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Research article

Comparison of Quadriceps and Hamstring Muscle Activity during an Isometric Squat between Strength-Matched Men and Women

Sophia Nimphius [1], Jeffrey M. McBride [2]✉, Paige E. Rice [1,2], Courtney L. Goodman-Capps [2] and Christopher R. Capps [2]

[1] Centre for Exercise and Sports Science Research, School of Medical and Health Sciences, Edith Cowan University, Joondalup, Australia; [2] Neuromuscular and Biomechanics Laboratory, Department of Health and Exercise Science, Appalachian State University, Boone, North Carolina, USA

Abstract

The primary purpose of this investigation was to determine whether strength-matched men and women exhibit a different magnitude and ratio of leg muscle activity during a maximal voluntary isometric squat. The secondary purpose was to assess the effect of normalization method on differences in strength between men and women. Thirty-two men (n = 16) and women (n = 16) were successfully strength-matched (≤10% difference) by maximal force produced during an isometric squat (IS) when normalized to body weight. Subjects first performed a maximal isometric knee extension (IKE) and knee flexion (IKF) followed by the IS and muscle activity (EMG_{max}) was recorded for the vastus medialis (VMO), vastus lateralis (VL), semitendinosus (ST) and biceps femoris (BF). Muscle activity during the IS was expressed relative to the maximums observed during the IKE and IKF ($\%EMG_{max}$). The results indicate that VMO, VL, ST and BF $\%EMG_{max}$ were not significantly different ($p > 0.05$) between men and women during the IS (Men VMO = 136.7 ± 24.9%, Women VMO = 157.1 ± 59.8%, Men VL = 126.2 ± 38.2%, Women VL = 128.1 ± 35.5%, Men ST = 25.5 ± 13.6%, Women ST = 25.2 ± 21.8%, Men BF = 46.1 ± 26.0%, Women BF = 42.2 ± 24.8%). Furthermore, the VMO:VL and hamstring to quadriceps (H:Q) $\%EMG_{max}$ ratio were not significantly different between groups in the IS (Men VMO:VL = 1.15 ± 0.28, Women VMO:VL = 1.22 ± 0.26, Men H:Q = 0.28 ± 0.14, Women H:Q = 0.24 ± 0.20). This investigation indicates that the magnitude of muscle activity and the ratios examined are not significantly different between men and women in a maximal voluntary isometric squat when matched for normalized strength. Future investigations should consider subject strength and normalization procedures in the experimental design to elucidate possible sex differences in neuromuscular performance capabilities.

Key words: Knee extension, knee flexion, agonist, antagonist.

Introduction

Several investigations have sought to determine sex differences in neuromuscular function between men and women (Hannah et al., 2015; Harput et al., 2014; Myer et al., 2005; Spiteri et al., 2014). Imbalances in ratio or magnitude of muscle activity are suggested to result in poor performance in physical activities and potentially increase risk of injury, particularly in women (Hewett et al., 2005). Prior evidence suggests that women have a greater imbalance in medial to lateral leg muscle activity (Myer et al., 2005), agonist to antagonist muscle activity in comparison to males during dynamic tasks (Ebben, 2009), and greater disproportional hamstring to quadriceps muscle activity ratios than men (Harput et al., 2014). However, strength was not controlled for in the aforementioned investigations. As such, it was hypothesized that strength might be a confounding variable not often discussed or accounted for in research comparing neuromuscular function in men and women. Such hypothesis is partially supported by recent findings demonstrating that matching men and women for strength may negate some of the previously observed differences in neuromuscular performance (Hatzikotoulas et al., 2004; Hunter et al., 2004; Rice et al., 2017). Thus, strength disparities commonly observed between men and women, but not a permanent attribute of men and women (e.g., trainable), may be a confounding factor influencing neuromuscular function more than the sex differences sought to be evaluated in prior neuromuscular research.

Several comparisons surrounding athletic performance of men and women propose that major neuromuscular and strength incongruities exist between sexes (Hanson et al., 2008; Rice et al., 2017). However, previous research has shown that resistance training interventions elicit similar levels of improvement in muscular strength as well as neural adaptations in men and women (Staron et al., 1994). A strength-matched participant approach has scarcely been implemented (Hatzikotoulas et al., 2004; Hunter et al., 2004; Rice et al., 2017) but provides a strong research design to elucidate actual differences between men and women versus modifiable differences attributed to training history or in this specific example, muscular strength. Although controlling factors amongst groups in this domain of research can be challenging, analysis of all modifiable variables must be considered.

