WEIGHT BEARING KNEE JOINT MUSCLE ACTIVATION: SEX DIFFERENCES IN STABILISATION STRATEGIES

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Evaluation of voluntary muscle action can be delineated as stabilisation strategies against externally applied loads. Deficits in neuromuscular function may increase one's risk of joint injury. This study evaluated sex-related differences in muscle action during weight-bearing force control tasks. Young adults maintained inferior loads generating direction dependent ground reaction forces against a force plate. Electromyographic data was used to display and quantify muscle activation patterns. Females demonstrated significantly different rectus femoris and vastus medialis activation characteristics compared to males. Also, in both sexes, the vastii and bicep femoris demonstrated activation different than its previously reported functional role. Observed sex-related differences in knee muscle action may provide insight into mechanisms of ACL injury.

KEY WORDS: electromyography, muscle action, injury, anterior cruciate ligament.

INTRODUCTION: The knee joint is subjected to high forces and moments during daily activities. The ability for the knee joint to remain stable results from the integration of articular geometry, soft tissue restraints and loads from muscle action and bearing weight. Of these, muscles are the only dynamic regulators of knee joint stability. Deficits in neuromuscular control may increase one's risk for knee joint injury due to an inability to effeciently attenuate externally applied loads across the joint's structures. Females have (1) a greater incidence and prevalence of non-contact anterior cruciate ligament (ACL) injuries (Gwinn, Wilckens, McDevitt, Ross & Kao, 2000) and (2) a decreased ability to stabilize the knee with muscular support compared to males (Wojtys, Ashton-Miller, & Huston, 2002). Thus, investigating sex-related differences in muscle action may shed light on mechanisms of knee joint injury.

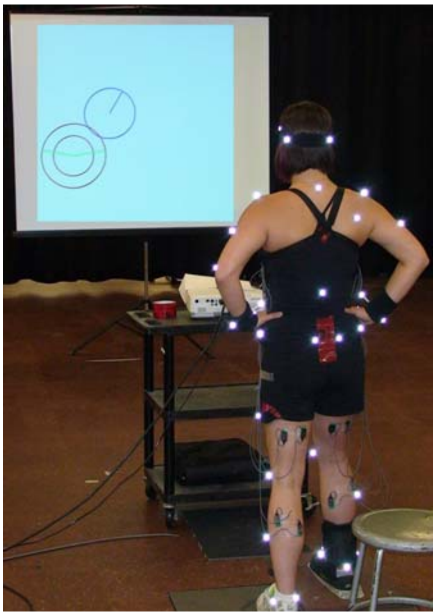

Figure 1: Laboratory setup: Subject standing with dominant foot in a boot fixed to a force platform and a projector screen displaying biofeedback of ground reaction forces is placed in front.

Typically, evaluations of neuromuscular function as it relates to knee joint stability involve functional assessments (i.e. walking, jumping); however, muscular contribution to force generation is dependent on biomechanical factors, thus results and interpretation of muscle function are confounded. It may be beneficial to limit biomechanical influences to force generation (i.e. isometric contractions) so individual muscle function can be more clearly associated with a measured task. The aim of this study was to evaluate sex-related differences in neuromuscular function during a weight-bearing isometric force generation and force control task. Our task elicits GRFs ranging from 0.48-0.58 N/kg (Smith, Flaxman, Speirs, Benoit, 2012), comparable to activities of daily living (McClay et al., 1994), as well as reliable within-subject and between-subject muscle activation patterns (Smith et al., 2012) leading us to believe we are observing physiologically relevant and non-random motor control strategies. Based on previous research (Krishnan, Huston, Amendola, & Williams, 2008; Sigward & Powers, 2006; Urabe et al., 2005; Youdas, Hollman, Hitchcock, Hoyme,. & Johnsen, 2007), it was hypothesised that females would have greater quadriceps activation compared to males.

METHODS: 41 healthy active young adults (20 male, 21 female) stood with their dominant foot fixed to a force plate (Figure 1). While controlling applied body weight (F_z), participants moved a projected image of a cursor to a target by modulating the horizontal ground reaction force (GRF) (F_x and F_y) direction and magnitude applied against the platform. Subjects were required to maintain constant joint angles of 30° hip flexion, 30° knee flexion, and 10° ankle flexion with their hips square to their shoulders. To match the cursor over the target, 30% of previously recorded maximal GRFs and 50% body weight was required. A successful match for one second triggered data collection of GRFs, kinematics and electromyography (EMG) of eight muscles crossing the knee joint. Twelve targets randomly appeared one at-a-time in locations representing horizontal loading directions at the force plate. Each target had to be matched three times. EMG signals of each muscle at each target location were conditioned, ensemble averaged, and normalised to a fraction of maximum voluntary isometric contraction (MVIC) (recorded previously with an isokinetic dynamometer). EMG values were plotted in polar coordinates to display muscle activation patterns. Statistical tests for muscle activation pattern asymmetry (about the polar plot origin) were conducted and mean magnitudes of muscle activations (X_{EMG}) were computed. GRFs and motion capture data were conditioned and processed to compute lower limb joint angles and moments. Significant sex-related differences were tested with independent T-tests and ANOVAs ($p<0.05$) and post hoc evaluations with adjusted alphas (α) of 0.025 and 0.017.

