Investigation of the Lower Limb Neuromuscular Activation in Children Following a Perturbation

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ABSTRACT

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Females and males are at risk for ACL injuries and are shown to benefit from injury-prevention programs. An ACL injury sustained during childhood or adolescence is associated with an increase in morbidity, including early development of osteoarthritis, long term disability, and chronic pain.

That the incidence of ACL injuries in children is higher in females when compared with males suggests that the pre-pubertal and pubertal period of growth and motor development may be a significant factor in injury risks related to the ACL. Unfortunately, very few studies have looked at situations that might contribute to injury and prevention of lower extremity injury in children. To determine potential injury risk, it is important to examine the activity and recruitment order of lower limb muscles to target deficiencies that can be addressed with IPPs.

Female and male children participants were recruited from sports teams and organizations in Montreal, QC. Data was collected using the Noraxon DTS EMG, and a goniometer. Participants were asked to maintain balance on their non-dominant leg during unexpected perturbations in the lateral, posterior, and rotational motions as well as a combination motion that mimics an ACL injury mechanism.

Our results show that differences exist between males and females 8-12 years old. For both sexes, muscle activation patterns previously identified as predisposing factors to ACL injuries were found, which suggests that injury prevention programs are of value to implement and study in this age group.

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Abbreviations

ACL: Anterior cruciate ligament
ANOVA: Analysis of variance
ASIS: Anterior superior iliac spine
BF: Biceps femoris
CNS: Central nervous system
COM: Center of mass
COP: Center of pressure
DTS: Direct transmission system
EMG: Electromyography
GM: Gluteus medius
GRF: Ground reaction force
IPP: Injury prevention program
LES: Left erector spinae
LESS: Landing error scoring system
LG: Lateral gastrocnemius
LRA: Left rectus abdominus
MG: Medial gastrocnemius
MOI: Mechanism of injury
MRI: Magnetic resonance imaging
ms: Milliseconds
MVIC: Maximal voluntary isometric contraction
NATA: National athletic trainers association
PL: Peroneus longus
Q-angle: Quadriceps angle
RES: Right erector spinae
RMS: Root mean square
RRA: Right rectus abdominus
ST: Semitendinosus
TA: Tibialis anterior
TFL: tensor fascia latae
TTM: Time to max
uV: Microvolt
VL: Vastus lateralis
VM: Vastus medialis

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1. Review of the literature

1.1. Burden of ACL injuries in sport

Both females and males are at risk for anterior cruciate ligament (ACL) injury and benefit from injury-prevention programs (DiStefano, Padua, DiStefano, & Marshall, 2009). In fact, previous estimates from the general population indicate that 1 to 5 ACL injuries occur per 5000 persons over a lifetime (Loes, Dahlstedt, & Thomee, 2000; Nordenvall et al., 2012), This risk increases in the athletic population, where the rate of ACL injury may be 10 to 100 times higher than in the general population (Padua et al., 2018). For example, a study found that the rate of ACL injury in the general population is less than 1 injury per 100 000 athlete-hours of sports exposure (Loes et al., 2000), but it rises dramatically up to 1 injury per 1000 athlete-hours for females playing in professional soccer games (Faude, Junge, Kindermann, & Dvorak, 2005). In the United States, epidemiology studies have found that approximately 200 000 ACL injuries occur annually (Padua et al., 2018); however, the incidence of ACL injury is greater among athletic and military populations (Moses, Orchard, & Orchard, 2012).

In addition, males have been found to sustain more ACL injuries than females in the general population(Gianotti, Marshall, Hume, & Bunt, 2009; Nordenvall et al., 2012; Padua et al., 2018) but high-school and college-aged females participating in comparable sports (eg, basketball, soccer, softball) are at 1.5 to 4.6 times greater risk of experiencing an ACL injury compared with their male counterparts (Agel, Arendt, & Bershadsky, 2005; Gwinn, Wilckens, McDevitt, Ross, & Kao, 2000; Hootman, Dick, & Agel, 2007; Joseph et al., 2013; Loes et al., 2000). ACL injuries have been found to occur with a four- to six-fold greater incidence in female athletes compared to males playing the same high risk sports(Arendt, Agel, & Dick, 1999; Chandy & Grana, 1985; Ferretti, Papandrea, Conteduca, & Mariani, 1992; Gray et al., 1985; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Huston & Wojtys, 1996; Malone, Hardaker, Garrett, Feagin, & Bassett, 1993).

Injuries to the ACL have important implications for athletes as it often results in loss of entire seasons of sports participation, which may in turn decrease scholarship amounts and lower academic performance (Hewett, Ford, Hoogenboom, & Myer, 2010).

In addition, an injury to the lower limb, like an ACL injury, sustained during childhood and adolescence is associated with an increase in morbidity, including early development of osteoarthritis, long term disability and chronic pain (Lohmander, Englund, Dahl, & Roos, 2007). As high as 50% of ACL injuries in the United States occur in athletes 15 to 25 years of age (Griffin et al., 2006). The rate of non-contact ACL injuries ranges from 70 to 84% of all ACL tears regardless of the sex of the athlete (Boden, Dean, Feagin, & Garrett, 2000; Fauno & Wulff Jakobsen, 2006; Griffin et al., 2000; McNair, Marshall, & Matheson, 1990). It is also important to note that ACL injury can become very costly, with the estimated cost of surgeries and rehabilitation at 17,000$-25,000$ per injury in the United States (Griffin et al., 2006). Therefore, the focus of this thesis is on the ACL and aspects that provide a better understanding and potential to reduce this type of injury.

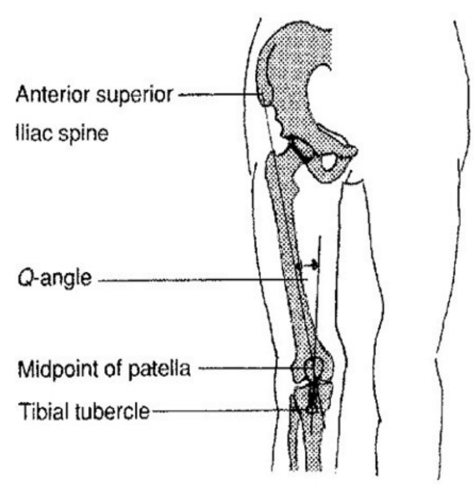
In a previous study, it was found that insurance injury claims in children aged 5-18 years showed that at ages 11–12, both males and females demonstrated an increased frequency of ACL injury claims, and the risk appeared to increase up to age 18 years (Shea, Pfeiffer, Wang, Curtin, & Apel, 2004). 31% of total knee injuries were females with ACL injuries (Shea et al., 2004). The overall ratio of ACL injury claims to total injury claims was significantly higher for females when compared to boys from 12 to 18 years old (Shea et al., 2004). An analysis of children presenting to a sports medicine clinic showed an increase in the ratio of ACL injuries to total injuries in girls after the age of 12 when compared with boys (Stracciolini, Stein et al., 2014). The fact that the incidence of ACL injuries in children is also higher in females when compared with males suggests that the pre-pubertal and pubertal period of growth and motor development may be a significant factor in injury risks related to the ACL (Stracciolini et al., 2014). Unfortunately, little research has been done on this age group. Very few studies have looked at the biomechanics of the lower extremity in children, even though 25% of ACL injuries in children (18 years old and younger) occur between the age of 5 and 12 years old (Stracciolini et al., 2014). Epidemiology studies have found that the incidence of ACL injuries in children increases with age in males and females, but that females show a steeper increase (Stracciolini et al., 2014), even though the percentage of males and females who sustained an ACL injury was almost equal (10.0% and 8.9% respectively) (Stracciolini, Casciano et al., 2014). Female athletes between 5 and 17 years old sustained more injuries to the lower extremity (65.8%) and spine (11.3%) as compared with male athletes (53.7% and 8.2%) (Stracciolini et al., 2014).

ACL injuries can be even more problematic in children than in adults because of the risk factors associated with treatments. An epidemiological study reported that non-operative treatment of ACL injuries in children may lead to knee instability and secondary injuries, especially in those who return to sports (Shea, Apel, & Pfeiffer, 2003). This study also highlighted the risks and complications of ACL reconstruction in skeletally immature patients because of potential damage to the proximal tibial and distal femoral physes, which may lead to premature growth arrest and/or leg length discrepancies (Shea, Apel, & Pfeiffer, 2003).

1.2. Risk factors affecting female ACL injuries

Multiple studies have tried to identify differences between males and females that could explain the higher incidence of injuries in the later. Many anatomical, hormonal, and neuromuscular factors differ between males and females during the pubertal process. These differences may contribute to the sex disparity in injury rates after puberty (Quatman, Ford, Myer, & Hewett, 2006; Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012). One of the first suggestions was that hormones played an important role in the rate of injuries. In their research, Warren et al. showed that an increase in sex hormone concentrations during the menstrual cycle affected knee laxity (Warren, Liu, Hatch, Panossian, & Finerman, 1999). There is also a higher knee laxity in the early luteal phase of the menstrual cycle(Shultz, Sander, Kirk, & Perrin, 2005) and although the relationship between knee laxity and ACL injury is yet to be established, evidence indicates that an increased knee laxity can lead to ACL injury (Woodford-Rogers, Cyphert, & Denegar, 1994) since there is an increase in the incidence of ACL injuries early and late in the follicular phases of the menstrual cycle (Beynnon et al., 2006). Although the research on hormonal risk factors is interesting and has discovered

Figure 1. Q angle of the knee



(Wikipedia, 2015)

a possible link to ACL injuries, hormone levels fluctuation can hardly be modified and are therefore not the focus of injury prevention for ACL injuries.

Anatomical differences have also been suggested as possible risk factors in female athletes. More specifically, the quadriceps angle (Q angle) (Figure 1) has been proposed as a contributor to the development of knee injuries. In a study investigating recreational basketball players, it was found that players with knee injuries had a higher mean Q angle than the uninjured players(Shambaugh, Klein, & Herbert, 1991). Other studies have also tried to establish the ligament size as a risk factor for ACL injury. In a prospective study of high school basketball players using MRI measurements of the ACL, it was found that ACLs in girls were smaller than in boys when normalized for body weight(Anderson, Dome, Gautam, Awh, & Rennirt, 2001). It is important to note, however, that although women might have smaller ACLs, more research needs to be done to identify if this difference in size is of enough importance to explain the higher incidence of injuries in females. In addition, anatomical differences cannot be modified so even though it may contribute to the inherent risk factors for ACL injuries, the implications might not be relevant for injury prevention programs (IPPs).

1.3. ACL injury mechanism

The study of mechanisms of non-contact ACL injuries is based on different approaches: interviews with injured athletes, video analysis, clinical in vivo and cadaver studies, mathematical modeling and simulation of injury situations (Krosshaug, Andersen, Olsen, Myklebust, & Bahr, 2005; Renstrom et al., 2008). The most common events forestalling ACL injuries include a change of direction or cutting maneuvers in combination with landing from a jump in or near full extension, pivoting with the knee near full extension, deceleration, and a planted foot (Boden et al., 2000; Fauno & Wulff Jakobsen, 2006; Feagin & Lambert, 1985). These playing situations create knee valgus and varus, internal rotation and external rotation moments, and anterior translation force (Boden et al., 2000; Markolf et al., 1995; Markolf, Gorek, Kabo, & Shapiro, 1990; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Wascher, Markolf, Shapiro, & Finerman, 1993; Yu & Garrett, 2007). The anterior translation force may be the most detrimental to ACL injuries, especially at knee flexion angles around 20°-30° (Alentorn-Geli et al., 2009).

This susceptibility range is often identified as an important contributing factor causing ACL injuries (Berns, Hull, & Patterson, 1992; Boden et al., 2000; Markolf et al., 1995; McNair et al., 1990; Yu & Garrett, 2007). Most ACL injuries occur in the 40ms following landing (Pappas & Carpes, 2012). Video motion analysis of trunk and knee motion during non-contact ACL injuries show that female athletes land with greater lateral trunk motion(Hewett, Torg, & Boden, 2009),higher knee abduction(Boden et al., 2000)·(Boden, Torg, Knowles, & Hewett, 2009; Hewett et al., 2009; Koga et al., 2010; Krosshaug et al., 2007; Olsen et al., 2004), lower knee flexion angle(Boden et al., 2000), increased tibial internal rotation or external rotation(Boden et al., 2000), limited ankle plantarflexion at initial contact, and excessive hip flexion. Increased lateral trunk motion and knee abduction motion are important components of the ACL injury mechanism in female athletes (Hewett et al., 2009). As shown in cadaveric studies, isolated knee internal rotation, external rotation, valgus and varus moments do not produce enough force to strain the ACL, in contrast with a multi-planar motion like the combination of anterior translation and valgus or internal rotation (Berns et al., 1992; Markolf et al., 1995). Thus, the evidence shows that the most common non-contact ACL injury mechanism in female athletes occurs during a deceleration task with high knee extension torque combined with dynamic valgus and a planted foot (Boden et al., 2000; Griffin et al., 2006; Krosshaug et al., 2007; Olsen et al., 2004).

These mechanisms are consistent with theories of neuromuscular deficits that were identified in biomechanical-epidemiological studies. The concept of “ligament dominance” was first introduced in 1985(Andrews & Axe, 1985) and was described as when the lower extremity musculature does not adequately absorb the forces during a sports maneuver which induces an excessive loading of the knee ligaments. Ligament dominance therefore often results in high ground reaction forces, valgus knee moments, and excessive knee valgus motion. Females that land with high knee valgus angle and moment, described as “ligament dominance” (Hewett et al., 2010)) and high side-to-side differences in knee valgus angle and moment (described as “leg dominance” (Hewett et al., 2010), are at a higher risk of future ACL injury (Hewett et al., 2005). A higher trunk displacement and poorer trunk proprioception, also described as “trunk dominance,” are indicators of a higher risk for ACL injury (Zazulak, Hewett, Reeves, Goldberg, &

Cholewicki, 2007a; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007b). Females who suffer ACL injury also have lower knee flexor strength and higher relative knee extensor strength when compared to male athletes; deficits described as "quadriceps dominance" (Myer et al., 2009). Another indicator of the quadriceps dominance deficits was found when analyzing muscle pre-activation during a side-cutting maneuver where female athletes who went on to tear their ACL had lower semitendinosis and higher vastus lateralis pre-activity than athletes who did not tear their ACL (Zebis, Andersen, Bencke, Kjaer, & Aagaard, 2009).

1.4. Influence of Neuromuscular factors

1.4.1. Joint Kinetics

During a single leg drop test, females have a prolonged GRF and a significantly greater activation of the rectus femoris when compared with males (Nagano, Ida, Akai, & Fukubayashi, 2007; Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007), as well as a significantly greater activation of the rectus femoris, medial and lateral hamstrings, and medial gastrocnemius when compared with bilateral landings (Pappas et al., 2007). Orishimo et al. didn't find any biomechanical differences between male and female dancers after examining knee joint landing biomechanics (Orishimo, Kremenic, Pappas, Hagins, & Liederbach, 2009). A study comparing the muscle activation of soccer players found that the gluteus medius activity was significantly lower in females when compared with males(Hart, Craig Garrison, Casey Kerrigan, Palmieri-Smith, & Ingersoll, 2007).

During two-legged hopping, women have higher quadriceps and soleus muscle activity than men (Padua, Carcia, Arnold, & Granata, 2005). Females also demonstrate greater average quadriceps EMG than males during a side-cutting task (Sigward & Powers, 2006). Females have a higher amplitude and area of contraction of the lateral hamstring during a single leg landing task compared to men (Rozzi, Lephart, Gear, & Fu, 1999). In contrast, females have an increased delay in activation of their lateral muscles when compared with their medial muscles and with the activation pattern of men during double-legged drop landing (Gehring, Melnyk, & Gollhofer, 2009). Females that have higher quadriceps to hamstring strength ratio are at a higher risk of injuring their anterior cruciate ligament (Myer et al., 2009).

During a stop-jump task, female subjects exhibited increased quadriceps activation, and increased hamstrings activation before landing but a trend of decreased hamstring activation after landing compared with male subjects (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007).

Studies have also tried to identify deficits in female trunk stabilization as a possible predisposing factor to ACL injuries. A study compared the trunk muscle activation in male and female athletes during a drop landing task (Kulas, Schmitz, Shultz, Henning, & Perrin, 2006). They found that males activated their transverse abdominus and internal oblique muscle in anticipation of landing (pre-activation) whereas females had no significant difference in the activation of all their trunk muscles and no difference in pre- or post-activation (Kulas et al., 2006). Although this study didn't look at the kinematics of the task, they were able to identify differences in trunk stabilization. Further research that would correlate muscle activation with trunk stabilization would be helpful to better understand the effect of trunk stability on the lower extremity and how it relates to injuries to the anterior cruciate ligament.