Therefore, the purpose of the current research was to determine whether strength-matched men and women exhibit a different magnitude and ratio of leg muscle activity during a maximal voluntary isometric squat. An isometric squat movement was utilized in efforts to first isolate whether strength differences between males and females might be a confounding variable in the study of basic neuromuscular function between sexes. A secondary purpose of this research was to examine the effect of different normalization procedures [e.g., relative to absolute, body weight (or body mass) and lean weight (or lean mass)] on differences in strength between men and women. It was hypothesized that there would be no significant differences in magnitude or ratio of muscle activity in strength-matched men and women, and there would be an effect of normali-

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zation procedure when comparing the magnitude of strength in men and women. Controlling for covariates such as strength will allow for research to identify more accurately the factors or variables that indeed underpin the differences between the sexes with respect to physical performance or risk for injury.

Methods

Participants

The institutional ethics committee approved the study, and written consent was obtained from each participant before commencement of testing. Participants were recruited if they were currently performing resistance training a minimum of two times per week, but no other physical activity or sporting experience were targeted. All participants were free of any musculoskeletal injuries within the paster year, including any prior anterior cruciate ligament injuries. An *a priori* power analysis based on previous research (Ebben, 2009) results ($\alpha = 0.05$; $\beta = 0.80$; $d = 0.64$) indicated that 22 participants (11 pairs) would provide an actual power of 0.82. Thirty-two men (n=16; age: 21.1 ± 1.8 yrs; resistance training age: 4.1 ± 2.5 yrs) and women (n = 16; age: 22.0 ± 1.7 yrs; resistance training age: 2.4 ± 2.4 yrs) were successfully matched (≤10% difference) for maximal force produced during an isometric squat when normalized to bodyweight as seen in Figure 1. Prior to further analysis, success of matching was evaluated using Pearson's correlation coefficient ($r = 0.988$; $p \leq 0.001$) and paired comparisons ($p = 0.89$; $d = 0.01$). All other physical characteristics are included in Table 1.

Study design

Participants completed a single 60-90 minute testing session. All participants' anthropometric measures and body composition were assessed before a standardized warm-up. Participants then completed submaximal and maximal trials of isometric knee extension (IKE), isometric knee flexion (IKF) and isometric squat (IS) while force produced and EMG activity of the vastus lateralis (VL), vastus medialis (VMO), semitendinosus (ST) and biceps femoris (BF) were measured.

Anthropometrics and body composition

Height and body mass (BM) were first measured. Dual-energy x-ray absorptiometry (DXA) (QDR-1500, Hologic Discovery A, Waltham, MA) was used to assess the magnitude and quality of body composition (fat, lean and total). Participants laid in a supine position on the scanning bed with both arms pronated by their side and internally rotated thighs with feet fixed to hold position (Hart et al., 2014). Segmental analysis was performed using the inbuilt analysis software (Version 12.4; QDR for Windows, Hologic, Waltham, WA) to assess the thigh mass to normalize knee extension and flexion torque. Length of the femur and tibia were assessed using the previously described inbuilt software as the distance between the most prominent aspect of the greater trochanter to the lateral epicondyle (femur length) and from the tibale mediale to medial malleolus (tibia length). The length of the tibia (corrected for force transducer cuff location) was used as the moment arm for calculation of torque during both the IKE and IKF. The segmental analysis has been previously described and reliability (intraclass correlation [ICC] and coefficient of variation [CV]) previously assessed (ICC ≥ 0.94; CV ≤ 2.6%) by our lab (Hart et al., 2014).

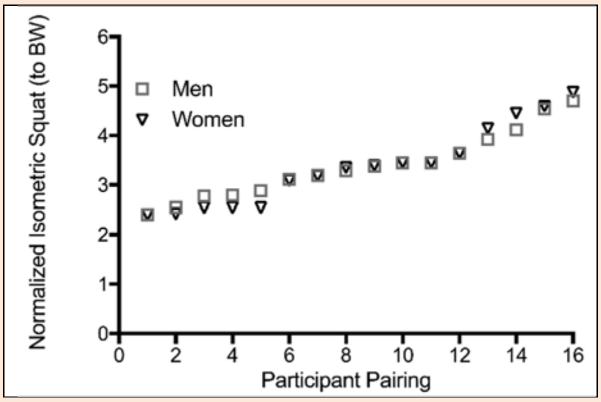

Figure 1. Strength-matched men (grey) and women (black) pairs based upon force produced during an isometric squat normalized to body weight (BW).

Standardised warm-up and maximal effort trial procedures

Each participant performed a five-minute warm-up on Monarch bicycle at 50W with a 60-80 rpm cadence before physical testing. To ensure maximal voluntary contractions, the following procedures were undertaken as previously recommended (Gandevia, 2001). Before each exercise (IKF, IKE and IS), participants were given specific instructions and practice efforts including submaximal contractions at their perceived ~50% and ~75% followed by three maximal effort trials (Hannah et al., 2012).