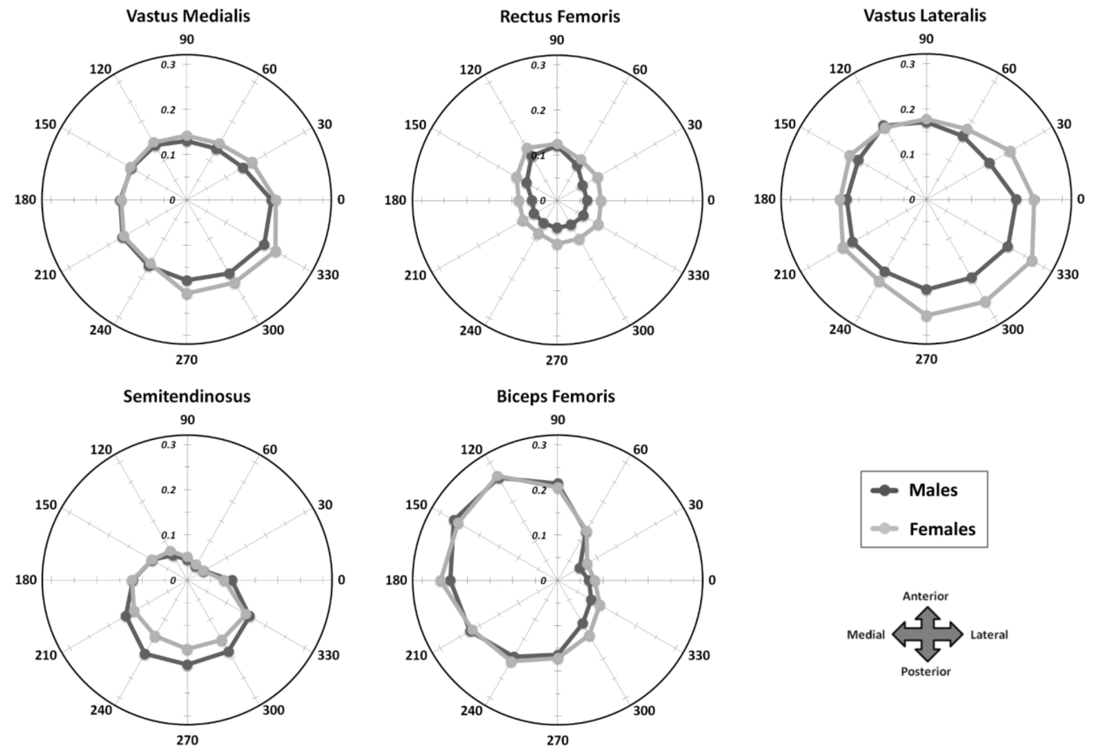

Figure 2: EMG polar plots of group mean activation patterns. Numbers along the circular trajectory represent the target location angle (º). Numbers along the radii represent normalised EMG magnitude. Plots are scaled from 0 to 0.33 (or 33% MVIC). Where the pattern on the target location's radius intersects represents the mean normalised EMG utilised to match that target.

RESULTS: EMG polar plots are presented in Figure 2 and hip and knee moments are presented in Figure 3. Females demonstrated signficantly (1) higher knee extension moments, (2) greater rectus femoris (RF) activation, (3) asymmetrical activation of the vastus medialis (VM), and (4) symmetrical activation of the rectus femoris (RF) compared to males.

DISCUSSION: This study compared voluntary knee muscle control strategies used by young healthy males and females during a weight bearing isometric force target matching protocol. Females were oberseved to generate significantly greater knee extension moments than males as well as varied quadriceps activations. Our results support our hypothesis as well as previous research: females have demonstrated relatively greater quadriceps activation during squatting, cutting, and jumping tasks while males activate their hamstrings to a greater extent (Sigward & Powers, 2006; Urabe et al., 2005; Youdas et al., 2007). Even though RF's X_{EMG} was <10% MVIC in both sexes - indicating minimal moment contribution- note that it has a large cross sectional area so low X_{EMG} could still represent functionally significant contributions to moment generation (Brand, Pedersen, & Friederich, 1986). Also, RF activation may be underestimated. Its EMG was normalised to a seated non-weight bearing MVIC value, and unlike the vastii, RF activity is greater during seated knee extensions compared to squatting or leg presses (Stensdotter, Hodges, Mellor, Sundelin, & Hager-Ross, 2003).