Active stiffness has been suggested as an important factor in knee stability and ligamentous injuries. It is defined as the resistive force that a muscle exerts in response to a given length change (Blackburn, Padua, Riemann, & Guskiewicz, 2004). Analysis of the ground reaction force and the displacement of the center of mass (COM) during repeated double-leg hopping, shows that leg stiffness in females is approximately 77% of the leg stiffness in males (Granata, Padua, & Wilson, 2002). However, when normalized for body mass, there was no significant difference between both sexes. The findings by Granata et al. are supported by a more recent study (Padua et al., 2005) that found that females had decreased leg stiffness that was eliminated when normalized for body weight. The latter study also found an increased quadriceps activation and hypothesized that this increased reliance on quadriceps suggests that women try to modify their muscle stiffness to compensate for their increased knee joint laxity (Padua et al., 2005). This further supports the “quadriceps dominance” theory as a potential injury mechanism for ACL injuries. The “quadriceps dominance” theory was also supported by studies that demonstrate an activation pattern in females that favors quadriceps when compared to males (Ahmad et al., 2006; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Sigward & Powers, 2006; Zazulak et al., 2005).

Co-contraction has been defined as the concurrent activity of muscles that are agonist and antagonist in the execution of specific tasks (Olney, 1985), including tasks requiring motor coordination and joint stability (Baratta et al., 1988). A study analyzing co-activation during gait in adults found that co-activation of the antagonist assists ligaments in maintaining joint stability and equalizing the articular surface pressure distribution (Baratta et al., 1988). A similar study done on children found that co-activation is a functional mechanism that helps improve balance and control of joint stability (Di Nardo et al., 2018).

A study electromyographically analyzed the single-legged squat in intercollegiate athletes and found that females had higher muscle activation in rectus femoris, vastus lateralis, medial gastrocnemius, biceps femoris, and gluteus maximus when compared with men(Zeller, McCrory, Ben Kibler, & Uhl, 2003). Females also had significantly greater mean and maximal quadriceps activation (Zeller et al., 2003).

1.5.Role of leg dominance in non-contact ACL injuries

Balance is a motor skill acquired with practice because of muscle synergies. Through the combined information from the vestibular, visual, and somatosensory system, which are coordinated by the central nervous system, an individual can stand straight and upright with correct posture (Gstöttner et al., 2009; Matsuda, Demura, & Uchiyama, 2008). The displacement of the center of pressure (COP) of the athlete is minimized with greater balance and is controlled by the central nervous system (Barone et al., 2010). Gstottner et al. found that there was no significant difference regarding balance when comparing the dominant and non-dominant legs. However, it was observed that the non-dominant leg was used more for improved balance. Similarly, a significant difference was not found between the dominant leg and non-dominant leg stance (Matsuda et al., 2008; Mokhtarzadeh et al., 2017).

Studies have examined if female athletes show more “leg dominance” during athletic maneuvers compared to their male counterparts, and how, if any, the asymmetries would contribute to an increased injury risk regarding ACL injury. Because differences in muscle activation have been observed between the kicking limb and the supporting limb, it is suggested that leg dominance can result in an imbalance that may cause ACL injuries as these athletes put differential demands on their lower extremities (Brophy, Silvers, Gonzales, & Mandelbaum, 2010). More female athletes have a preferred leg as the dominant leg compared to male athletes. The dominance preference may be due to the greater difference in muscle strength and recruitment patterns as well as flexibility when comparing both limbs in female athletes (Hewett et al., 2010). As it was suggested, lower leg asymmetries would put athletes at higher risk of having an ACL injury on either limb and because females have more asymmetries than males especially in forward landing (Pappas & Carpes, 2012), limb dominance might explain the discrepancy between males and females in the occurrence of ACL injuries. In addition, most non-contact ACL injuries of female soccer athletes occur in the non-dominant, supporting, leg. In contrast, male non-contact ACL injuries occur in the dominant, kicking, leg (Brophy et al., 2010). The difference in leg incidence between males and females suggests that gender does play a role in non-contact ACL injuries.

Stability during single leg stance versus double leg stance is not consistent between sports and is dependent upon the level of the athlete as well as their sport and position on the team (Matsuda et al., 2008). For example, when comparing female NCAA basketball, gymnastics and soccer athletes, the basketball athletes displayed lower dynamic stability than gymnasts and lower static stability than soccer players. The latter difference may be due to soccer athletes performing single leg reaching tasks away from their base of support during passing, receiving, and shooting motions (Bressel, Yonker, Kras, & Heath, 2007). In addition, when comparing COP displacement between athletes from different sports, specifically soccer, basketball, and swimming, with non-athletic individuals, the soccer athletes exhibited less sway in the vertical and horizontal directions compared to athletes on basketball and swim teams and nonathletic individuals, indicating that the soccer athletes are more stable during single leg stance compared to the other groups. This may be the result of training as the dominant leg in soccer is used to kick the ball, while the non-dominant leg is used to support the weight of the athlete (Barone et al., 2010; Hewett et al., 2010; Matsuda et al., 2008).

Limb dominance might explain the gender differences because of the stress it puts on the lower extremities. Training experience and sport might also play a role in the incidence of ACL injuries as they affect single-leg balance abilities.

1.6. Research done on children

In a study, prepubescent children and adults were compared during a vertical jump task. It was found that children demonstrate a stiffer landing technique (greater knee and hip extension) and greater knee valgus (Swartz, Decoster, Russell, & Croce, 2005). Although no differences were found between male and female children, their results show that children have deficits in landing technique that could be addressed using an IPP. Another study used vertical drop-jump test to assess vertical jump performance and landing technique and identify differences in males and females throughout the pubertal Tanner Stages (Hewett, Myer, Ford, & Slauterbeck, 2006). Their results show that females did not demonstrate the increased ability to generate power and absorb forces across the stages of development as was seen in the male participants. This indicates that females lack the neuromuscular spurt seen in males during maturation, which may be related to the higher incidence of ACL injuries in females at maturity.

Postural assessment of children of different maturational stages shows that, although changes were observed in both males and females, males have a greater decrease in Q-angle and knee laxity compared to females, and females had an increased internally rotated hip and knee valgus compared to males (Shultz, Nguyen, & Schmitz, 2008). Those differences were more important in the later maturation groups. It is important to note that these findings were not correlated with dynamic hip and knee function and injury risk during physical activities. More research is therefore required in this area to better understand the relationship between postural and neuromuscular changes in young athletes before, during and after puberty.

A study comparing adults with pre-pubertal children assessed the landing neuromuscular control of individuals (Russell, Croce, Swartz, & Decoster, 2007). It was found that adults recruit their muscles, and particularly their hamstrings, in preparation of a landing task (Russell et al., 2007). It was also found that at landing, adults used their distal muscles (ankle-muscle group) whereas children used their bigger proximal muscles (hip-muscle group) to stabilize (Russell et al., 2007). The difference between adults and children suggests that children use different activation patterns to absorb the landing forces that they otherwise wouldn't be able to control because of their lower force production capabilities (Russell et al., 2007). In addition, it was found that low-skilled children showed greater preparatory hamstring and quadriceps coactivation than highly skilled children (Hamstra-Wright et al., 2006), suggesting that experience might also influence the muscle activation patterns.

A study assessed the influence of age, sex, technique, and exercise program on movement patterns after an IPP in youth soccer players (L. DiStefano, Padua, DiStefano, & Marshall, 2009). They used the Landing Error Scoring System (LESS) to score 3 trials of a drop jump before and after the IPP (between 4 and 9 months). They found that the participants that scored higher on LESS at baseline (worse) had the best improvements post-test, suggesting that neuromuscular training programs are most effective with athletes presenting poor movement techniques before starting the program. They also found that high school aged participants improved more than the pre-high school participants. This indicates that existing IPPs might not be appropriate for prepubescent athletes and that there might be a need for IPPs that match their stage of motor and growth development (L. DiStefano et al., 2009).

Hewett et al. compared pre-pubertal, early pubertal and late or post-pubertal boys and girls for medial knee motion, maximal knee angle and lower extremity varus-valgus angle when landing from a jump. There was a significant difference in kinematics and kinetics between post-pubertal boys and girls as female athletes landed with greater total medial knee motion and a greater maximum lower extremity valgus angle than did the male athletes. The girls also demonstrated decreased flexor torques compared with the boys as well as a significant difference between the maximum valgus angles of their dominant and non-dominant lower extremities after maturation. These results indicate that girls have poorer neuromuscular control after the onset of puberty when compared with boys (Hewett, Myer, & Ford, 2004).

Another study found that valgus joint loads were similar in males and females in pre- and early-adolescence but higher in females at late-adolescence (Hewett, Myer, Kiefer, &

Ford, 2015). A study measured surface EMG during gait in school-age children and found that children regularly use a co-contraction activity between quadriceps and hamstring muscles in weight acceptance during walking, supporting the hypothesis of a regulatory role of co-contraction in providing knee joint stability (Di Nardo et al., 2018) even in children.

A study comparing knee and hip kinematics during a vertical jump in children and adults found that children's landing patterns demonstrated more hip and knee extension and more knee valgus, suggesting that they landed with more leg stiffness. Children also exhibited greater and more abrupt vertical ground reaction forces than adults. No sex differences were found in children or adults. These age differences suggest that landing patterns change with physical development (Swartz et al., 2005).

Movement patterns play a critical role in ACL injury because they influence anterior tibial shear force, which directly strains the ACL (Graziano, Green, & Cordasco, 2013). Because growth spurt starts on average at 10.5 years for girls and 12.5 years for boys (Marshall & Tanner, 1986), and because children as young as 10 years of age have demonstrated movement patterns associated with injury risk(Shea et al., 2004; Swartz et al., 2005), it is important to better understand movement patterns and muscle activation in that age group to be able to intervene in movement modification during sport-specific tasks by implementing IPPs in this ideal intervention time. Early intervention is also important because young athletes' bodies change as they grow, affecting bony levers and center of body mass, which impact postural alignment and neuromuscular control (Hewett, Myer, Ford, Paterno, & Quatman, 2012). Indeed, during growth spurts, core strength, neuromuscular ability, coordination, and proprioception become imbalanced and contribute to injury risk (Gianotti et al., 2009; Hewett et al., 2012).

1.7. Perturbations

Previous studies have analyzed perturbations and their effects on stabilization and biomechanical responses. A study indicated that bending the knees to attain a crouched position allowed for better balance during anterior and posterior perturbations than initial stance (LeVangie, 2013). LeVangie's findings suggest that adults might be better at stabilizing when their knee is flexed. Mathematical modeling has demonstrated that a perturbation during a side-step maneuver may cause external valgus (Quatman & Hewett, 2009). The findings of Quatman & Hewett suggest that perturbations may impact knee kinematics by creating body alignments that can put the knee at risk of an ACL injury.

A study by Hurd et al. also demonstrated that neuromuscular training improved quadriceps-hamstring balance and active stiffness at the knee joint when comparing male and female athletes (Hurd, Chmielewski, & Snyder-Mackler, 2006). In this study, the participants walked on a platform moving in the lateral direction at heel contact before and after neuromuscular training. Prior to training, female participants demonstrated quadriceps dominance and decreased active knee stiffness compared to male participants. Female participants also had greater co-contraction indices between medial gastrocnemius and vastus lateralis muscles during both preparatory and weight acceptance phases of gait compared to the male participants (Hurd et al., 2006).

A recent study explored dynamic knee stability, comprised of the interaction of the visual, vestibular, and somatosensory systems, during single-planar and multi-planar perturbations. They used multi-planar perturbations of different amplitudes, velocities, and accelerations to reproduce the suspected ACL injury mechanism. The multi-planar perturbation combined posterior and lateral translations to induce a knee abduction; rotation around a vertical axis to induce external rotation; and rotation around an anterior-posterior axis to induce foot pronation, as these movements have been previously identified as potential ACL injury mechanisms. Their results showed no significant differences in muscle activity between the multi-planar and single-planar perturbations of the same amplitude (Malfait et al., 2015).

A study reported significantly greater vastus medialis, vastus lateralis, and medial hamstring activity during a multi-planar perturbation compared to a lateral single planar perturbation. No differences were reported in neuromuscular activity, peak knee flexion, and peak knee abduction angles when comparing the single planar perturbations to the multi-planar perturbations (Malfait et al., 2015).

A study compared deep and superficial abdominal muscle activation following a perturbation and found that the rectus abdominis was relatively low (15% MVIC) during the first 300ms following a translation perturbation (Carpenter, Tokuno, Thorstensson, &

Cresswell, 2008). Furthermore, they found no significant difference in rectus abdominis activation between perturbations (antero-posterior, medial-lateral) in the first 200ms following perturbation but found that it was significantly increased in forward when compared to backward translations in the 200-300ms range (Carpenter et al., 2008).

A study examined the EMG response to multi-directional surface perturbations and found that the direction of maximal activity for all muscles was generally in response to diagonal translations, except for the tensor fascia latae (TFL), which was maximally active in response to lateral translations (Henry, Fung, & Horak, 1998b).

A study analyzed muscle activation patterns following lateral, anterior, and posterior perturbations. They found that EMG patterns were similar in that there was an early proximal (trunk or hip) muscle activation in all directions as well as an underlying distal-to-proximal muscle activation pattern (Henry, Fung, & Horak, 1998a).

A study compared muscle activation patterns between slow and fast perturbations. The slow velocities' muscle activation responses were characterized by activity in gastrocnemius, hamstrings, and paraspinals and relatively little knee and hip angles. At fast velocities, a hip strategy was added to the response, as demonstrated not only by rectus abdominis, abdominal activity, and increased hip flexion, but more importantly by an early hip flexor torque, which established active initiation of the hip flexion (Runge, Shupert, Horak, & Zajac, 1999).

Another study suggested that the magnitudes of balance reaction, i.e., peak hip, knee, and ankle angular displacements and magnitude of muscle responses, were scaled to the velocity and acceleration of the platform (Szturm & Fallang, 1998). More challenging perturbations would, therefore, result in increased muscle responses. In contrast, a study by Chen et al. found that different types and directions of perturbations have a significant effect on onset latency instead of the magnitude of muscle activation (Chen et al., 2014).

In 1985, Nashner and McCollum hypothesized the existence of two strategies that could be used separately or combined by the nervous system to stabilize the center of mass (COM) in the sagittal plane. The ankle strategy repositioned the COM by moving the whole body as a single-segment inverted pendulum by the production of torque at the ankle, whereas the hip strategy, moved the body as a double-segment inverted pendulum with counterphase motion at the ankle and hip. They further suggested that hip strategy should be observed in situations that limit the effectiveness of ankle torque at producing whole-body motion (e.g. perturbations of high velocities) (Nashner & McCollum, 1985). Furthermore, Horak & Nashner analyzed muscle activation following a brief forward and backward horizontal surface perturbations. They found that muscle activation happened with 73- to 110ms latencies. Horak & Nashner also found an activation pattern that began in the ankle and then radiated to the thigh and then trunk muscles on the same dorsal or ventral aspect of the body. Horak & Nashner termed this activation pattern the ankle strategy because it restores equilibrium by moving the body primarily around the ankle joints (Horak & Nashner, 1986).

Henry et al. analyzed muscle activation patterns in adults during four different perturbations (anterior, posterior, medial and lateral) and found a similarity in that there was an early proximal (trunk or hip) in all directions as well as an underlying distal-to-proximal muscle activation pattern. The lateral perturbation created an early TFL activation at a latency of 103ms followed by activation of muscles from the lower leg (tibialis anterior, gastrocnemius, soleus, and peroneus longus) 20ms later. For the A/P translations, there was a distal-to-proximal muscle activation pattern with the tibialis anterior, the soleus, and the gastrocnemius at a latency between 105-116ms followed by the vastus medialis (posterior) or the semimembranosus (anterior) 20ms later and the rectus abdominus (posterior) or erector spinae (anterior) at 80-to 90-ms later (Henry et al., 1998a).

Previous studies analyzing postural responses to perturbation found two components of movement. An early passive component and a later active component were identified in body kinematics. They stated that the early passive component was induced by the platform movement, and the later active component was a corrective response to the platform movement (Alexander, Shepard, Gu, & Schultz, 1992; Hughes, Schenkman, Chandler, & Studenski, 1995). These two components were later defined as two phases, i.e., a balance disturbance phase and a balance reaction phase (Szturm & Fallang, 1998).

1.8. Future of ACL injury research

Injury prevention programs (IPPs) have been found to help decrease the incidence of injuries in young adults but show controversial results with children population (L. J. DiStefano et al., 2011). A recent meta-analysis demonstrated a greater effect of preventive training programs when they were implemented during the mid-teens versus older ages (Myer, Sugimoto, Thomas, & Hewett, 2013), but no evidence indicated a specific age or maturation stage at which the program should begin. That might be explained by the lack of understanding of the biomechanical reactions to unpredicted movements in that population. Further research that could identify specific risk factors in children would allow the creation of age-specific IPPs that could be more beneficial to them.

Earlier intervention is important as the middle-school age range is the best time for children to develop neuromuscular control (Padua et al., 2018). In fact, motor development is not complete at this point and preadolescent children may be at an optimal age to master fundamental motor skills (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Improving neuromuscular control in children younger than 15 years may also decrease their susceptibility to injury during the highest-risk years (i.e. adolescence) and might improve long-term compliance and outcomes (Padua et al., 2018). It is recommended in the NATA position statement on ACL injury (Padua et al., 2018) to target all children who participate in high risk sports involving landing, jumping, and cutting tasks (e.g. basketball, soccer, football) for preventive training programs (L. J. DiStefano et al., 2011; Myer et al., 2011; Myer et al., 2013; Swartz et al., 2005).