Table 1. Descriptive physical characteristics of men and women.

	Men (n = 16)		Women (n = 16)			
	Mean ± SD	(95%CI)	Mean ± SD	(95%CI)	*p*	*d*
Height (m)*	1.78 ± 0.06	(1.75-1.82)	1.67 ± 0.07	(1.63-1.71)	≤ 0.001	1.75
Total BM (kg)*	80.0 ± 8.7	(75.4-84.6)	67.9 ± 11.8	(61.6-74.1)	≤ 0.001	1.17
Total body LM (kg)*	63.2 ± 8.4	(58.7-67.7)	48.6 ± 7.2	(44.7-52.4)	≤ 0.001	1.86
Body fat %*	16.2 ± 6.3	(12.9-19.6)	24.0 ± 5.4	(21.1-27.0)	≤ 0.001	-1.42
Total body fat mass (kg)	12.8 ± 5.0	(10.2-15.5)	16.5 ± 6.7	(12.9-20.1)	0.053	-0.71
Thigh mass (kg)	11.0 ± 1.2	(10.3-11.6)	10.2 ± 2.9	(8.6-11.7)	0.149	0.52
Thigh LM (kg)*	8.75 ± 1.15	(8.14-9.37)	7.02 ± 1.61	(6.16-7.88)	0.002	1.24
Femur length (cm)*	43.4 ± 2.1	(42.3-44.6)	40.8 ± 2.4	(39.5-42.1)	0.002	1.19
Tibia length (cm)	37.4 ± 2.9	(35.9-38.9)	35.4 ± 2.8	(33.9-36.9)	0.054	0.71

BM: Body mass; LM: Lean mass; Data is presented as mean ± SD with 95% confidence intervals (95%CI) and Cohen's effect size (*d*).
*Significant difference between men and women ($p \leq 0.05$)

All participants were provided with feedback during each trial and asked if their efforts were considered maximal allowing those considered not maximal to be discarded in replacement for another maximal effort. Values were also checked prior to removal. Two minutes of rest was provided between all trials. The ICC ≥ 0.98; CV ≤ 3.2% demonstrated high reliability for peak force during the IKF, IKE and IS.

Electromyography

Electromyography (EMG) of VL, VMO, ST and BF was assessed using standardized protocols as described by SENIAM (Hermens et al., 2000) and described for open-source access at http://seniam.org/. Each site was abraded and cleaned using rubbing alcohol followed by fixation of the electrode (Delsys Trigno Wireless System, Natlick, Massachusetts, USA) directly to the skin using double-sided adhesive tape. EMG data were sampled at 2000Hz and collected using a custom LabVIEW program (National Instruments Version 14, Austin, TX). EMG data was offline bandpass filtered between 6 and 500Hz using a 2nd order Butterworth filter. Maximal EMG (EMG_{max}) of all isometric tasks were analyzed using root mean square with an averaging window of 250 ms over an epoch of 500 ms (250 ms on either side) of the time when either maximum isometric force or torque occurred, as recommended by both SENIAM guidelines and previous research (Buckthorpe et al., 2012; Hannah et al., 2012). The maximal muscle activity during the IS was calculated relative to maximal activity of the VL, VMO, ST and BF recorded during either the IKF or IKE respectively (%EMG_{max}) with an ICC of 0.96 – 0.99 and CV of 2.9 – 7.8 %. The ratio of VMO:VL %EMG_{max} and the ratio of hamstring: quadriceps (H:Q) %EMG_{max} as the sum of VL and VMO divided by the sum of BF and ST were also calculated.

Maximal voluntary isometric knee flexion and extension

Maximal voluntary IKE torque and EMG_{max} was assessed while seated with a knee angle of 100° (hip angle of 90°) (Buckthorpe et al., 2012). Participants were instructed to push as hard as possible for three seconds while provided with verbal encouragement. Maximal voluntary IKF torque and EMG_{max} was assessed in a set up similar to that previously reported (Worrell et al., 2001). This position has been shown to result in maximal torque and maximal EMG activity of the knee flexors (Worrell et al., 2001). Subjects were prone on a table while flexing the knee 30° (hip angle of 180°), as described previously (Worrell et al., 2001). Participants were instructed to pull as hard as possible for three seconds while provided with verbal encouragement. Maximal isometric torque during both flexion and extension tests were assessed with a force transducer (SL1000lb, Lafayette Instrument Company, Lafayette, Indiana, USA) sampling at 1000 Hz. The force transducer was fixed between an immovable pole during the knee extension and knee flexion trials. A harness with a strap placed approximately 2 cm proximal of the medial malleolus and an additional strap was wrapped underneath the foot to secure position (Buckthorpe et al., 2012). Equal ability of men and women to elicit EMG_{max} for the process of normalization during a maximal voluntary isometric contraction has been previously demonstrated (Krishnan and Williams, 2009). Subjects performed three trials of both the IKE and IKF with 2 minutes of rest between trials. All data from the force transducer were smoothed using a low pass 4th order Butterworth filter with a cut-off frequency of 15 Hz. Forces were collected and analyzed using a customized LabVIEW program to determine peak torque. Peak torque during IKF and IKE was normalized to total BM and thigh lean mass (LM). The ratio between IKF to IKE peak torque was also calculated.