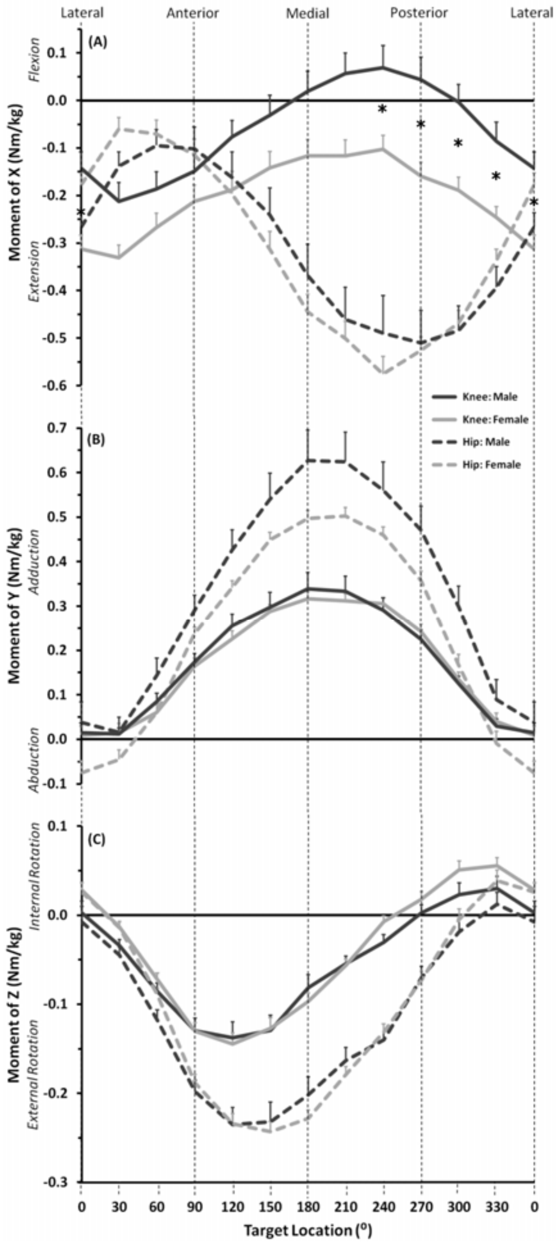

Figure 3: Group mean and standard errors of knee and hip joint moments of the (A) x-, (B) y- and (C) z-axes, expressed in Newton meters and normalised to weight (Nm/kg). Significant differences (p<0.017) denoted with asterisks (*).

Our findings indicate significant, clinically relevant sex-related differences in active knee joint stabilisation. Subjects had to maintain static joint positions such that the lower limb acted as a rigid segment-interconnected at the knee. Dominant hip strategies were elicited in both sexes (Figure 3B) such that hip muscles acted as moment actuators, applying moments to the proximal femur and transmitting forces through the knee to the foot-ground interface. Knee muscle contractions are required to balanced these applied forces and remain in a static position. Without knee muscle contribution, applied forces are unbalanced and a change in rotation and/or translation will occur, increasing loads exposed to the knee's soft tissue restraints such that the risk for traumatic injury increases (Withrow, Huston, Wojtys, & Ashton-Miller, 2006).

Previously, a muscle's activation was thought to be dependent on its moment arm orientation (Andriacchi, Andersson, Ortengren, & Mikosz, 1984) such that greatest activation would occur about its functional axis as it acts as an agonist and minimal activation when acting as an antagonist. Our results, however, contrast this concept: based on an earlier study (Flaxman, Speirs, Benoit, 2012), we have trichotomised the roles of muscles as they relate to knee joint stabilisation: (1) general joint stabiliser (2) specific joint stabiliser (3) moment actuator. Although traditionally deemed knee extensors, the vastus lateralis, VM of males and RF of females had symmetrical activation suggesting roles of *general joint stabilisers* - little preferential activation regardless of GRF direction. The VM of females and biceps femoris' asymmetrical activations opposite of their respectively reported extensor and flexor moment arm orientations (Buchanan & Lloyd, 1997) implies them to be *specific joint stabilisers* roles against valgus loads. Semitendinosus and RF of males were identified as a *moment actuators* since their asymmetrical activation patterns corresponded to their moment arm orientation, reflecting previous sitting force matching studies that addressed moment generation abilities of muscles (Buchanan & Lloyd, 1997; Krishnan et al., 2008).

CONCLUSION: Our protocol elicits GRFs comparable to functional activities suggesting we are observing physiologically relevant neuromuscular support strategies. We classified muscles as moment actuators, general joint stabilizers or specific joint stabilizers. Joint stabilizers are thought to increase joint compressive forces and create a stable mechanical system from which moment generators can initiate directed forces. Females were observed to generate significantly greater knee extension moments than males as well as varied quadriceps activations (stabilisation strategies) which may, in part, be a contributing factor in ACL injury (Withrow et al., 2006). Findings may provide insight into joint injury mechanisms and contribute to evidence-based rehabilitation and prevention training protocols.

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