It is suggested that children need to develop a general foundation of motor skills and strength to decrease the risk of future injury (DiFiori et al., 2014). Because they develop fundamental motor skills, such as running, jumping, and landing, at different rates (Lubans et al., 2010; Morgan et al., 2013), implementing programs that match an individual child's cognitive and neuromuscular development levels is key to promote confidence and intrinsic motivation to participate and continuously improve (Malina, Bouchard, & Bar-Or, 2004). A study done on dancers showed that even though males and females have anatomical and hormonal differences, similar biomechanics can still be achieved with early specific training(Orishimo et al., 2009). The findings by Orishimo et al. are important to consider for the development of IPPs as they highlight not only the importance of proper biomechanical training but also that beginning landing-specific and balance-specific training early may counteract the potentially harmful adaptations in landing biomechanics observed in females after puberty.

2. Rationale and Research Objectives

From the literature, we can identify that an important area of research is to explore lower limb muscle activity and muscle recruitment of the non-dominant leg of physically active children during a maneuver that imitates an ACL injury mechanism. Although there is ongoing research exploring the mechanism of an ACL injury, there are very few studies that measure muscle activity and explore movement at the knee joint during an unexpected perturbation in children. Specifically, it is important to determine the muscle activity and the order of lower limb muscle recruitment to be able to target deficiencies that can be addressed with IPPs. The purpose of the study was to explore and determine the reaction of lower extremity muscles based on initial stance, specifically at the knee joint, during perturbations that imitate an ACL injury mechanism in physically active children. This information can improve the existing knowledge of the ACL injury mechanism and allow for improvement of IPPs based on the understanding of muscle activity and lower limb movements specific to young athletes. Therefore, the objectives were the following:

1) To understand and compare male and female lower extremity muscle activity and recruitment in children during a mimicked ACL injury mechanism.
2) To determine the relationship between lower extremity muscle activation measured using EMG of physically active male and female children and knee flexion angle during a perturbation that mimics an ACL injury mechanism.

3. Hypotheses

1) There will be no differences between male and female physically active children in mean and maximum %MVIC, and in mean time to peak.

2) Within 250ms following an unexpected perturbation the quadriceps muscle contraction will decrease whereas the hamstring muscle activity will increase in physically active children in the straight knee condition
3) Within 250ms following an unexpected perturbation, physically active children will have a proportionally higher gluteus medius muscle activation as compared with ankle muscles.

4. Methodology

4.1. Subjects

Female and male participants were recruited from the Concordia Stingers Hockey School, from various soccer teams in the Montreal area, from the Paris Saint-Germain Soccer Academy in Montreal and through the Concordia University teachers and staff. Inclusion criteria: 1) age 8 to 12 years; 2) physically active at least 3 days a week; Exclusion criteria: 1) Recent or prior history of major lower extremity injuries; 2) regular use of knee and/or ankle braces or taping for stability during physical activity; 3) previous enrollment in an injury prevention exercise intervention program. The eligibility criteria are to ensure that confounding factors are minimized as well as ensuring patient safety.

4.2. Material and Apparatus

Muscle activity data was collected using 12-channel DTS EMG with a sampling frequency of 1500 Hz (Noraxon U.S.A. INC, Scottsdale, AZ, USA). The interelectrode distance was 2cm. The EMG signals were smoothed by digital filters in Myoresearch 1.08.17 (Noraxon U.S.A. INC, Scottsdale, AZ, USA), which uses a proprietary smoothing algorithm and a rolling RMS window of 100ms (Noraxon, MyoResearch XP Master Manual, 2011) Maximal voluntary isometric contraction (MVIC) was found using a peak rolling average value in 500ms windows. The parameters for the perturbations were tested and set to be challenging without any risk of injury for the participants and were consistent with previous studies in this lab. During posterior and lateral perturbations of the platform, the acceleration was set at 3500 mm/s^2, the speed was set at 200mm/s, and the platform travel distance was set at 50mm. During rotational motion, the acceleration was set a 400 °/s^2, the speed was set at 20 °/s, and the angle that the platform moves was set at 5°. The combination motion combined the lateral, posterior, and rotational motions. A goniometer was used to measure the angle at the knee joint for the bent condition.

4.3. Procedure

The research study is a counterbalanced research design. The experiment is a single-blind experiment. The participants who accepted to take part in the study after receiving information in person or via email and meet the eligibility criteria were tested to obtain measurements during a one-hour session. All data collection was completed at the PERFORM Center (Montreal, QC).

During the session, the subjects and their parents were able to understand and complete the informed consent. Measurements of the leg length, from the anterior superior iliac spine (ASIS) to the medial malleolus, were obtained with the patient lying supine on a table. Knee width and ankle width were obtained with the patient standing and putting most of their weight on the tested leg. The patient's weight was measured using a numeric scale, and height was measured using a stadiometer. We also obtained information such as age, sport, activity level (#of activity session/week) from the child and/or their parent. The data collection process and the preparatory tasks were explained to the participant and their parent before starting. The data collection process includes the EMG electrode placement, manual muscle testing to measure MVIC and the task on the perturbation platform. The non-dominant leg, also known as the balance leg, was used for EMG data collection and was determined by asking the participants which leg they would use to kick a ball and testing the opposite leg (Gstöttner et al., 2009). EMG data were collected from the following muscles: lateral gastrocnemius (LG), medial gastrocnemius (MG), biceps femoris (BF), semitendinosus (ST), gluteus medius (GM), vastus lateralis (VL), vastus medialis (VM), peroneus longus (PL), tibialis anterior (TA), left and right rectus abdominus (RA), left and right erector spinae (ES). The muscles were located using manual muscle testing (Kendall, McCreary, Provance, Rodgers, & Romani, 2005)(Kendall et al., 2005) for the placement of the electrode between the motor point and the myotendinous junction, at the middle of the muscle belly (Konrad, 2005). Detailed positioning of the electrodes was based on description from SENIAM (Hermens et al., 1999) adjusted by putting the electrodes on the bulge of the muscle when contracted. (See

Table 1 in the Appendix). To decrease skin impedance and to ensure proper electrode contact and adhesion, the skin was abraded and cleaned using gauze and alcohol before placing the electrodes. The selected muscles were tested to obtain MVIC measures prior to performing experimental tasks on the perturbation platform. During manual muscle testing, the participant was instructed to push as hard as possible to meet the resistance applied by the tester and to hold for approximately 6 seconds, until they were instructed to relax. All the muscles were tested once, following the manual muscle testing procedure as described by Kendall (Kendall et al., 2005). See Table 2 (Appendix) for detailed positioning of manual muscle testing. Prior to stepping onto the perturbation platform, the participants were fitted with an upper body harness adjusted so it does not impede their balance response.

After completing the set-up, the participants were asked to stand on the perturbation plate with both feet to familiarize them with the four perturbations (posterior, lateral, rotational, combination). The combination perturbation is a combination of the posterior, lateral, and rotational perturbations to mimic the mechanism of an ACL injury. Following the familiarization period, the subjects were asked to maintain balance while standing on their non-dominant leg, or balance leg, as the perturbation platform moved. It was indicated to them that if they lose their balance and bring down the dominant leg to touch the platform, they may keep both legs on the platform. If they were able to remain on the balance leg for the entire perturbation, they were instructed to place the dominant leg on the platform once the platform began to reposition itself to the center. The conditions were straight, without hyperextension at the knee, and bent at 30 degrees, which was measured by the researcher prior to each perturbation using a goniometer. These conditions (straight and bent) were alternated between each trial. The participant was exposed to perturbation in every condition (straight and bent) four times for a total of 32 trials. The order of the perturbations was randomized, and the participants were blind to the order of the perturbation throughout the experiment. The participants had 15 seconds of rest between each perturbation as it is the approximate time it takes for the platform to reset.

Once the data collection was complete, the participants were unhooked from the harness and all equipment was removed. The skin was checked for blemishes and cleaned using rubbing alcohol and gauze. The participant was debriefed about the purpose of the project and all questions were answered. The MVIC and the time to peak were analyzed. Previous research has demonstrated that EMG investigations with surface electrodes during stance and perturbations of stance provide highly reliable results with respect to intraindividual changes (Horstmann, Gollhofer, & Dietz, 1988). It has been noted, however, that adaptational effects exist and should be circumvented by preadapting the subjects or restriction of the period of measurement (Horstmann et al., 1988).

5. Data Analysis

5.1. Power Calculation

The objectives of our study were to explore the lower limb muscle activity at the knee joint of physically active male and female children following a complex perturbation that resembles the mechanism of an ACL injury. Previous studies (Malinzak et al., 2001; Myer et al., 2009; Rozzi et al., 1999) using EMG and motion analysis had a sample size of ± 30 participants to obtain significant differences. Additional lower limb EMG data collected from varsity athletes for a previous study at PERFORM Center was used for the power calculation. By setting power at 0.8 and P = 0.05, the power calculation was performed to determine the number of participants needed for this counterbalanced research design. For our experiment, a sample size of 30 was targeted. Recruitment was challenging and after a few months of data collection, we collected data from 28 participants. There were issues with data collection of 2 of these participants, so the final sample size after analysis was 26. The planned analysis was ANOVA.

5.2. EMG Processing

Each perturbation was separated into three phases for the mean EMG value: pre-perturbation (150ms before the initiation of the perturbations), perturbation (500ms during the perturbations), and post-perturbation (250ms after the perturbations). The onset of the perturbation was when the speed reached 5mm/s. Four reflective markers were put at the corners of the perturbation platform to determine the initiation of the perturbations and calculate the speed of the platform movement. The EMG of the lower extremity muscles were recorded using a wireless system (Noraxon TeleMyo DTS, Scottsdale, Arizona, USA) and transferred to NEXUS Software (ViconTM system, Vicon, Los Angeles, USA) for further processing. To verify the synchronization of those systems, the onset of the muscular activities was contrasted to the motion of the 4 reflective markers that were put at the corners of the perturbation platform. We corrected for a delay in the EMG signal due to its passage through the NEXUS Software. For all the trials, that phase lag was considered in determining the onset of the perturbations, and accordingly, pre-perturbation, perturbation, and post-perturbation windows. All the data were processed using biomechZoo (Dixon, Loh, Michaud-Paquette, & Pearsall, 2017) and custom codes in Matlab (v2017b, The Math Works Inc., Natick, MA, USA) using C3D files exported from VICON. To extract the EMG variables, first, the averages of the EMG values from the static trial were used to remove offsets for the muscle activities during each perturbation. Then, the raw EMG signals were filtered using a 4th order zero-lag high-pass and low-pass Butterworth filters at a cut-off frequency of 20 Hz and 500 Hz, respectively. Afterward, the EMG signals were rectified and their root mean squares (RMS) were calculated and normalized to the maximum RMS of the corresponding MVIC for each muscle. The dependent variables were the ensemble mean and maximum (peak) amplitudes of each muscle EMG values (%MVIC) and the time that the peak amplitude occurred during the perturbation phases (%perturbation). The values we obtained were very low. Through expert consultation and inspection of the outputs, it was determined that a correction factor of 1000 should be applied to the Vicon output to put all EMG data in millivolts.

5.3. Statistical Analysis

The activity of each muscle as a percentage of MVIC was compared between males and females between perturbations (posterior, lateral, rotation, combination) using analyses of variance (ANOVA). These statistical analyses were performed at a 5% level of significance using SPSS for Windows Version 24 (SPSS Inc., Chicago, IL, USA). The activity of each muscle as a percentage of MVIC was compared between knee bent and knee straight conditions between perturbations (posterior, lateral, rotation, combination) using ANOVA. These statistical analyses were performed at a 5% level of significance using SPSS for Windows Version 24 (SPSS Inc., Chicago, IL, USA). The EMG values from each phase (pre-, during, and post-perturbation) were compared for each direction of perturbation using single factor repeated measures ANOVA. These statistical analyses were performed at a 5% level of significance using SPSS for Windows Version 24 (SPSS Inc., Chicago, IL, USA). Differences among perturbations within each phase were compared using repeated measures ANOVA for each direction of perturbation (combination, lateral, posterior, rotation). These statistical analyses were performed at a 5% level of significance in SPSS. A Bonferroni post hoc test was performed if a statistical main effect for conditions was observed ($\alpha=0.05$).

6. Significance

The purpose of the study was to explore lower limb muscle activity and knee joint movement in children during a perturbation that mimics an ACL injury mechanism. Since ACL tears occur in children, it was important to understand if the neuromuscular activation differences seen in adolescents and adults were also present in the younger group. More information on children's kinetics will help in making IPPs specific to the deficits found in children. To date, there is a lack of published studies regarding ACL injuries with an unexpected perturbation that mimics and ACL injury mechanism, and very little is known about the biomechanics of children during physical tasks. By exploring muscle activation and recruitment and the effect of a posterior, lateral, and rotational motion in balance as well as the combination of these motions, which mimic the occurrence of an ACL injury, we will be able to improve exercise intervention programs that target injury prevention of the knee joint in children. Addressing and correcting neuromuscular deficits early in young athletes has the potential to decrease the incidence of ACL injuries in their future as they continue to be physically active.

7. Results

7.1. Demographics

Participants were children from age 8-12. We collected data for 16 males and 10 females as shown in Table 3. Male participants were almost two times more active than our female participants (4.2 > 2.5), but the average age of the participants was similar.

Table 3. Demographics

	AVERAGE AGE (YEARS)	ACTIVITIES /WEEK	LEG TESTED	
GENDER (N)	Mean (SD)	Mean (SD)	Left	Right
MALE (16)	9.5 (1.6)	4.2 (1.8)	14	2
FEMALE (12)	10.5 (1.5)	2.5 (0.5)	9	1

7.2. Comparison by phase

7.2.1. Comparing mean values

The post-perturbation mean %MVIC values were significantly higher than the pre-perturbation and the perturbation phases for all muscles in all directions, except for the LRA that was only significant in rotation. See tables 4, 5 and 6 (Appendix) for the mean %MVIC values, significance and 95% confidence intervals. The effect size (partial eta squared) can be found in tables 32, 33 and 34 (Appendix). We didn’t find a higher GM activation post-perturbation when compared with the other muscles. The average of mean %MVIC activation of the GM was 8%.

7.2.2. Comparing max values

See tables 7, 8 and 9 (Appendix) for the max %MVIC values, significance and 95% confidence intervals.

The max %MVIC in the post-perturbation was significantly higher than during the perturbation phase for the MG, the ST, the BF, the VM, the VL, and the RES in all directions. It was also significant in the PL in the rotation perturbation; in the TA in the posterior perturbation; in the LG in the lateral, posterior, and rotation perturbations; in the

GM in the posterior rotation; in the RRA in the lateral, posterior, and rotation perturbations; and in the LES in the posterior perturbation.

The max %MVIC in post-perturbation was significantly higher than pre-perturbation for all muscles in all directions except for the LRA.

The max %MVIC during the perturbation was significantly higher than the pre-perturbation in all directions in the MG, the LG, the TA, the PL, the ST, the BF, and the RRA. It was also significantly higher in the combination perturbation for the VL, the GM, the RES, and the LES. The perturbation phase was significantly higher than the pre-perturbation phase for the VL in the lateral and rotation perturbations; for the GM in lateral perturbation; for the RES in the rotation perturbation; and for the LES in the lateral perturbation.

7.3. Comparison by sex

7.3.1. Comparing mean values

Mean values (SD), confidence intervals, F value, and p-value can be found in Tables 10, 11 and 12 (Appendix). The effect size (partial eta squared) can be found in tables 32, 33 and 34 (Appendix).

For the RES, males had a higher %MVIC mean than females in the lateral perturbation and the posterior perturbation. For the LRA the %MVIC mean was significantly higher in females than males in the combo perturbation, the lateral perturbation, and the posterior perturbation. For the RRA in the combo perturbation, the %MVIC mean was significantly higher in females than males.

For the BF in the posterior perturbation, the %MVIC mean was significantly higher in males than females.

For the LG the %MVIC mean was significantly higher in females than males in the combo perturbation, the posterior perturbation, and the rotation perturbation. For the MG the %MVIC mean was significantly higher in females than males in the combo perturbation, the posterior perturbation, and the rotation perturbation.

For the TA the %MVIC mean was significantly higher in females than males in the combo perturbation, the lateral perturbation, the posterior perturbation, and the rotation perturbation.

7.3.2. Comparing max values

Max %MVIC values (SD), confidence intervals, F and p-value can be found in Tables 13, 14 and 15 (Appendix).

Females had a higher %%MVIC max than males in the combination perturbation for the PL, the TA, the LG, the ST, the VL, and the GM. GM maximal %MVIC was also higher in females than in males in the lateral and the rotation perturbation. TA maximal %MVIC was also higher in females than in males in the lateral, posterior, and the rotation perturbations. Males had a higher maximal %MVIC than females in the BF only in the posterior perturbation.

7.3.3. Comparing mean time to max

Mean values (SD), confidence intervals, F value, and p-value can be found in Tables 16, 17 and 18 (Appendix). See Graph 4 and Graph 5 (Appendix) for a representation of sex differences in mean time to max(TTM) by muscle during the perturbation and post-perturbation phases.

During the perturbation, females reached their maximal %MVIC later than males for all muscles. During the post-perturbation phase, females reach their maximal %MVIC significantly later than males for the VL and GM, and males reach their max %MVIC later than females for the BF, ST, and TA.