Maximal voluntary isometric squat

Maximal voluntary IS force and %EMG_{max} (EMG_{max} during IS relative to EMG_{max} during IKE and IKF) was assessed with a knee angle of 100° (hip angle was approximately 150°). Participants were positioned with an immovable bar across their shoulders and feet centered on a force plate (AMTI, BP6001200; Watertown, MA). Data were sampled at 1000 Hz using a customized LabView program. All participants were instructed to push as hard as possible through the ground while verbal encouragement was provided for five seconds. Three trials with two minutes of rest between trails were performed. All data from the force plate were smoothed using a low pass 4th order Butterworth filter with a cut-off frequency of 15 Hz. Forces were analyzed using a customized LabVIEW program to determine peak force. Measures of force during the IS were normalized to body weight (BW) and lean BW. This normalization by body weights is common in the literature and is conceptually easy to understand for practitioners. The reason for the difference in normalization between IKE, IKF and IS was for comparison to other investigations and additional normalization of IKE and IKF to thigh LM provided strength normalized to only muscle mass. Isolating the lean mass (which is primarily composed of and highly correlated to skeletal muscle mass), assists in isolating the mass that contributes to the torque production.

Statistical analysis

Variables with data not normally distributed were log transformed, re-assessed for normality and used for subsequent test statistics. The variables transformed for statistical analysis included: body fat percentage (%), total body fat mass, thigh mass, %EMG_{max} of VMO, VL, ST and %EMG_{max} H:Q ratio. Differences between men and women were assessed in families of variables (e.g., descriptive, anthropometric, strength, quadriceps and hamstrings ratio and magnitude of %EMG_{max} and where required correction of multiple comparisons using the Holm-Sidak method for multiple T-tests was performed (GraphPad Prism 6.0f, CA, USA). Statistical analysis was assessed on strength-matched pairs (n =32; 16 pairs) as per study design. Cohen's effect size (*d*) was calculated using either raw means or the transformed means where appropriate and pooled standard deviation (Cohen, 1992). Effect sizes were interpreted by the following scale: trivial: < 0.1; small: 0.10 – 0.59; moderate: 0.60 – 1.1; large: 1.2 – 1.9; very large: 2.0 -3.9; nearly perfect ≥ 4.0 (Cohen, 1992).

