possess a greater proportional area of fast-twitch (type II) muscle fibers than women, who have smaller muscles with a greater proportional area of slow-twitch (type I) muscle fibers (Porter et al., 2002). Mainly because of this, men are typically stronger and more powerful than women are (Hunter, 2014). However, women consequently have a greater resistance to fatigue than men when muscles are used at the same relative intensity of contraction (Søgaard et al., 2006; Wust et al., 2008; Yoon et al., 2007). Nevertheless, women have a lower pain threshold to electric shocks and fatiguing exercise (both of which are normally used in testing neuromuscular function) than men and this influences motor output and fatigability (Hunter, 2014; Kajantie and Phillips, 2006; Martin et al., 2008).

Here, we have questioned whether the tests used to assess neuromuscular function are equally reliable for men and women? Despite developments in our understanding of the mechanisms of muscle fatigue (Gandevia, 2001; Kent-Braun et al., 2012), the knowledge and appreciation of sex-based differences in fatigability and the prevailing mechanisms under different task conditions remain desirable (Hunter, 2014). Most reliability studies to date have been conducted by taking both sexes as one group (Norcross et al., 2009; Taşkıran et al., 2011; Weir et al., 1998) or separately, with only men (Blacker et al., 2013; Morton et al., 2005; Place et al., 2007), or with only women (Bernecke et al., 2015). Different testing objectives, protocols, methods, procedures, tests, and equipment used by various researchers in reliability studies do not allow the results to be readily compared between the sexes, and so it is not clearly known whether any differentiation between sexes for periodic athletic testing is needed. Therefore, in our present study, we combined three different methods (dynamometry, electrical stimulation, and surface electromyography) to evaluate central or peripheral fatigue, or both, in a sex-specific manner, and identified test–retest cross-correlations between the characteristics measured by these methods over five identical trials. However, it is important to notice that low reliability, or differences in the reliability of neuromuscular function tests, or both, between the sexes suggest differentiation or test modification in order to evaluate athletes more accurately during periodic testing, which is critically important for sports and/or rehabilitation practitioners.

At least two sex-specific hypotheses are suggested by the literature: (i) despite women being less fatigable than men during fatiguing tasks (Russ et al., 2008; Wust et al., 2008; Yoon et al., 2007), women experience greater perception of pain than men. This pain is likely to impair motor output and increase fatigability in women more than it does in men (Martin and Rattey, 2007; Martin et al., 2008) because of stress-inducing events such as repeatedly evoked electrical stimulation (250 millisecond stimulation train test at 100 hertz) during sustained fatiguing exercise (2 minutes isometric maximal voluntary contraction), women would experience greater perception of pain than men and pain will impair motor output and will increase fatigability more in women than in men. Consequently, interactions with increased pain during intense sustained isometric maximal voluntary contraction exercise (Falla et al., 2008; Johansen et al., 2013), will stress greater changes in task performance strategy and would produce less reliability (i.e., lower ICCs) and multidimensional stability (i.e., 2-dimensional [2-D] correlations) over 5 identical trials in women than in men; (ii) alternatively, mainly because of sex-specific differences in muscle mass and composition of the fibers making up the muscle (Wust et al., 2008), greater intramuscular pressure in stronger muscles during sustained isometric maximal voluntary contraction may lead to a greater discharge of group III and IV muscle afferents (Hunter, 2014), and to a greater utilization of foodstuffs and accumulation of metabolites in men than in women (Russ and Kent-Braun, 2003; Russ et al., 2008; Wust et al., 2008; Yoon et al., 2007). Therefore, greater central and peripheral fatigue, and lower reliability and multidimensional stability might be expected for men than women.

In this study, we aimed to repeat the testing protocol used in our previous study of women (Bernecke et al., 2015) in a group of men. We aimed to estimate sex-specific effects in the test–retest cross-reliability of peripheral and central changes during a brief and sustained isometric maximal voluntary contraction combined with superimposed electrical stimulation involving the ankle plantar flexors over five identical trials.

Methods

Rationale for the experiment

This study was designed to repeat the testing protocol used in our previous study conducted in 10 women (Bernecke et al., 2015) in a group of 10 men to determine the sex-specific test–retest reliability of their response to different tests (dynamometry, electrical stimulation, and surface electromyography) used to evaluate central, peripheral, and combined central–peripheral changes during brief isometric maximal voluntary contraction (5 second) and fatiguing sustained isometric voluntary contraction (2 minute) of the ankle plantar flexors. The same examiner who conducted the tests in our previous study (Bernecke et al., 2015) measured these variables over two months. One familiarization session and five identical test–retest sessions were chosen with the aim of establishing whether the learning effect or sex-specific anatomical and physiological factors, or both, influenced the results of the test–retest sessions, and to identify any cross-correlations between the characteristics measured by these tests and whether these correlations were stable over time.

Participants

Anthropometric characteristics of women participants group were previously described elsewhere (Bernecke et al., 2015). Ten right-leg dominant women (mean age 20.9 years, SD = 0.3 years; body mass 59.7 kg, SD = 9.9 kg; height 1694 mm, SD = 75 mm; body mass index 20.7, SD = 2.3; fat 15.7 kg, SD = 3.1 kg) and ten right-leg dominant male volunteer participants were recruited from the university population (mean age 21.2, SD = 0.4 years; body mass 79.5 kg, SD = 8.3 kg; height 1840 mm, SD = 43 mm; body mass index 23.5, SD = 2.4; fat 15.7 kg, SD = 3.4 kg). In order to determine leg dominance two standard tests were used. In the