7.4.Comparison by knee angle (bent or straight)

7.4.1. Comparing mean values

Refer to tables 19, 20 and 21 (Appendix) for the mean time to max values (SD), CI, f value and p-value. The effect size (partial eta squared) can be found in tables 32, 33 and 34 (Appendix).

RES in the rotation perturbation, the %MVIC mean was higher with a bent knee than straight.

For the VL, the %MVIC mean was higher with a bent knee than straight in the lateral perturbation, the posterior perturbation, and the rotation perturbation. For the VM in the combo perturbation, the %MVIC mean was higher with a bent knee than straight in the combination perturbation, the lateral perturbation, the posterior perturbation, and the rotation perturbation.

7.4.2. Comparing max values

Max %MVIC values (SD), confidence intervals, F and p-value can be found in Tables 22, 23 and 24 (Appendix).

For the vastus medialis, the max % MVIC was higher in the bent condition than in the straight condition in the lateral, posterior and rotation perturbations. For the VL, the max % MVIC was higher in the bent condition than in the straight condition in the lateral, posterior and rotation perturbations.

7.4.3. Comparing mean time to max

Refer to tables 25, 26 and 27 (Appendix) for the mean time to max values (SD), CI, f value and p-value. See Graph 6 and Graph 7 (Appendix) for a representation of knee flexion angle differences in mean TTM by muscle during the perturbation and post-perturbation phases.

During the pre-perturbation, perturbation and the post-perturbation phases, the RES, GM, VL, and VM reached their maximum significantly later in the bent condition than in the straight condition whereas the MG reached its max value significantly earlier in the bent knee condition than the straight knee condition. During the perturbation, the hamstrings muscles reached their maximum value before the quadriceps muscles in the bent knee condition. The more proximal muscles also reached their maximum earlier than the distal muscles.

7.5. Comparison by perturbation

7.5.1. Comparing mean values

See Table 28 (Appendix) for mean values (SD), CI, f and p-values. The mean %MVIC was significantly higher during the combination perturbation than during the rotation perturbation in the post-perturbation phase.

7.5.2. Comparing max values

See Table 28 (Appendix) for max values (SD), CI, f and p-values. The max %MVIC was significantly higher in the combination perturbation versus all the other perturbations during the perturbation. It was also significantly higher in the combination movement than in the lateral and rotation movements in the post-perturbation phase.

7.5.3. Comparing mean time to max

Refer to tables 29, 30 and 31 (Appendix) for the mean TTM values (SD), CI, f value and p-value. See Graph 8 and Graph 9 (Appendix) for a representation of perturbation differences in mean TTM by muscle during the perturbation and post-perturbation phases.

For the LES, the mean TTM for combination perturbation was significantly later than the other 3 perturbations during the perturbation and the post-perturbation phases. For the RES, the mean TTM for combination perturbation was significantly later than the other 3 perturbations during the post-perturbation phase.

For the RRA, the mean TTM for combination perturbation was significantly later than the lateral perturbation during the perturbation phase. The mean TTM for combination perturbation was significantly later than the other 3 perturbations during the post-perturbation phases.

For the GM, the mean TTM during the combination perturbation was significantly later than the posterior and rotation perturbations during the post-perturbation phase.

During the post-perturbation phase, the VL reached its maximal value significantly later in the combination perturbation than all other 3 perturbations and during the lateral perturbation versus the rotation perturbation. During the post-perturbation phase, the VM reached its maximal value significantly later in the combination perturbation than the posterior and rotation perturbations and during the lateral perturbation versus the posterior and rotation perturbations.

For the BF, the mean TTM for combination perturbation was significantly later than the lateral and posterior perturbations during the perturbation phase. During the post-perturbation phase, the mean TTM for the combination perturbation was significantly later than the other 3 perturbations and for the lateral perturbation when compared with the posterior and rotation perturbations.

For the ST, the mean TTM for combination perturbation was significantly later than the lateral and posterior perturbations during the perturbation phase. During the post-perturbation phase, the mean TTM for the combination perturbation was significantly later than the other 3 perturbations and for the lateral perturbation when compared with the posterior and rotation perturbations.

During the perturbation phase, the LG reached its maximal value significantly later in the combination perturbation than the lateral and rotation perturbations. During the post-perturbation phase, it reached its max during the combination perturbation significantly later than during the lateral and rotation perturbations. The posterior perturbation also resulted in a longer TTM when compared with the lateral and rotation perturbations.

During the perturbation phase, the MG reached its maximal value significantly later in the combination perturbation than the lateral and rotation perturbations. MG also reached its maximal value significantly later in the posterior perturbation than the lateral perturbation. During the post-perturbation phase, it reached its max during the combination perturbation significantly later than during the lateral and rotation perturbations. The posterior perturbation also resulted in a longer TTM when compared with the lateral and rotation perturbations. The rotation perturbation also resulted in a longer TTM when compared with the lateral perturbation.

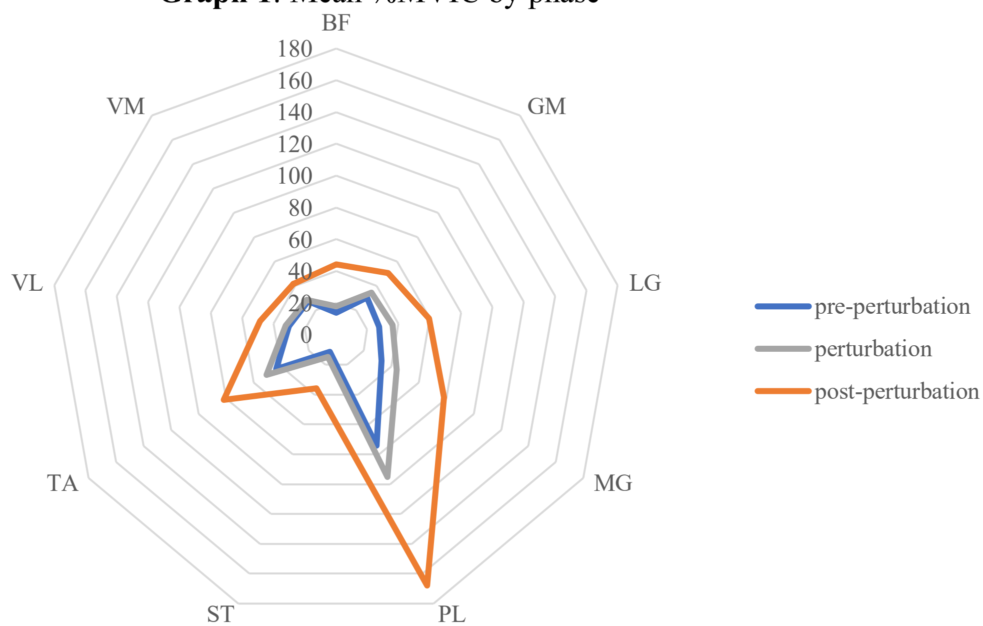
For the PL during the perturbation phase, the combination and the lateral perturbations resulted in a significantly longer TTM when compared with the posterior and rotation perturbations. During the post-perturbation phase, the PL reached its maximal value significantly earlier during the rotation perturbation when compared with the other 3 perturbations. The combination and lateral perturbations resulted in a significantly longer TTM than the posterior perturbation.

8. Discussion

8.1. Understanding mean and maximal EMG values – Phase

Our results showed that the post-perturbation phase (after the platform stops) had significantly higher mean and max %MVIC for all muscles in all perturbations, expect the LRA that was only significant in rotation. The mean %MVIC values for the lower extremity muscles are represented in Graph 1. The higher muscle activation in the post-perturbation phase could illustrate a "late active component" identified in body kinematics

Graph 1: Mean %MVIC by phase



in previous research (Alexander et al., 1992; Hughes et al., 1995), and described as a corrective response to the platform movement versus an "early passive component" suggested to be induced by the platform movement. Croce et al. found a higher hamstring co-activation post-landing in pre-adolescents vs post-adolescents and suggested it was the result of a reflexive activation in response to ground impact. In contrast, Croce et al.

suggested that the pre-activation found in post-pubescents indicated a strategy of pre-tuning the hamstrings prior to landing (more CNS pre-activation) to control the ground reaction forces and anterior tibial displacement experienced by the knee during landing (Croce, Russell, Swartz, & Decoster, 2004).

Contrary to what we hypothesized, we didn't find a proportionally higher GM muscle activation during the post-perturbation phase when compared to other muscles. Reduced GM muscle activity may result in less resistance to hip adduction and internal rotation (Hart et al., 2007). Because hip adduction and internal rotation are associated with a high-risk lower extremity positioning that may lead to a non-contact ACL injury (Ireland, 1999), less muscular resistance to this "position of no return" (Ireland, 1999) at the hip may leave the knee exposed to injury. Therefore, it would be interesting to analyze the kinetics with the kinematics in our study to see if the GM activation entails changes in the knee valgus in children.

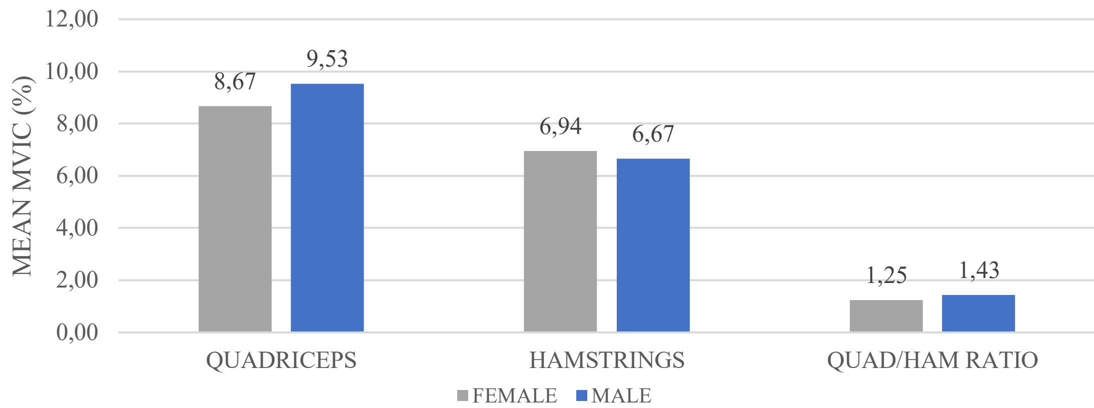
8.2. Understanding mean and maximal EMG values – Sex

Contrary to what we hypothesized, there were significant differences in %MVIC when comparing males and females in our study. Sex differences by muscle and perturbation are illustrated in Figure 2 (Appendix). Males had a higher mean RES activation in the lateral and posterior perturbations. Video motion analysis of ACL injury mechanisms found that females that tore their ACL had an increased lateral trunk motion vs males and females who didn't tear their ACL (T E Hewett, J S Torg, and B P Boden, 2009). This increased trunk motion suggests that females have less trunk control and thus activate their trunk muscles less than males, which supports our findings. Kulas et al. also suggested in their study that females don't recruit their trunk muscles as much as males to stabilize (Kulas, Schmitz, Shultz, Henning, & Perrin, 2006). Kulas et al. found that males activated their transverse abdominus and internal oblique muscle in anticipation of landing (pre-activation) whereas females had no significant difference in the activation of all their trunk muscles and no difference in pre-or post-activation (Kulas et al., 2006), which further supports our findings.

In our study, males also had a significantly higher BF mean activation during posterior perturbations. Females had a higher mean %MVIC for both LG and MG in the combo, posterior and rotation perturbations and of TA in all 4 perturbations when compared to males. This may suggest that females use more of their distal muscles to stabilize during a perturbation when compared to males. Because the gastrocnemius muscle crosses the knee, it has an impact on knee stabilization. The sex differences in the gastrocnemius should be researched to determine the potential effect on knee stability and influence on ACL injury. The high activation of lower leg muscles observed with our female participants suggests that they use their ankle muscles more to stabilize. This is contrary to previous research that had found that at landing, adults used their distal muscles (ankle-muscle group) whereas children used their bigger proximal muscles (hip-muscle group) to stabilize (Russell et al., 2007). We, therefore, would expect both male and female participants in our study to have similar muscle activation patterns. The increased reliance on distal muscles by our female participants may be linked to a decrease in core stability. Core muscle function has been reported to influence structures from the low back to the ankle (Willson, Dougherty, Ireland, & Davis, 2005). For example, patients with a history of ankle sprain and ankle hypermobility demonstrated delayed latency of activation of the ipsilateral GM (Beckman & Buchanan, 1995). The importance of core function is also true in regard to knee stabilization as Chaudhari et al. found that the force necessary to move the knee into valgus is particularly sensitive to the level of hip muscle stiffness (Chaudhari, Camarillo, Hearn, Leveille, & Andriacchi, 2003). The preferred use of ankle muscles illustrates the ankle strategy in contrast with a hip stabilization strategy that has been found in previous research to happen in more demanding situations like in increased velocity perturbations (Nashner & McCollum, 1985). The decreased trunk muscle activation we found in females from our study suggests that they used poor stabilization strategies evidenced by their increased use of an ankle-strategy to stabilize. These activation patterns are potentially placing them at-risk for ACL injuries.

When comparing the means of quadriceps and hamstrings activity, females were found to have more hamstring activation and less quadriceps activation when compared with males in the combination perturbation (see Figure 3).

Figure 2. Sex differences in quadriceps and hamstrings activity during combination perturbation



These results are interesting because females that have a higher quadriceps-hamstring strength ratio are at a higher risk of injuring their anterior cruciate ligament (Myer et al., 2009). The results of Myer et al. were supported by studies that demonstrate an activation pattern in females that favors quadriceps when compared to males (Ahmad et al., 2006; Malinzak et al., 2001; Sigward & Powers, 2006; Zazulak et al., 2005). Although we didn't measure strength, our results of EMG would suggest that young females don't have the respective increased quadriceps-hamstring activation ratio when compared with males and may not be at an increased risk of ACL injury. A previous study also compared the quadriceps to hamstrings activation ratio using EMG values presented as %MVIC (Ebben et al., 2010). Ebben et al. found an increased hamstring activation during the postcontact phase of a cutting maneuver in men (Ebben et al.,2010), which is in contrast with our results. Findings by Malinzak et al. (2011) also showed that adult men produce more hamstring activation than women during landing and cutting tasks and Landry et al. (2007) demonstrated that adult women have lower lateral hamstring activation than men during running. Greater hamstring activation has been suggested as a knee protective mechanism. As shown in a cadaveric study, hamstrings force significantly reduced internal rotation and anterior translation, increased quadriceps force and normal resultant force on the tibia and reversed the direction of the shear force on the tibia, which are all considered to reduce strain on the ACL ligament (MacWilliams, Wilson, DesJardins, Romero, & Chao, 1999). Females in our study were found to have more hamstrings and less quadriceps activation than males, and therefore seem to have a quadriceps/hamstring co-contraction ratio more beneficial to prevent ACL injuries.

Previous research comparing males and females across developmental stages found no significant sex differences in hamstrings and quadriceps EMG activity, and hamstring-quadriceps co-contraction ratio of pre-pubescent and post-pubescent participants during a self-initiated vertical jump landing (Croce et al., 2004). Considering that our male participants were involved approximately twice as much in organized sports as our female participants, the sex differences we have observed might be related to experience and exposure to sports. The more favorable Q:H ratio found in our female participants could be due to an increased reliance on preparatory coactivation as it was found in previous research that low-skilled children show greater preparatory hamstring and quadriceps coactivation than highly skilled children (Hamstra-Wright et al., 2006), which suggests that experience might also influence muscle activation patterns. A previous study also highlighted that experience might play a role in muscle activation patterns as they found that children aged 6-10 participating in organized sports were better at performing motor skills vs nonorganized sports (Ulrich, 1987). Although females in our study have a better Q:H ratio, it might be due to an increased reliance on preparatory co-contraction as a strategy to compensate for a lower skill level. Interestingly, previous studies have found an increased reliance on quadriceps activation in adult female (Ahmad et al., 2006; Malinzak et al., 2001; Sigward & Powers, 2006; Zazulak et al., 2005) which is in contrast with our findings in children. Experience is important because the replication of specific movements and the resulting frequent stimulation of nervous pathways that occurs with sports experience leads to the refinement of motor programs (Garrett & Kirkendall, 2000). The lower exposure to sports in young female might explain why this better stabilization strategy isn't maintained into teens or adulthood.