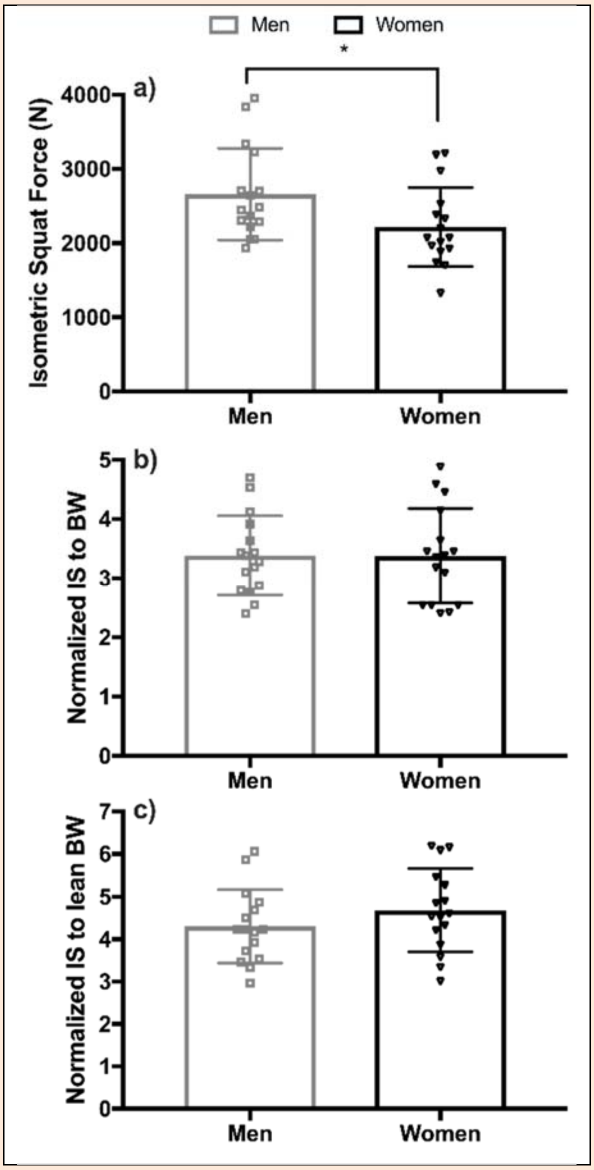

Figure 2. **Isometric squat (IS) (a) absolute peak force * = significant difference between groups at $p \leq 0.05$ and (b) IS normalized peak force relative to body weight (BW) ($p > 0.05$) and (c) IS normalized to lean BW ($p > 0.05$) in men (grey) and women (black).**

Results

Descriptive and anthropometric characteristics of the men and women are shown in Table 1. Height, BM, total body LM, body fat %, thigh LM and femur length were all significantly different between groups ($p \leq 0.05$). As intended by research design, the strength-matched men and women, shown in Figure 1, had no significant difference in their normalized strength (peak force) as determined by the isometric squat (IS) when normalized to BW nor when normalized to total lean BW (Table 2). However, there was a significant difference in absolute force produced during the IS (Table 2, Figure 2a). Absolute peak torque produced during both IKE and IKF was significantly higher in men than women (Table 2, Figure 3a). IKF peak torque normalized to total BM was significantly higher for men than women but not IKE (Table 2, Figure 3b). Relative to thigh LM there were no significant differences between men and women for IKE or IKF peak torque (Table 2, Figure 3c). The IKF to IKE ratio was not significantly different between men and women (Table 2).

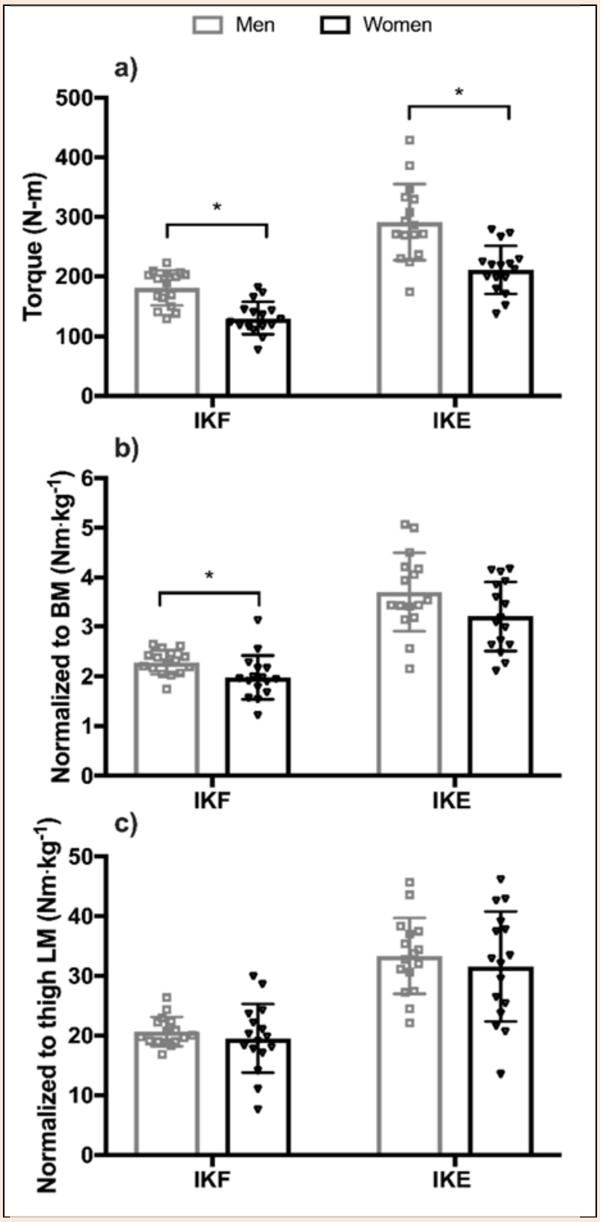

Figure 3. **Isometric knee flexion (IKF) and isometric knee extension (IKE) (a) absolute peak torque * = significant difference between groups at $p \leq 0.05$, (b) relative to body mass (BM) * = significant difference between groups at $p \leq 0.05$, and (c) relative to thigh lean mass (LM) ($p > 0.05$) in men (grey) and women (black).**

There were no significant differences in $\%EMG_{max}$ of any muscle measured during the IS with trivial to small effect sizes: VMO ($p = 0.32$; $d = -0.36$), VL ($pv= 0.94$; $d = 0.03$), BF ($p = 0.97$; $d = 0.19$), and ST ($p = 0.57$; $d = 0.21$) between men and women (Figure 4a). Further, there were no significant differences during the IS in any ratio of $\%EMG_{max}$ with small effect sizes: VMO:VL ($p = 0.44$; $d = -0.27$), H:Q ($p = 0.41$; $d = 0.29$), and medial thigh to lateral thigh (Med:Lat) (p = 0.28; d = -0.36) between men and women (Figure 4b).

Discussion

The primary finding in this investigation is that strength-matched men and women do not differ in magnitude or ratio of muscle activity in an isometric multi-joint task. The secondary finding was that the normalization method (or lack of use of normalization) resulted in different results when comparing strength between men and women. The current investigation was unique in that strength-matching the men and women were performed to remove strength (as a function of total body weight) as a confounding variable in determining differences between the neuromuscular characteristics of men and women. It should be noted that these results apply specifically to an isometric multi-joint task at a 100-degree knee angle and may not apply to other knee angles or dynamic tasks. Future investigations may want to examine strength-matching between men and women when examining muscle activity in both isometric or dynamic complex tasks at a variety of knee angles.

Magnitude of muscle activity

In several investigations involving isometric tasks, it has been reported that there are no significant difference in neuromuscular function of the quadriceps (Hannah et al., 2012; Pincivero et al., 2004) or hamstrings (Hannah et al., 2015) during a maximal single joint open kinetic chain task between men and women. The current research extends such findings by demonstrating that during a maximal multi-joint isometric closed kinetic chain task (IS), the magnitude of EMG activity of the quadriceps and hamstrings are not significantly different between men and women (Figure 4). A majority of the research demonstrating a significant difference in magnitude of EMG activity between men and women involves research during dynamic controlled tasks (e.g. squat or lunge) (Dwyer et al., 2010; Youdas et al., 2007; Zeller et al., 2003) or dynamic athletic tasks (e.g. running, cutting and drop landing) (Beaulieu et al., 2009; Hanson et al., 2008; Malinzak et al., 2001; Palmieri-Smith et al., 2009). However, only one of the aforementioned studies attempted to control for strength differences between men and women (Shultz et al., 2009) and did so statistically, not *a priori* by research design. The investigation reported that thigh muscle strength explained some of the variance in quadriceps and hamstring muscle activation (Shultz et al., 2009) and supports the current study implicating the importance of strength as a co-variate to be controlled when comparing males and females.

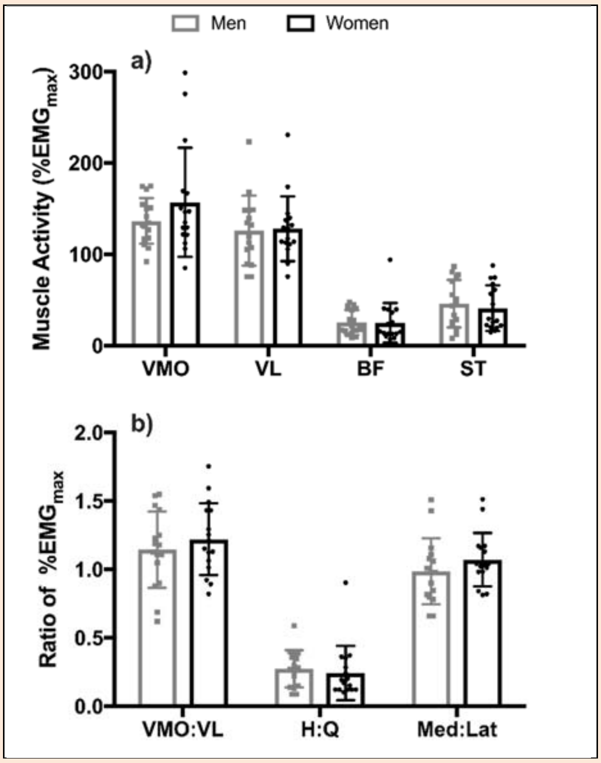

Figure 4. Relative muscle activity (%EMG$_{max}$) (a) of vastus medialis (VMO), vastus lateralis (VL), biceps femoris (BF) nor semitendinosus (ST) between men and women (p > 0.05) and (b) ratio of vastus medialis: vastus lateralis (VMO:VL), hamstring: quadriceps (H:Q) nor medial: lateral thigh (Med:Lat) muscle activity between men and women (p > 0.05). Raw data is presented, however, as per description in statistical analysis, data not normally distributed were transformed (and checked for normality) for subsequent statistical analysis.