8.3. Understanding mean and maximal EMG values – Knee angle

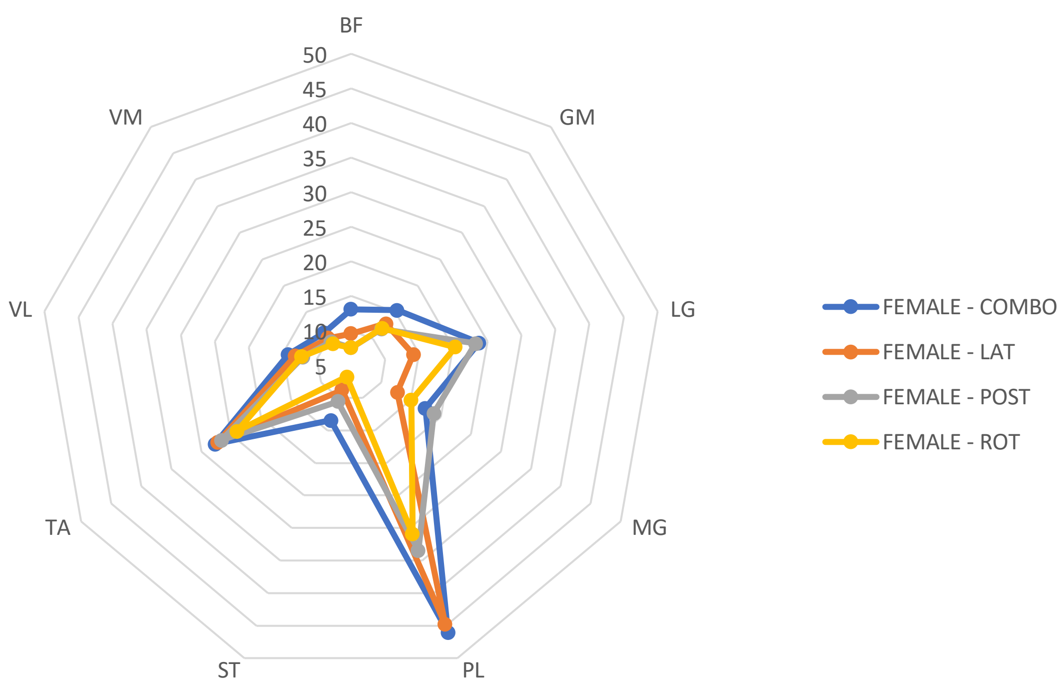
The bent knee condition (30 degrees of knee flexion) created a higher mean %MVIC in the VL in the lateral, posterior and rotation perturbations and in the VM in all 4 perturbations. This suggests that in a flexed position, children rely more on their quadriceps to stabilize after a perturbation. This “quadriceps dominance” was described in a previous study as a potential risk factor predisposing females to ACL injury (Myer et al., 2009). Our results are in contrast with findings by Thompson-Kolesar et al. who found that preadolescents had a greater co-contraction (flexor-extensor) during cutting, unanticipated cutting, double leg jump, and single leg jump versus adolescents. A greater co-contraction ratio means that the children were activating their quadriceps and hamstrings to a similar extent versus adolescents who were relying on their quadriceps more. The greater co-contraction ratio suggests that the children in the Thompson-Kolesar & al. study were using a better biomechanical strategy to knee stabilization (Thompson-Kolesar, Gatewood, & Tran, 2017). Even though our findings are in contraction with the findings by Thompson-Kolesar & al., their results are still interesting for our study because even though they didn’t use perturbations, the unanticipated cutting task they used in their study is a movement we wanted to replicate with the lateral perturbation. Although our results point to children using a detrimental muscle activation by relying on their quadriceps in the bent knee condition, it might be due to the positioning which requires the quadriceps to activate to maintain the flexed knee position. It is also important to note that female participants in our study had a better Q:H ratio versus the male participants, something that was not found in the Myer et al. study mentioned above (Myer et al., 2009). A study indicated that bending the knees to attain a crouched position allowed for better balance during anterior and posterior perturbations than initial stance (LeVangie, 2013). LeVangie’s findings suggest that even tough the flexed knee position increases the Q:H ratio, it might be a better position to favor proper knee stability.

8.4. Understanding mean and maximal EMG values – Perturbation

As shown in cadaveric studies, isolated knee internal rotation, external rotation, valgus and varus moments do not produce enough force to strain the ACL, in contrast with a multi-planar motion like the combination of anterior translation and valgus or internal rotation (Berns et al., 1992; Markolf et al., 1995). The combination perturbation in our study resulted in significantly higher muscle activation than the other 3 perturbations during the perturbation phase. This suggests that the combination perturbation was more challenging and required more muscle activity to stabilize. The combination perturbation could, therefore, be a better reproduction of the ACL injury mechanism, although we used speeds of platform movement below injury risk levels.

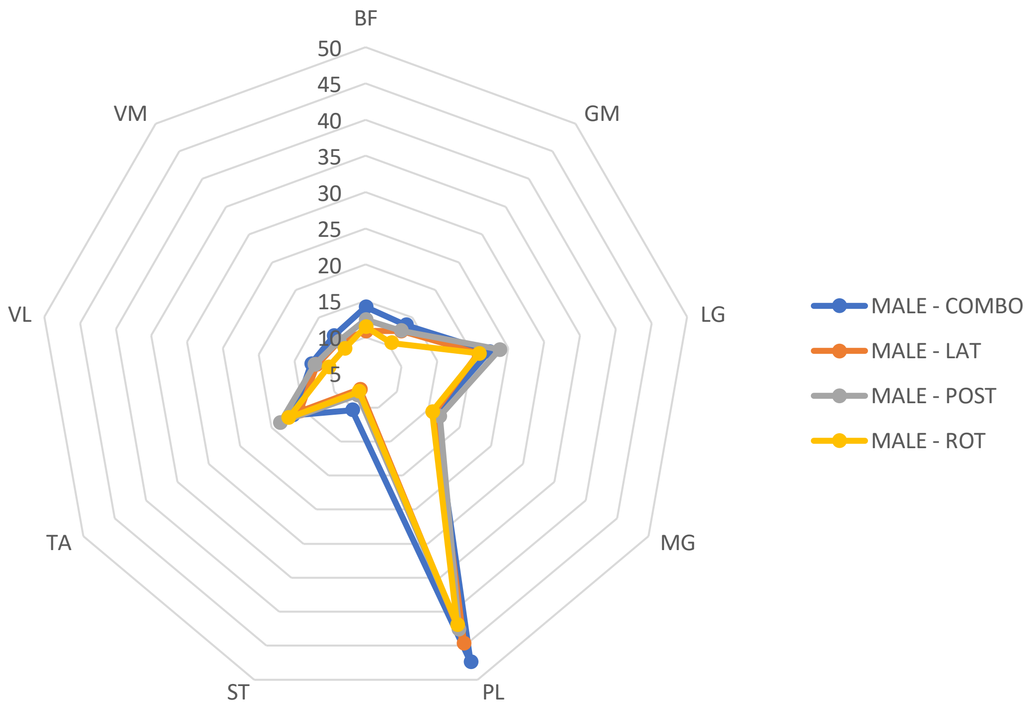
As illustrated in Graph 2 and Graph 3, females showed more variations in muscle activation by perturbation than males, with lower mean % MVIC in lateral and rotation perturbations and higher in combination and posterior perturbations. Both males and females showed a greater mean % MVIC of the hamstrings (BF and ST) and quadriceps (VM and VL) in the combination perturbation. This suggests that the combination perturbation was more challenging as it required more muscle activation to stabilize. Males had a higher mean and max %MVIC for the biceps femoris in the posterior perturbation. Our results show differences between the rotation perturbation and the

Graph 2: Mean muscle activation in females by perturbation



lateral and posterior perturbations. In contrast, Chen et al. found no differences in magnitudes of the muscle activity of the hamstring lateralis (HL) and the rectus femoris (RF)when comparing single-planar rotational with single-planar translational perturbations(Chen et al., 2014).

Graph 3: Mean muscle activation in males by perturbation



8.5. Understanding mean time to maximal EMG values

Our results showed that the BF and ST were activated earlier during the rotational perturbation versus the lateral translation. The LG and MG were activated earlier in the rotational perturbation than in the posterior translation. The PL was also activated earlier in the rotational perturbation than in the other 3 perturbations. This is in contrast with a previous study where all muscles were activated earlier for translational perturbations than rotational perturbations except the BF muscle(Chen et al., 2014). Chen et al. measured a higher COM displacement and upper body instability during their translational perturbations and hypothesized that this induced an earlier muscle activation as well as faster and larger hip and knee motion. Although we didn't measure upper body instability, we can hypothesize that the rotational perturbation in our study created more upper body instability than the lateral and posterior perturbations which might explain why muscles stabilizing the knee like the BF, ST, LG, and MG were activated faster in those perturbations.

Our results show that the hamstrings muscles reached their maximum values earlier than the quadriceps muscles in the bent knee condition during the perturbation. The proximal muscles (RRA, LRA, LES, RES, GM, ST, BF, VM, VL) also reached their maximal values earlier than the distal muscles (PL, TA, LG, MG). A study comparing EMG activity during lateral, anterior and posterior perturbations also found an early proximal muscle activation (Henry, Fung, & Horak, 1998). Because big proximal muscles like the gluteus medius, the hamstrings, and the quadriceps play a major role in knee stability, our results suggest that children use a good stabilizing strategy by activating their proximal muscles first instead of the ankle muscles. Henry et al. found an early proximal (trunk or hip) followed by an underlying distal-to-proximal muscle activation pattern for anterior and posterior translational perturbations in adults (Henry et al., 1998). Henry et al. used perturbations of mean speeds of 35cm/s versus our perturbations of 200mm/s (20cm/s). Previous research identified perturbations to be of low speed if they were of 20cm/s or slower and fast perturbations for perturbations faster than 25cm/s based on body sway and stepping reactions in adults (Runge, Shupert, Horak, & Zajac, 1999). Nashner and McCollum hypothesized that a hip strategy should be observed in situations that limit the effectiveness of ankle torque at producing whole-body motion (e.g. perturbations of high velocities) (Nashner & McCollum, 1985). Our perturbations were slower than perturbations in the study by Henry et al., but we still found similar results in the muscle activation pattern. We can hypothesize, based on the perturbation speed classifications by Runge et al., that our perturbations were “fast” for our children participants because they induced a proximal muscle activation pattern.

A study found that the mean onset of all the muscles was within 250ms after the onset of a perturbation(Chen et al., 2014). Our results support this as all muscles reached their maximal EMG values early after the onset of the perturbation (<30% of total perturbation time) as illustrated in Graph 4 (see Appendix).

9. Conclusion

Our results show that some differences exist between males and females in the 8-12 years old age group. For both males and females, muscle activation patterns previously identified as predisposing factors to ACL injuries were found. Indeed, male participants were found to have a higher Q:H activation ratio which could be detrimental. Female participants had a lower trunk muscle activation which has also been found to be detrimental to ACL injuries. However, we don't have information on pubertal stages and this could have affected our results. Because some of our male participants were elite soccer players and the female participants were more recreational, our results could be affected by the difference in the level of play. The presence in our participants of muscle activation patterns that have previously been linked to ACL injuries illustrates that injury prevention programs are worth starting at this young age.

The combination perturbation in our study created the most muscle activation which could demonstrate that it was more challenging and therefore a better representation of the ACL injury mechanism.

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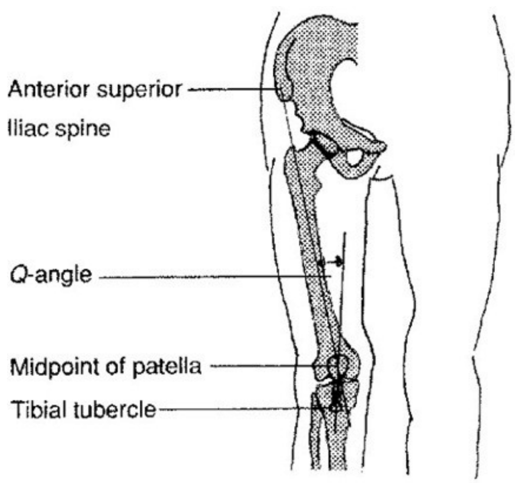
11. Appendix

11.1. Figures

Figure 1. Q angle of the knee



(Wikipedia. 2015)

Figure 2. Sex comparison of mean %MVIC by perturbation

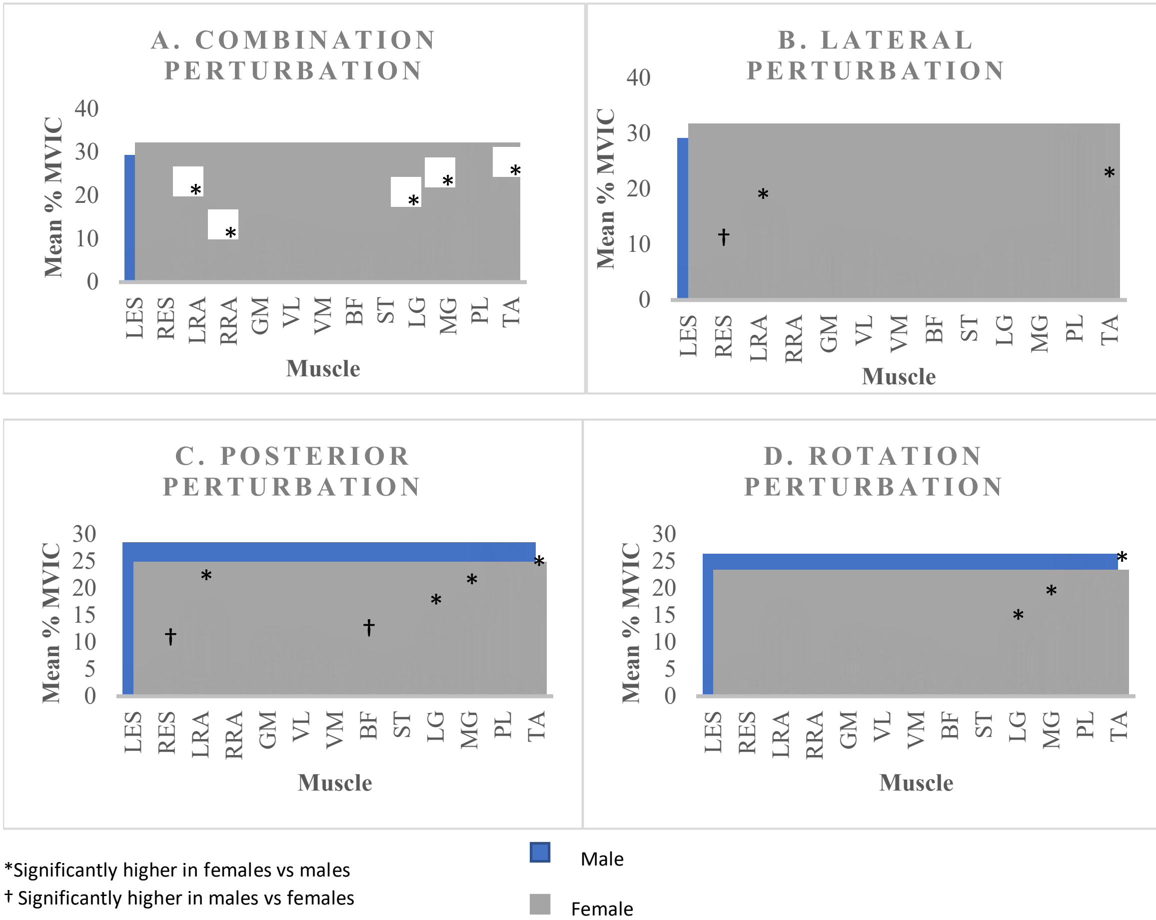
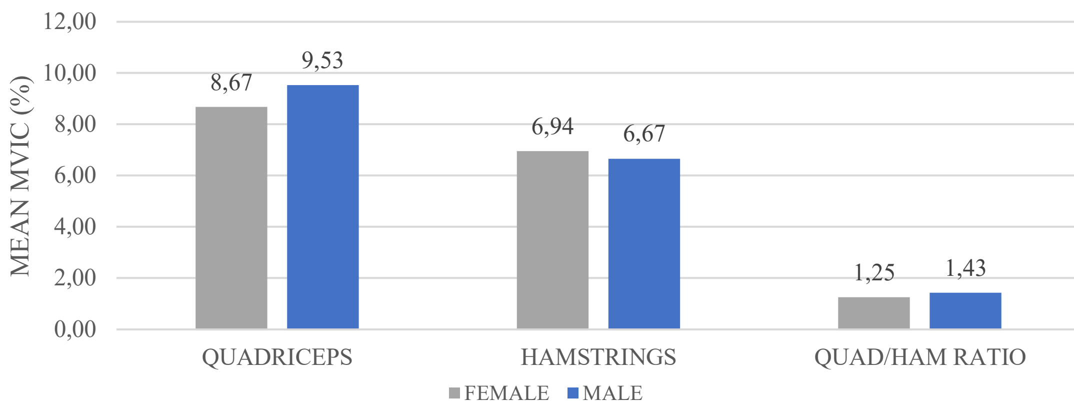
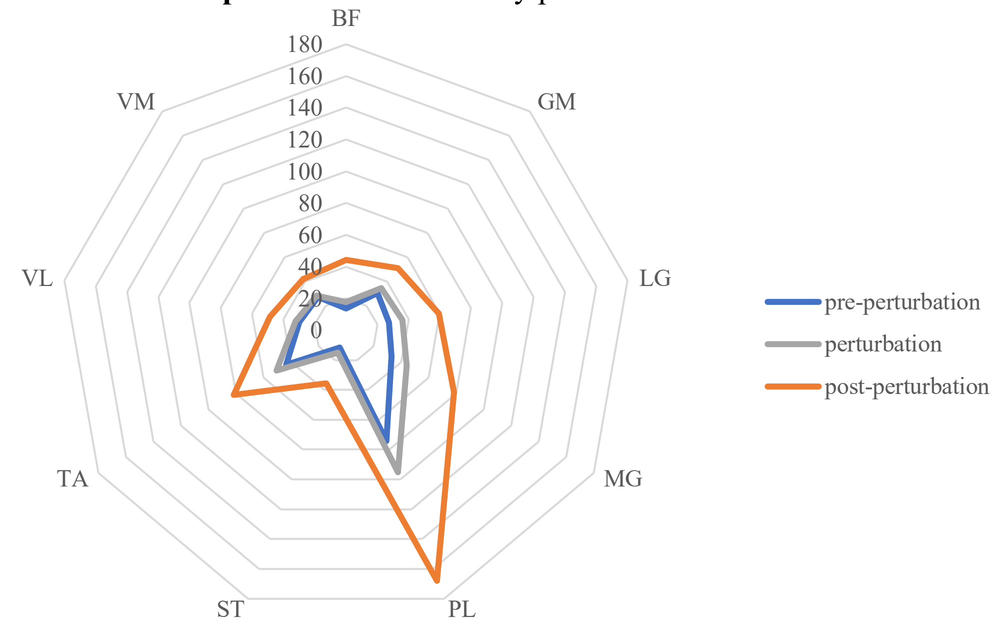


Figure 3. Sex differences in quadriceps and hamstrings EMG activity during combination perturbation

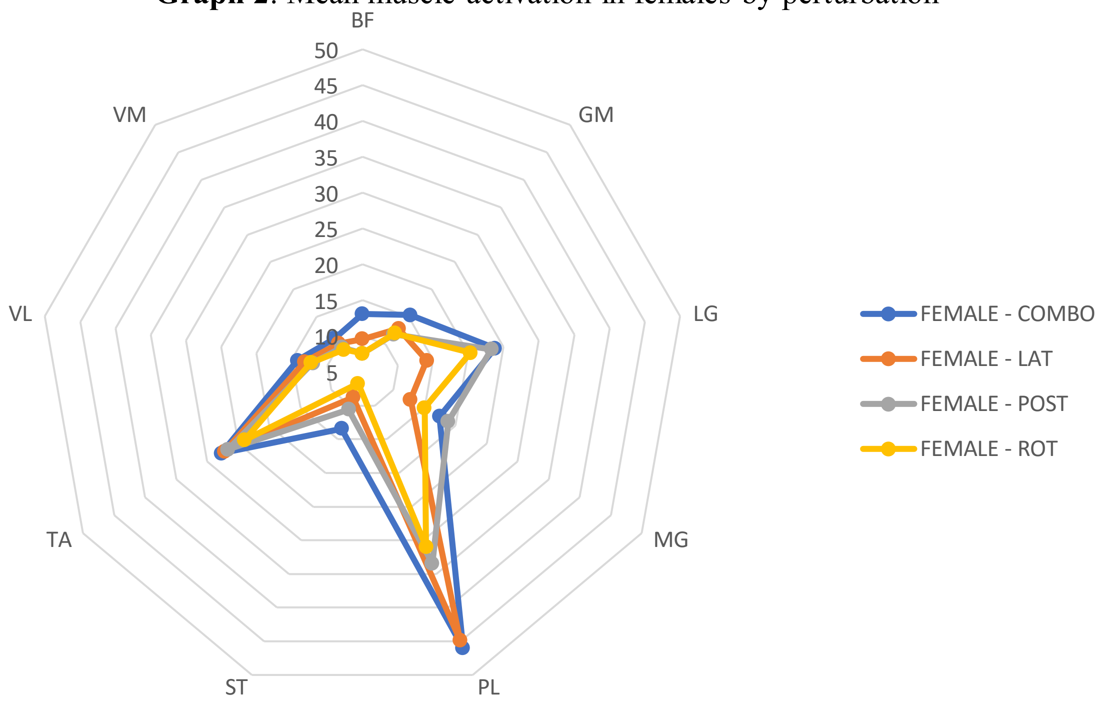


11.2. Graphs

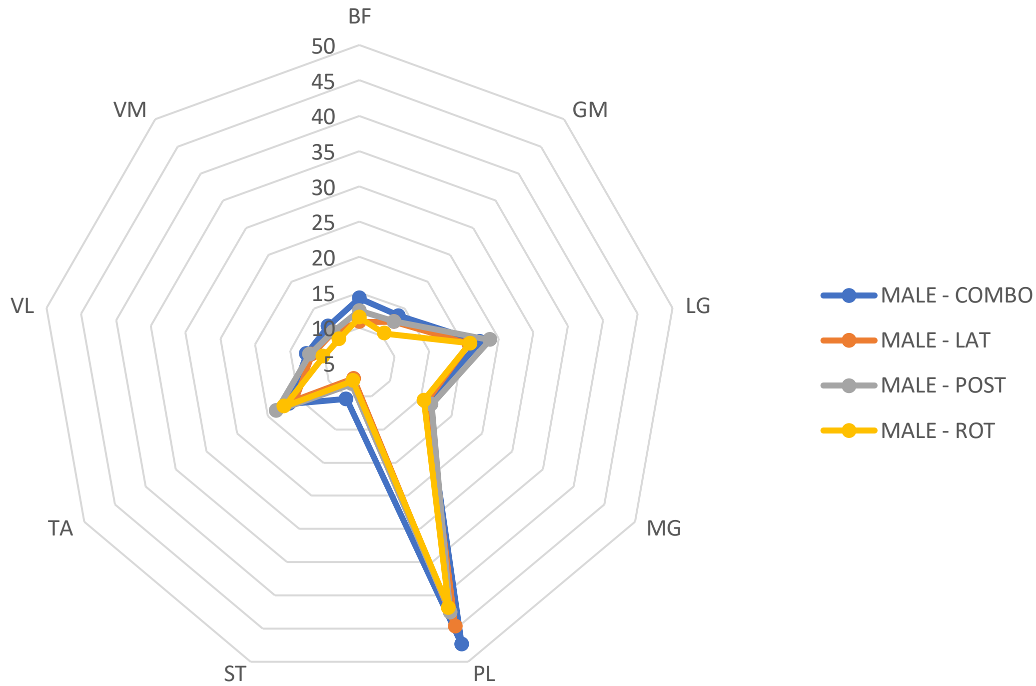
Graph 1: Mean %MVIC by phase



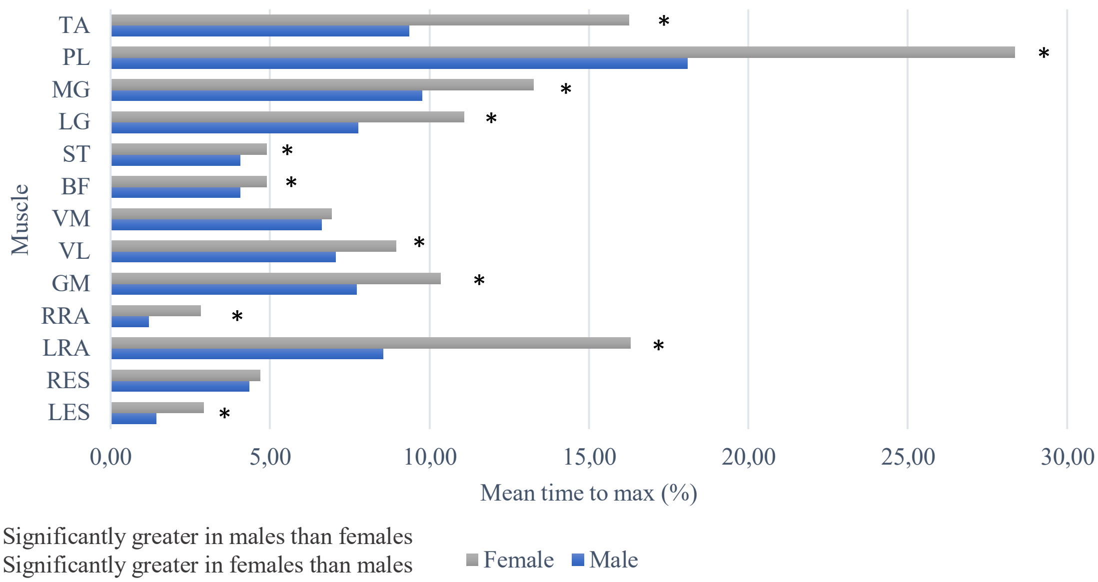
Graph 2: Mean muscle activation in females by perturbation



Graph 3: Mean muscle activation in males by perturbation

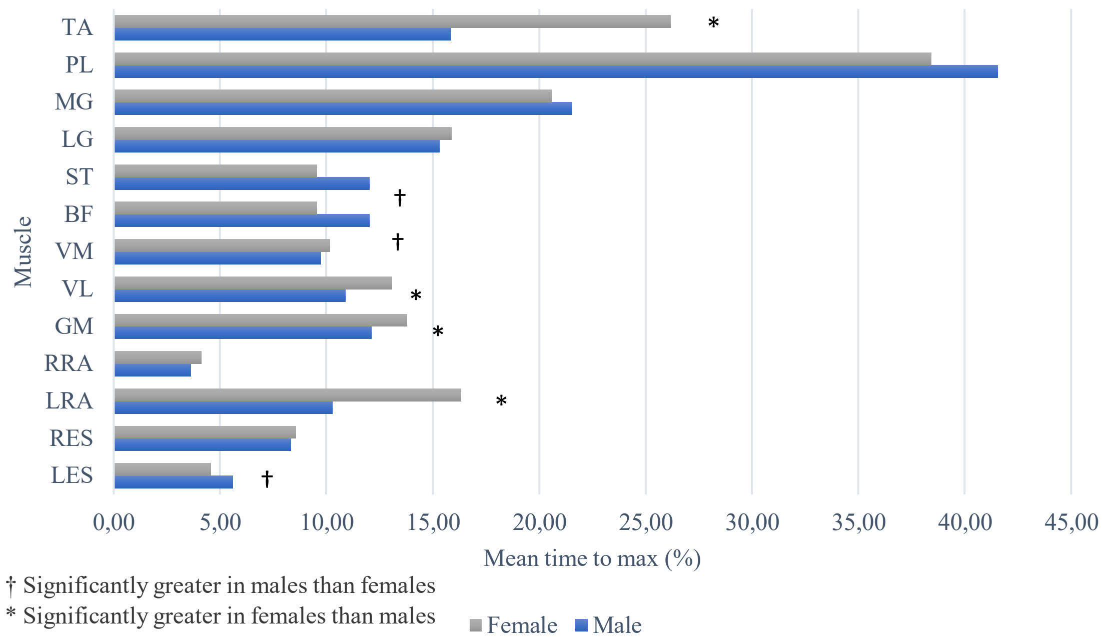


Graph 4 Sex comparison of mean time to max by muscle during perturbation



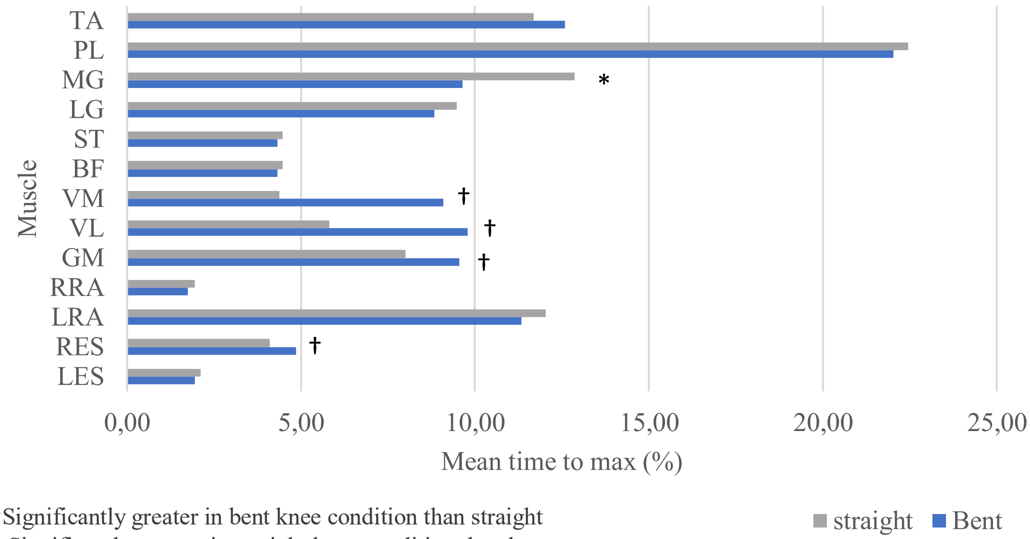
† Significantly greater in males than females
* Significantly greater in females than males

Graph 5 Sex comparison of mean time to max by muscle post-perturbation

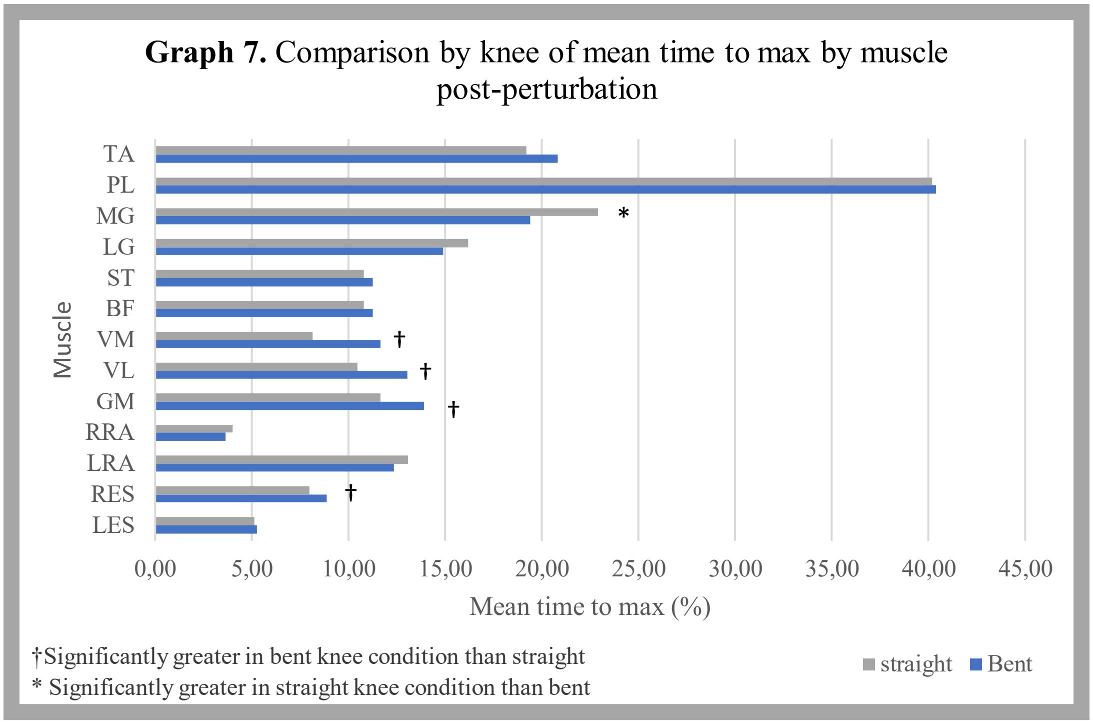


† Significantly greater in males than females
* Significantly greater in females than males

Graph 6. Comparison by knee position of mean time to max by muscle during perturbation

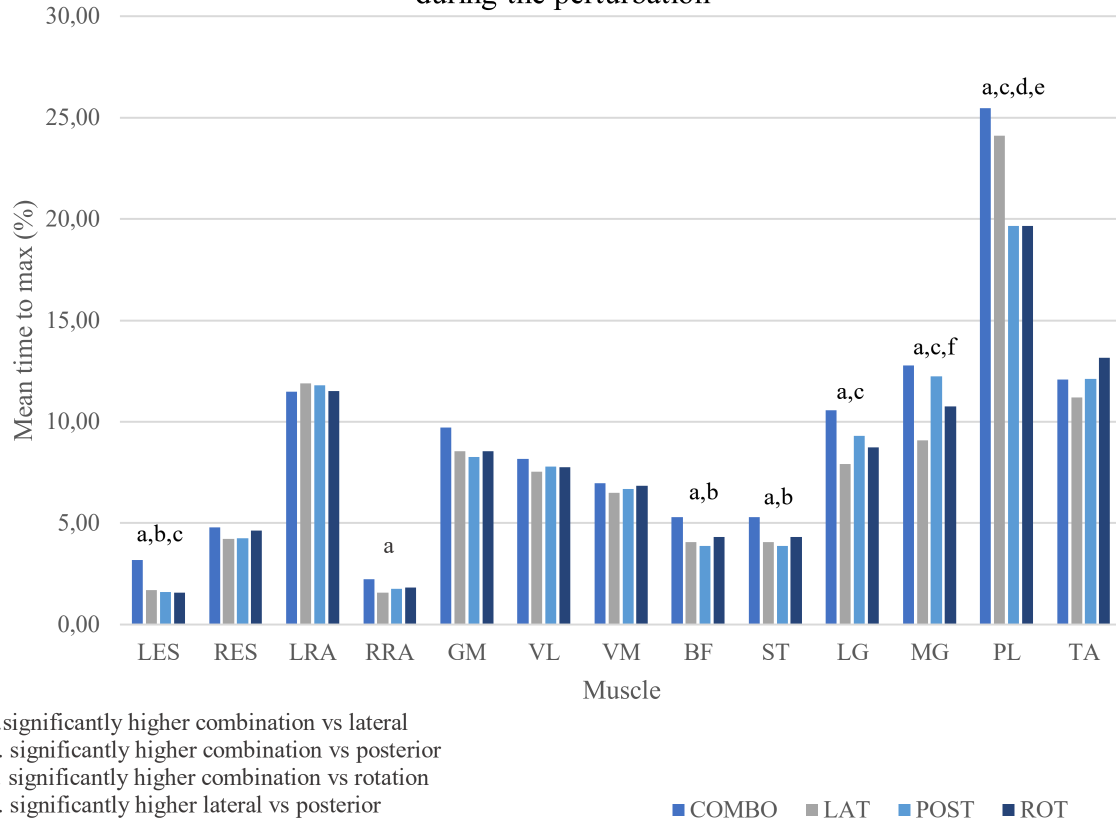


†Significantly greater in bent knee condition than straight
* Significantly greater in straight knee condition than bent