Table 2. Strength data for men and women.

	Men (n = 16)		Women (n = 16)			
	Mean ± SD	**(95%CI)**	**Mean ± SD**	**(95%CI)**	***p***	***d***
IS force (N)*	2660 ± 618	(2331-2989)	2219 ± 533	(1935-2503)	0.039	0.76
Normalized IS to BW	3.39 ± 0.68	(3.03-3.75)	3.38 ± 0.80	(2.95-3.81)	0.981	0.01
Normalized IS to lean BW	4.31 ± 0.87	(3.85-4.77)	4.69 ± 0.97	(4.16-5.20)	0.261	-0.41
IKF torque (N·m)*	180.4 ± 29.4	(164.8-196.1)	130.4 ± 27.0	(116.0-144.8)	≤ 0.001	1.77
Normalized IKF to BM (Nm·kg^{-1})*	2.28 ± 0.24	(2.15-2.41)	1.98 ± 0.44	(1.74-2.21)	0.023	0.85
Normalized IKF to thigh LM (Nm·kg^{-1})	20.7 ± 2.5	(19.3-22.0)	19.5 ± 5.7	(16.5-22.6)	0.531	0.25
IKE torque (N·m)*	290.8 ± 63.9	(256.8-324.9)	210.6 ± 40.3	(189.1-232.0)	≤ 0.001	1.50
Normalized IKE to BM (Nm·kg^{-1})	3.70 ± 0.79	(3.28-4.13)	3.21 ± 0.70	(2.83-3.58)	0.072	0.66
Normalized IKE to thigh LM (Nm·kg^{-1})	33.3 ± 6.4	(29.9-36.7)	31.6 ± 9.2	(26.7-36.5)	0.480	0.22
Ratio of H:Q Isometric Torque	0.64 ± 0.14	(0.57-0.72)	0.63 ± 0.16	(0.55-0.72)	0.869	0.07

IS: Isometric squat; BW: Body weight; IKF: Isometric knee flexion; IKE: Isometric knee extension; BM: Body mass (of entire body) was used for normalization of IKE and IKF for comparison to previous research; LM: lean mass; H:Q, hamstring to quadriceps ratio of torque maximal produced during the IKF and IKE respectively. Data is presented as mean ± SD with 95% confidence intervals (95%CI) and Cohen's effect size (d). *Significant difference between men and women (p ≤ 0.05).

Ratio of muscle activity

There were three different ratios of muscle activity compared between men and women in the current investigation: VMO:VL, H:Q, and Med:Lat. Previous research has compared one, or a combination of, these ratios during a variety of isometric (Pincivero et al., 2004), and dynamic tasks (Ebben et al., 2009; Hanson et al., 2008; Harput et al., 2014; Hewett et al., 1996; Hewett et al., 2005; Malinzak et al., 2001; Myer et al., 2005; Palmieri-Smith et al., 2009; Youdas et al., 2007). During a maximal IKE at varying angles, it was found that there was no significant effect of sex on the VMO:VL activity (Pincivero et al., 2004). However, during dynamic tasks that mimic an ACL risk position, research has reported the VMO:VL to be significantly higher in men versus women (Myer et al., 2005). The difference in findings from the current research (Figure 4b) and previous research may either be that strength was different between the men and women used in the prior research, as expected by a random sample (Ebben et al., 2009), or that the demand of the task determined differences in neuromuscular function potentially present between the sexes. Ebben and colleagues (2009) concluded that when analyzed within sex, stronger women demonstrated higher H:Q activation ratios than weaker women, suggesting strength may affect the ratio of activity and supporting why in strength-matched men and women of the current study there were no significant differences in ratio of muscle activity.

Ratio of isometric hamstring to quadriceps torque

Although the current investigation strength-matched men and women by their IS normalized to BW, it was still considered of interest to investigate if there was a difference between the men and women in their IKF to IKE torque ratio. The results demonstrated there was no significant difference in the ratio of isometric torque produced during IKF and IKE in men (0.62 ± 0.12) and women (0.63 ± 0.15). The ratio of IKF to IKE has been presented in a number of research investigations using a variety of methodologies (Aagaard et al., 1998) and has been reported to be a factor for injury risk (Myer et al., 2009). The current study used the joint angles within range for maximal torque of the hamstrings (Worrell et al., 2001) and quadriceps (Thorstensson et al., 1976). As a result, the values are similar to the range reported during a peak moment conventional knee flexion to knee extension isokinetic assessment (0.5-0.6). However, the most important finding relevant to the current research primary purpose, independent of comparison to other studies, is that the between group comparison of strength-matched men and women did not significantly differ developing the notion that overall strength or individual differences may affect IKF to IKE torque ratio more so than sex.

Normalization of strength considerations

When investigating weight-bearing activities or tasks, such as squatting, jumping or running, normalization of force production to BM may be most appropriate for comparison of loading (e.g., magnitude of BM) (Suchomel et al., 2018). As demonstrated in the current study, there was a significant difference in BM of men and women and a concurrent significant difference in absolute force production during the IS that was no longer present when normalized to body weight or total body lean weight (Table 2; Figure 2). When investigating movement patterns such as running, jumping and cutting, including the total body mass or weight as the ability to control one's own body is of utmost importance and most related to performance. On the other hand, single joint research investigating muscle function (e.g. mechanistic research using a knee extensor model) may consider normalization to total thigh lean mass in addition to the common procedure of normalizing to total body mass (Lephart et al., 2002; Pincivero et al., 2004; Shultz et al., 2009). The difference in these two normalization techniques is demonstrated by the results of the current study (Table 2; Figure 3), where isometric knee flexor torque normalized to total body mass was significantly different between men and women but not significantly different when normalized to lean mass of the thigh. More specifically, the difference between men and women during single joint IKF was 8.1% versus 0.8% when normalized to body mass and thigh lean mass respectively, and the difference was 7.5% and 2.2% during IKE, respectively. Use of thigh lean mass is an improvement in normalization accuracy compared to use of the entire body mass. Such a procedure removes potential bias as a result of upper and lower body muscle mass distributions being significantly different between the sexes (Janssen et al., 2000) or individuals.

Conclusion

The current investigation demonstrated that men and women were not significantly different in the magnitude or ratio of muscle activity during a maximal isometric multi-joint task when strength as a confounding variable was removed by study design. Further, when researching neuromuscular sex differences, strength normalization to body mass or weight may be important for weight bearing activities and to total thigh lean mass or lean weight for non-weight bearing activities if attempting to remove strength as a confounding factor. Controlling for covariates such as strength will allow for research to identify more accurately the factors or variables that indeed underpin the differences between the sexes with respect to physical performance or risk for injury. Future investigations may want to utilize strength-matching between men and women when examining muscle activity in isometric or dynamic complex tasks at a variety of knee angles. Further, to extend our knowledge on differences in performance between men and women, other methodological design considerations should be included to control for confounding modifiable variables such as training history, movement competency and as assessed in the current study, muscular strength. The findings of this research provide a practical foundation to suggest that increasing strength in women may be a sizeable modifiable factor that research has previously attributed to sex that may reduce or eliminate the magnitude of difference in muscle activity that may subsequently optimize athletic performance and decrease injury risk.

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Key points

- Agonist/Antagonist and medial/lateral muscle activity is not different between men and women when they are strength matched.
- Strength should be considered as a confounding variable when examining potential sex or gender differences in neuromuscular function.
- Strength normalization method can influence results and should be chosen on relevance to task.
- This investigation provides a foundation based on an isometric task to now examine dynamic tasks to see if similar results exist.

AUTHOR BIOGRAPHY

Sophia NIMPHIUS
Employment
Associate Professor at Edith Cowan University in the School of Medical and Exercise Sciences.
Degree
PhD
Research interests
Sports biomechanics, sport technology, coaching science, strength and conditioning, movement strategies
E-mail: s.nimphius@ecu.edu.au

Jeffrey M. McBRIDE
Employment
Professor in Biomechanics at Appalachian State University in the Department of Health & Exercise Science and the Director of the Neuromuscular & Biomechanics Laboratory.
Degree
PhD
Research interests
Stretch-shortening cycle and muscle power.
E-mail: mcbridejm@appstate.edu

Paige RICE
Employment
Doctoral Candidate at Edith Cowan University
Degree
MSc
Research interests
Dancers' triceps surae complex mechanical properties and stretch-shortening cycle function.
E-mail: p.rice@ecu.edu.au

Courtney GOODMAN-CAPPS
Employment
Graduate assistant for the Neuromuscular and Biomechanics laboratory and an adjunct professor for the Exercise Science department.
Degree
MSc
Research interests
Lower extremity biomechanics and the relationship to ACL injuries.

Christopher CAPPS
Employment
Graduate assistant for the Neuromuscular and Biomechanics laboratory and Appalachian State cross country and track & field teams.
Degree
BSc
Research interests
Running biomechanics and strength training.

✉ **Jeffrey M. McBride**
Neuromuscular & Biomechanics Laboratory, Department of Health and Exercise Science, Appalachian State University 045 Convocation Center, Boone, NC 28607, USA