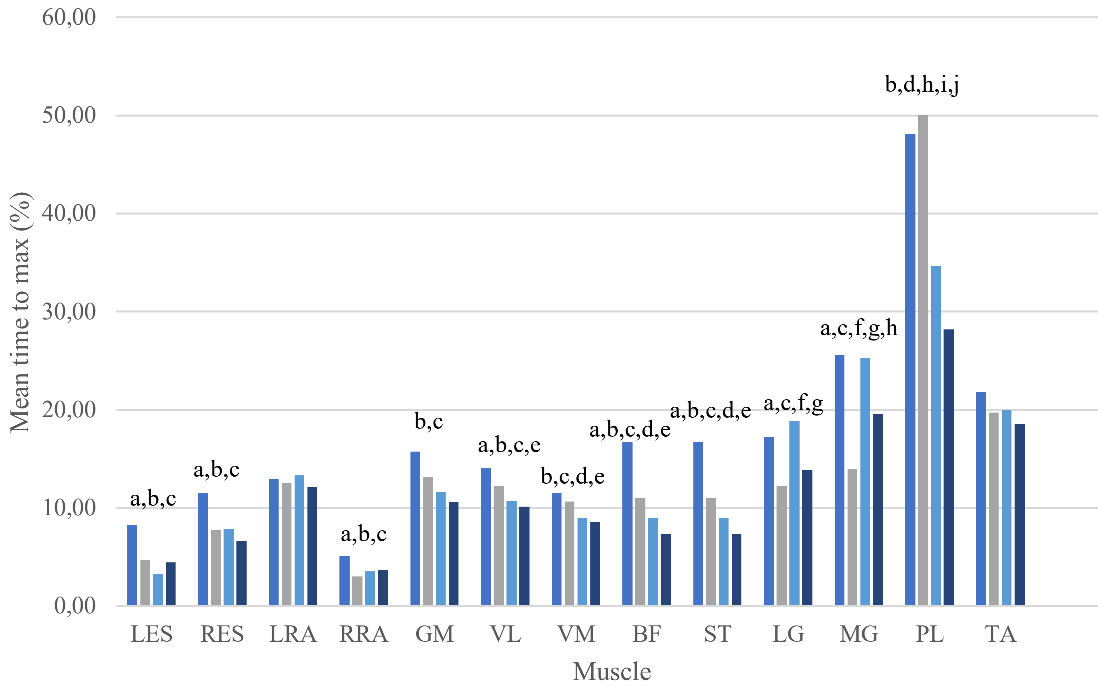
Graph 7. Comparison by knee of mean time to max by muscle post-perturbation
TA
PL
MG
LG
ST
BF
VM
VL
GM
RRA
LRA
RES
LES
Muscle
0,00
5,00
10,00
15,00
20,00
25,00
30,00
35,00
40,00
45,00
Mean time to max (%)
†Significantly greater in bent knee condition than straight
* Significantly greater in straight knee condition than bent
straight
Bent

Graph 8. Comparison by perturbation of mean time to max by muscle during the perturbation



a.significantly higher combination vs lateral
b. significantly higher combination vs posterior
c. significantly higher combination vs rotation
d. significantly higher lateral vs posterior
e. significantly higher lateral vs rotation
f. significantly higher posterior vs lateral
g. significantly higher posterior vs rotation
h. significantly higher rotation vs lateral
i. significantly higher rotation vs posterior
j. significantly higher rotation vs combination

Graph 9. Comparison by perturbation of mean time to max post-perturbation by muscle



a.significantly higher combination vs lateral
b. significantly higher combination vs posterior
c. significantly higher combination vs rotation
d. significantly higher lateral vs posterior
e. significantly higher lateral vs rotation
f. significantly higher posterior vs lateral
g. significantly higher posterior vs rotation
h. significantly higher rotation vs lateral
i. significantly higher rotation vs posterior
j. significantly higher rotation vs combination

■ COMBO ■ LAT ■ POST ■ ROT

11.3. Tables

Table 1. Detailed electrode placement for EMG collection

Muscles	**Location**	**Orientation**
Erector Spinae (LES & RES)	At 2 finger width lateral from the spinous process of L4.	Vertical.
Rectus Abdominis (LRA & RRA)	At 2 finger width lateral from the belly button.	Vertical.
Gluteus Medius (GM)	At 50% on the line from the iliac crest to the trochanter.	In the direction of the line from the iliac crest to the trochanter.
Biceps Femoris (BF)	At 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia.	In the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia.
Semitendinosis (ST)	at 50% on the line between the ischial tuberosity and the medial epicondyle of the tibia.	In the direction of the line between the ischial tuberosity and the medial epicondyle of the tibia.
Vastus Lateralis (VL)	At 2/3 on the line from the ASIS to the lateral side of the patella.	Vertical.
Vastus Medialis (VM)	At 80% on the line between the ASIS and the joint space in front of the anterior border of the medial ligament.	Almost perpendicular to the line between the ASIS and the joint space in front of the anterior border of the medial ligament.
Lateral Gastrocnemius (LG)	At 1/3 of the line between the head of the fibula and the heel.	In the direction of the line between the head of the fibula and the heel.
Medial Gastrocnemius (MG)	On the most prominent bulge of the muscle.	In the direction of the muscle fiber.
Peroneus Longus (PL)	At 25% on the line between the tip of the head of the fibula to the tip of the lateral malleolus.	In the direction of the line between the tip of the head of the fibula to the tip of the lateral malleolus.
Tibialis Anterior (TA)	At 1/3 on the line between the tip of the fibula and the tip of the medial malleolus.	In the direction of the line between the tip of the fibula and the tip of the medial malleolus.

Table 2. Detailed MMT positioning for MVIC collection

Muscles	Participant's position	Resistance	Action of participant
Erector Spinae (LES & RES)	Prone, with hands behind head	Against upper back in the direction to bring participant's chest back on table	Trunk extension
Rectus Abdominis (LRA & RRA)	Supine, with legs extended and hands behind head	Against participant's chest under clavicles, in the direction to bring participant's upper back flat on the table	Trunk curl to complete spine flexion
Gluteus Medius (GM)	Sideling, with the underneath leg flexed at the hip and knee to stabilize pelvis	Stabilize pelvis with one hand, other hand against leg, near the ankle, in the direction of adduction and slight flexion	Abduction of the hip, with slight extension and slight external rotation
Biceps Femoris (BF)	Prone, flexion of the knee at 50°, with the thigh in slight lateral rotation and the leg in slight lateral rotation on the thigh	Against the leg, proximal to the ankle, in the direction of knee extension	Knee flexion
Medial Hamstrings (ST)	Prone, flexion of the knee at 50°, with the thigh in medial rotation and the leg medially rotated on the thigh	Against the leg, proximal to the ankle, in the direction of knee extension	Knee flexion
Quadriceps (VL and VM)	Supine, with knees bent	Lace one arm under the knee of tested leg and rest hand on opposite knee. Other arm resist on leg, proximal to the ankle, in the direction of knee flexion	Knee extension by kicking up with leg
Gastrocnemius (LG & MG)	Standing on tested leg	Body weight and downward pressure against shoulders	rising on toes, pushing the body weight directly upward
Peroneus Longus (PL)	Supine, with leg medially rotated	Against the lateral borer and sole of the foot, in the direction of inversion of the foot and dorsiflexion of the ankle joint	Eversion of the foot, with plantar flexion of the ankle joint
Tibialis Anterior (TA)	Supine	Against medial side, dorsal surface of the foot, in the direction of plantar flexion of the ankle joint and eversion of foot	Dorsiflexion of ankle joint and inversion of foot

Table 3. Demographics

	AVERAGE AGE (YEARS)	ACTIVITIES /WEEK	LEG TESTED	
GENDER (N)	Mean (SD)	Mean (SD)	Left	Right
MALE (16)	9.5 (1.6)	4.2 (1.8)	14	2
FEMALE (10)	10.5 (1.5)	2.5 (0.5)	9	1

Table 4. Mean muscle activation by perturbation and phase for the trunk musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Left Erector Spinae	Combination	Pre-perturbation	1.06 (0.82)	0.84 - 1.28		
		Perturbation	2.67 (2.99)	1.85 - 3.48	19.118	.000
		Post-perturbation	5.98 (6.61)*	4.18 - 7.79		
	Lateral	Pre-perturbation	1.01 (0.67)	0.83 - 1.19		
		Perturbation	1.79 (1.71)	1.32 - 2.25	26.716	.000
		Post-perturbation	5.00 (4.88)*	3.67 - 6.33		
	Posterior	Pre-perturbation	1.03 (0.75)	0.83 - 1.24		
		Perturbation	1.53 (1.16)	1.21 - 1.85	16.203	.000
		Post-perturbation	4.68 (6.10)*	3.02 - 6.34		
	Rotation	Pre-perturbation	1.05 (0.78)	0.84 - 1.27		
		Perturbation	1.64 (2.20)	1.04 - 2.24	19.551	.000
		Post-perturbation	3.95 (3.73)*	2.93 - 4.96		
Right Erector Spinae	Combination	Pre-perturbation	4.04 (2.52)	3.35 - 4.73		
		Perturbation	4.66 (3.01)	3.84 - 5.48	34.685	.000
		Post-perturbation	9.90 (5.74)*	8.34 - 11.47		
	Lateral	Pre-perturbation	4.07 (2.38)	3.42 - 4.72		
		Perturbation	4.35 (2.64)	3.63 - 5.07	18.119	.000
		Post-perturbation	7.78 (5.05)*	6.40 - 9.16		
	Posterior	Pre-perturbation	4.25 (2.61)	3.53 - 4.96		
		Perturbation	4.42 (2.74)	3.68 - 5.17	19.538	.000
		Post-perturbation	8.61 (6.02)*	6.97 - 10.26		
	Rotation	Pre-perturbation	3.95 (2.37)	3.30 - 4.60		
		Perturbation	4.34 (2.52)	3.65 - 5.03	16.319	.000
		Post-perturbation	7.13 (4.23)*	5.98 - 8.29		
Left Rectus Abdominis	Combination	Pre-perturbation	10.79 (12.48)	7.39 - 14.20		
		Perturbation	10.84 (12.55)	7.41 - 14.26	.177	.838
		Post-perturbation	12.17 (15.71)	7.88 - 16.46		
	Lateral	Pre-perturbation	10.83 (12.75)	7.35 - 14.32		
		Perturbation	10.88 (12.85)	7.37 - 14.39	.035	.966
		Post-perturbation	11.43 (13.77)	7.67 - 15.19		
	Posterior	Pre-perturbation	10.99 (13.38)	7.34 - 14.64		
		Perturbation	11.10 (13.56)	7.40 - 14.80	.161	.852
		Post-perturbation	12.44 (17.15)	7.76 - 17.12		
	Rotation	Pre-perturbation	3.95 (2.37)	3.30 - 4.60		
		Perturbation	4.34 (2.52)	3.65 - 5.03	19.551	.000
		Post-perturbation	7.13 (4.23)*	5.98 - 8.29		
Right Rectus Abdominis	Combination	Pre-perturbation	1.27 (1.53)	0.86 - 1.69		
		Perturbation	1.93 (2.47)	1.25 - 2.60	13.937	.000
		Post-perturbation	3.79 (3.38)*	2.87 - 4.72		
	Lateral	Pre-perturbation	1.23 (1.27)	0.88 - 1.58		
		Perturbation	1.56 (1.84)	1.05 - 2.06	16.039	.000
		Post-perturbation	3.40 (2.98)*	2.59 - 4.22		
	Posterior	Pre-perturbation	1.27 (1.67)	0.82 - 1.73		
		Perturbation	1.60 (1.84)	1.09 - 2.10	14.020	.000
		Post-perturbation	3.76 (3.87)*	2.71 - 4.82		
	Rotation	Pre-perturbation	1.29 (1.51)	0.88 - 1.71		
		Perturbation	1.85 (2.29)	1.22 - 2.47	9.706	.000
		Post-perturbation	3.54 (3.91)*	2.47 - 4.60		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 5. Mean muscle activation by perturbation and phase for thigh musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Gluteus Medius	Combination	Pre-perturbation	8.11 (8.65)	5.75 - 10.47		
		Perturbation	9.52 (9.72)	6.86 - 12.17	7.000	.001
		Post-perturbation	14.37 (8.97)*	11.92 - 16.82		
	Lateral	Pre-perturbation	7.38 (5.38)	5.91 - 8.85		
		Perturbation	8.66 (7.52)	6.61 - 10.71	7.051	.001
		Post-perturbation	12.73 (9.68)*	10.09 - 15.37		
	Posterior	Pre-perturbation	7.58 (5.46)	6.09 - 9.07		
		Perturbation	8.23 (7.68)	6.14 - 10.33	6.390	.002
		Post-perturbation	12.41 (9.26)*	9.89 - 14.94		
	Rotation	Pre-perturbation	7.48 (6.12)	5.81 - 9.15		
		Perturbation	8.15 (6.74)	6.31 - 9.98	4.581	.012
		Post-perturbation	11.34 (8.21)*	9.10 - 13.58		
Vastus Lateralis	Combination	Pre-perturbation	7.57 (4.35)	6.38 - 8.75		
		Perturbation	8.21 (4.82)	6.90 - 9.53	18.610	.000
		Post-perturbation	13.25 (6.49)*	11.48 - 15.03		
	Lateral	Pre-perturbation	7.68 (3.90)	6.61 - 8.74		
		Perturbation	8.25 (4.02)	7.15 - 9.34	18.077	.000
		Post-perturbation	12.25 (4.93)*	10.90 - 13.60		
	Posterior	Pre-perturbation	7.46 (4.16)	6.32 - 8.59		
		Perturbation	7.80 (4.06)	6.69 - 8.91	13.907	.000
		Post-perturbation	12.04 (6.49)*	10.27 - 13.81		
	Rotation	Pre-perturbation	7.21 (4.08)	6.10 - 8.33		
		Perturbation	7.80 (4.38)	6.60 - 9.00	9.582	.000
		Post-perturbation	11.04 (5.99)*	9.40 - 12.67		
Vastus Medialis	Combination	Pre-perturbation	6.85 (4.49)	5.62 - 8.08		
		Perturbation	7.12 (4.40)	5.92 - 8.32	15.024	.000
		Post-perturbation	11.52 (5.88)*	9.91 - 13.12		
	Lateral	Pre-perturbation	7.27 (4.56)	6.02 - 8.51		
		Perturbation	7.44 (4.28)	6.27 - 8.61	9.117	.000
		Post-perturbation	10.54 (4.61)*	9.28 - 11.80		
	Posterior	Pre-perturbation	6.66 (4.27)	5.50 - 7.83		
		Perturbation	6.95 (4.30)	5.78 - 8.12	8.396	.000
		Post-perturbation	10.36 (6.71)*	8.53 - 12.19		
	Rotation	Pre-perturbation	6.78 (4.64)	5.51 - 8.04		
		Perturbation	6.98 (4.48)	5.75 - 8.20	4.601	.011
		Post-perturbation	9.37 (5.66)*	7.83 - 10.92		
Biceps Femoris	Combination	Pre-perturbation	3.38 (2.34)	2.74 - 4.02		
		Perturbation	5.03 (4.68)	3.75 - 6.31	50.946	.000
		Post-perturbation	13.72 (8.41)*	11.42 - 16.01		
	Lateral	Pre-perturbation	3.57 (2.33)	2.93 - 4.20		
		Perturbation	4.29 (3.27)	3.40 - 5.19	47.527	.000
		Post-perturbation	10.28 (5.49)*	8.78 - 11.78		
	Posterior	Pre-perturbation	3.65 (2.39)	3.00 - 4.31		
		Perturbation	4.25 (3.10)	3.40 - 5.09	39.711	.000
		Post-perturbation	10.40 (6.46)*	8.64 - 12.17		
	Rotation	Pre-perturbation	3.17 (2.07)	2.60 - 3.73		
		Perturbation	4.31 (3.27)	3.42 - 5.21	29.753	.000
		Post-perturbation	9.83 (7.36)*	7.82 - 11.84		
Semitendinosis	Combination	Pre-perturbation	2.87 (2.08)	2.31 - 3.44		
		Perturbation	4.22 (3.13)	3.36 - 5.07	30.377	.000
		Post-perturbation	11.65 (10.24)*	8.85 - 14.45		
	Lateral	Pre-perturbation	2.87 (1.94)	2.34 - 3.41		
		Perturbation	3.61 (2.42)	2.95 - 4.27	37.148	.000
		Post-perturbation	7.85 (4.67)*	6.58 - 9.13		
	Posterior	Pre-perturbation	3.03 (2.41)	2.37 - 3.69		
		Perturbation	3.54 (2.42)	2.88 - 4.21	26.028	.000
		Post-perturbation	9.10 (7.66)*	7.01 - 11.19		
	Rotation	Pre-perturbation	2.80 (2.02)	2.25 - 3.35		
		Perturbation	3.52 (2.60)	2.81 - 4.23	24.756	.000
		Post-perturbation	7.23 (5.10)*	5.83 - 8.62		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 6. Mean muscle activation by perturbation and phase for lower leg musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Lateral Gastrocnemius	Combination	Pre-perturbation	6.74 (3.76)	5.72 - 7.77		
		Perturbation	9.54 (5.78)	7.97 - 11.12	27.476	
		Post-perturbation	15.39 (8.21)*	13.15 - 17.63		
	Lateral	Pre-perturbation	6.95 (3.76)	5.93 - 7.98		
		Perturbation	8.44 (4.73)	7.15 - 9.73	20.584	
		Post-perturbation	13.41 (7.32)*	11.41 - 15.41		
	Posterior	Pre-perturbation	7.11 (3.69)	6.10 - 8.12		
		Perturbation	9.30 (5.58)	7.78 - 10.83	23.526	
		Post-perturbation	16.36 (10.78)*	13.42 - 19.31		
	Rotation	Pre-perturbation	6.81 (3.57)	5.83 - 7.78		
		Perturbation	8.85 (5.38)	7.38 - 10.32	21.986	
		Post-perturbation	14.22 (8.14)*	11.99 - 16.44		
Medial Gastrocnemius	Combination	Pre-perturbation	8.21 (4.53)	6.97 - 9.44		
		Perturbation	12.25 (7.71)	10.14 - 14.36	34.720	
		Post-perturbation	21.28 (11.36)*	18.18 - 24.38		
	Lateral	Pre-perturbation	8.18 (4.42)	6.98 - 9.39		
		Perturbation	9.10 (4.54)	7.87 - 10.34	26.407	
		Post-perturbation	16.33 (9.06)*	13.86 - 18.80		
	Posterior	Pre-perturbation	8.17 (3.96)	7.09 - 9.25		
		Perturbation	11.64 (6.95)	9.74 - 13.53	44.069	
		Post-perturbation	21.70 (10.85)*	18.74 - 24.67		
	Rotation	Pre-perturbation	8.57 (4.95)	7.22 - 9.92		
		Perturbation	11.13 (6.59)	9.33 - 12.93	29.756	
		Post-perturbation	19.19 (9.97)*	16.47 - 21.91		
Peroneus Longus	Combination	Pre-perturbation	17.81 (11.58)	14.65 - 20.97		
		Perturbation	26.07 (17.10)	21.40 - 30.73	37.731	
		Post-perturbation	46.82 (23.08)*	40.52 - 53.12		
	Lateral	Pre-perturbation	19.13 (12.01)	15.85 - 22.41		
		Perturbation	26.31 (17.46)	21.54 - 31.07	36.651	
		Post-perturbation	44.71 (17.90)*	39.82 - 49.59		
	Posterior	Pre-perturbation	19.89 (11.76)	16.68 - 23.10		
		Perturbation	22.25 (12.23)	18.91 - 25.59	27.568	
		Post-perturbation	38.94 (18.59)*	33.86 - 44.01		
	Rotation	Pre-perturbation	17.43 (10.41)	14.59 - 20.27		
		Perturbation	20.59 (11.99)	17.32 - 23.86	30.532	
		Post-perturbation	37.43 (19.00)*	32.24 - 42.61		
Tibialis Anterior	Combination	Pre-perturbation	10.96 (5.79)	9.38 - 12.54		
		Perturbation	12.77 (8.82)	10.36 - 15.17	19.765	
		Post-perturbation	21.03 (11.17)*	17.98 - 24.08		
	Lateral	Pre-perturbation	11.00 (6.30)	9.28 - 12.72		
		Perturbation	12.74 (8.00)	10.56 - 14.92	14.754	
		Post-perturbation	19.49 (10.81)*	16.54 - 22.44		
	Posterior	Pre-perturbation	10.68 (5.17)	9.27 - 12.09		
		Perturbation	12.09 (6.78)	10.24 - 13.94	24.058	
		Post-perturbation	21.40 (12.48)*	17.99 - 24.80		
	Rotation	Pre-perturbation	10.83 (5.91)	9.22 - 12.44		
		Perturbation	12.89 (8.11)	10.68 - 15.10	14.032	
		Post-perturbation	19.66 (12.08)*	16.37 - 22.96		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 7. Maximal muscle activation by perturbation and phase for the trunk musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Left Erector Spinae	Combination	Pre-perturbation	1.06 (0.82)	0.84 - 1.28	19.118	0.000
		Perturbation	2.67 (2.99)	1.85 - 3.48		
		Post-perturbation	5.98 (6.61)	4.18 - 7.79		
	Lateral	Pre-perturbation	1.01 (0.67)	0.83 - 1.19	26.716	0.000
		Perturbation	1.79 (1.71)	1.32 - 2.25		
		Post-perturbation	5.00 (4.88)	3.67 - 6.33		
	Posterior	Pre-perturbation	1.03 (0.75)	0.83 - 1.24	16.203	0.000
		Perturbation	1.53 (1.16)	1.21 - 1.85		
		Post-perturbation	4.68 (6.10)	3.02 - 6.34		
	Rotation	Pre-perturbation	1.05 (0.78)	0.84 - 1.27	19.551	0.000
		Perturbation	1.64 (2.20)	1.04 - 2.24		
		Post-perturbation	3.95 (3.73)	2.93 - 4.96		
Right Erector Spinae	Combination	Pre-perturbation	4.04 (2.52)	3.35 - 4.73	34.685	0.000
		Perturbation	4.66 (3.01)	3.84 - 5.48		
		Post-perturbation	9.90 (5.74)	8.34 - 11.47		
	Lateral	Pre-perturbation	4.07 (2.38)	3.42 - 4.72	18.119	0.000
		Perturbation	4.35 (2.64)	3.63 - 5.07		
		Post-perturbation	7.78 (5.05)	6.40 - 9.16		
	Posterior	Pre-perturbation	4.25 (2.61)	3.53 - 4.96	19.538	0.000
		Perturbation	4.42 (2.74)	3.68 - 5.17		
		Post-perturbation	8.61 (6.02)	6.97 - 10.26		
	Rotation	Pre-perturbation	3.95 (2.37)	3.30 - 4.60	16.319	0.000
		Perturbation	4.34 (2.52)	3.65 - 5.03		
		Post-perturbation	7.13 (4.23)	5.98 - 8.29		
Left Rectus Abdominis	Combination	Pre-perturbation	10.79 (12.48)	7.39 - 14.20	0.177	0.838
		Perturbation	10.84 (12.55)	7.41 - 14.26		
		Post-perturbation	12.17 (15.71)	7.88 - 16.46		
	Lateral	Pre-perturbation	10.83 (12.75)	7.35 - 14.32	0.035	0.966
		Perturbation	10.88 (12.85)	7.37 - 14.39		
		Post-perturbation	11.43 (13.77)	7.67 - 15.19		
	Posterior	Pre-perturbation	10.99 (13.38)	7.34 - 14.64	0.161	0.852
		Perturbation	11.10 (13.56)	7.40 - 14.80		
		Post-perturbation	12.44 (17.15)	7.76 - 17.12		
	Rotation	Pre-perturbation	3.95 (2.37)	3.30 - 4.60	16.319	0.000
		Perturbation	4.34 (2.52)	3.65 - 5.03		
		Post-perturbation	7.13 (4.23)	5.98 - 8.29		
Right Rectus Abdominis	Combination	Pre-perturbation	1.27 (1.53)	0.86 - 1.69	13.937	0.000
		Perturbation	1.93 (2.47)	1.25 - 2.60		
		Post-perturbation	3.79 (3.38)	2.87 - 4.72		
	Lateral	Pre-perturbation	1.23 (1.27)	0.88 - 1.58	16.039	0.000
		Perturbation	1.56 (1.84)	1.05 - 2.06		
		Post-perturbation	3.40 (2.98)	2.59 - 4.22		
	Posterior	Pre-perturbation	1.27 (1.67)	0.82 - 1.73	14.020	0.000
		Perturbation	1.60 (1.84)	1.09 - 2.10		
		Post-perturbation	3.76 (3.87)	2.71 - 4.82		
	Rotation	Pre-perturbation	1.29 (1.51)	0.88 - 1.71	9.706	0.000
		Perturbation	1.85 (2.29)	1.22 - 2.47		
		Post-perturbation	3.54 (3.91)	2.47 - 4.60		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 8. Maximal muscle activation by perturbation and phase for thigh musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Gluteus Medius	Combination	Pre-perturbation	8.11 (8.65)	5.75 - 10.47	7.000	0.001
		Perturbation	9.52 (9.72)	6.86 - 12.17		
		Post-perturbation	14.37 (8.97)	11.92 - 16.82		
	Lateral	Pre-perturbation	7.38 (5.38)	5.91 - 8.85	7.051	0.001
		Perturbation	8.66 (7.52)	6.61 - 10.71		
		Post-perturbation	12.73 (9.68)	10.09 - 15.37		
	Posterior	Pre-perturbation	7.58 (5.46)	6.09 - 9.07	6.390	0.002
		Perturbation	8.23 (7.68)	6.14 - 10.33		
		Post-perturbation	12.41 (9.26)	9.89 - 14.94		
	Rotation	Pre-perturbation	7.48 (6.12)	5.81 - 9.15	4.581	0.012
		Perturbation	8.15 (6.74)	6.31 - 9.98		
		Post-perturbation	11.34 (8.21)	9.10 - 13.58		
Vastus Lateralis	Combination	Pre-perturbation	7.57 (4.35)	6.38 - 8.75	18.610	0.000
		Perturbation	8.21 (4.82)	6.90 - 9.53		
		Post-perturbation	13.25 (6.49)	11.48 - 15.03		
	Lateral	Pre-perturbation	7.68 (3.90)	6.61 - 8.74	18.077	0.000
		Perturbation	8.25 (4.02)	7.15 - 9.34		
		Post-perturbation	12.25 (4.93)	10.90 - 13.60		
	Posterior	Pre-perturbation	7.46 (4.16)	6.32 - 8.59	13.907	0.000
		Perturbation	7.80 (4.06)	6.69 - 8.91		
		Post-perturbation	12.04 (6.49)	10.27 - 13.81		
	Rotation	Pre-perturbation	7.21 (4.08)	6.10 - 8.33	9.582	0.000
		Perturbation	7.80 (4.38)	6.60 - 9.00		
		Post-perturbation	11.04 (5.99)	9.40 - 12.67		
Vastus Medialis	Combination	Pre-perturbation	6.85 (4.49)	5.62 - 8.08	15.024	0.000
		Perturbation	7.12 (4.40)	5.92 - 8.32		
		Post-perturbation	11.52 (5.88)	9.91 - 13.12		
	Lateral	Pre-perturbation	7.27 (4.56)	6.02 - 8.51	9.117	0.000
		Perturbation	7.44 (4.28)	6.27 - 8.61		
		Post-perturbation	10.54 (4.61)	9.28 - 11.80		
	Posterior	Pre-perturbation	6.66 (4.27)	5.50 - 7.83	8.396	0.000
		Perturbation	6.95 (4.30)	5.78 - 8.12		
		Post-perturbation	10.36 (6.71)	8.53 - 12.19		
	Rotation	Pre-perturbation	6.78 (4.64)	5.51 - 8.04	4.601	0.011
		Perturbation	6.98 (4.48)	5.75 - 8.20		
		Post-perturbation	9.37 (5.66)	7.83 - 10.92		
Biceps Femoris	Combination	Pre-perturbation	3.38 (2.34)	2.74 - 4.02	50.946	0.000
		Perturbation	5.03 (4.68)	3.75 - 6.31		
		Post-perturbation	13.72 (8.41)	11.42 - 16.01		
	Lateral	Pre-perturbation	3.57 (2.33)	2.93 - 4.20	47.527	0.000
		Perturbation	4.29 (3.27)	3.40 - 5.19		
		Post-perturbation	10.28 (5.49)	8.78 - 11.78		
	Posterior	Pre-perturbation	3.65 (2.39)	3.00 - 4.31	39.711	0.000
		Perturbation	4.25 (3.10)	3.40 - 5.09		
		Post-perturbation	10.40 (6.46)	8.64 - 12.17		
	Rotation	Pre-perturbation	3.17 (2.07)	2.60 - 3.73	29.753	0.000
		Perturbation	4.31 (3.27)	3.42 - 5.21		
		Post-perturbation	9.83 (7.36)	7.82 - 11.84		
Semitendinosis	Combination	Pre-perturbation	2.87 (2.08)	2.31 - 3.44	30.377	0.000
		Perturbation	4.22 (3.13)	3.36 - 5.07		
		Post-perturbation	11.65 (10.24)	8.85 - 14.45		
	Lateral	Pre-perturbation	2.87 (1.94)	2.34 - 3.41	37.148	0.000
		Perturbation	3.61 (2.42)	2.95 - 4.27		
		Post-perturbation	7.85 (4.67)	6.58 - 9.13		
	Posterior	Pre-perturbation	3.03 (2.41)	2.37 - 3.69	26.028	0.000
		Perturbation	3.54 (2.42)	2.88 - 4.21		
		Post-perturbation	9.10 (7.66)	7.01 - 11.19		
	Rotation	Pre-perturbation	2.80 (2.02)	2.25 - 3.35	24.756	0.000
		Perturbation	3.52 (2.60)	2.81 - 4.23		
		Post-perturbation	7.23 (5.10)	5.83 - 8.62		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 9. Maximal muscle activation by perturbation and phase for lower leg musculature

Muscle	Perturbation	Phase	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Lateral Gastrocnemius	Combination	Pre-perturbation	6.74 (3.76)	5.72 - 7.77	27.476	0.000
		Perturbation	9.54 (5.78)	7.97 - 11.12		
		Post-perturbation	15.39 (8.21)	13.15 - 17.63		
	Lateral	Pre-perturbation	6.95 (3.76)	5.93 - 7.98	20.584	0.000
		Perturbation	8.44 (4.73)	7.15 - 9.73		
		Post-perturbation	13.41 (7.32)	11.41 - 15.41		
	Posterior	Pre-perturbation	7.11 (3.69)	6.10 - 8.12	23.526	0.000
		Perturbation	9.30 (5.58)	7.78 - 10.83		
		Post-perturbation	16.36 (10.78)	13.42 - 19.31		
	Rotation	Pre-perturbation	6.81 (3.57)	5.83 - 7.78	21.986	0.000
		Perturbation	8.85 (5.38)	7.38 - 10.32		
		Post-perturbation	14.22 (8.14)	11.99 - 16.44		
Medial Gastrocnemius	Combination	Pre-perturbation	8.21 (4.53)	6.97 - 9.44	34.720	0.000
		Perturbation	12.25 (7.71)	10.14 - 14.36		
		Post-perturbation	21.28 (11.36)	18.18 - 24.38		
	Lateral	Pre-perturbation	8.18 (4.42)	6.98 - 9.39	26.407	0.000
		Perturbation	9.10 (4.54)	7.87 - 10.34		
		Post-perturbation	16.33 (9.06)	13.86 - 18.80		
	Posterior	Pre-perturbation	8.17 (3.96)	7.09 - 9.25	44.069	0.000
		Perturbation	11.64 (6.95)	9.74 - 13.53		
		Post-perturbation	21.70 (10.85)	18.74 - 24.67		
	Rotation	Pre-perturbation	8.57 (4.95)	7.22 - 9.92	29.756	0.000
		Perturbation	11.13 (6.59)	9.33 - 12.93		
		Post-perturbation	19.19 (9.97)	16.47 - 21.91		
Peroneus Longus	Combination	Pre-perturbation	17.81 (11.58)	14.65 - 20.97	37.731	0.000
		Perturbation	26.07 (17.10)	21.40 - 30.73		
		Post-perturbation	46.82 (23.08)	40.52 - 53.12		
	Lateral	Pre-perturbation	19.13 (12.01)	15.85 - 22.41	36.651	0.000
		Perturbation	26.31 (17.46)	21.54 - 31.07		
		Post-perturbation	44.71 (17.90)	39.82 - 49.59		
	Posterior	Pre-perturbation	19.89 (11.76)	16.68 - 23.10	27.568	0.000
		Perturbation	22.25 (12.23)	18.91 - 25.59		
		Post-perturbation	38.94 (18.59)	33.86 - 44.01		
	Rotation	Pre-perturbation	17.43 (10.41)	14.59 - 20.27	30.532	0.000
		Perturbation	20.59 (11.99)	17.32 - 23.86		
		Post-perturbation	37.43 (19.00)	32.24 - 42.61		
Tibialis Anterior	Combination	Pre-perturbation	10.96 (5.79)	9.38 - 12.54	19.765	0.000
		Perturbation	12.77 (8.82)	10.36 - 15.17		
		Post-perturbation	21.03 (11.17)	17.98 - 24.08		
	Lateral	Pre-perturbation	11.00 (6.30)	9.28 - 12.72	14.754	0.000
		Perturbation	12.74 (8.00)	10.56 - 14.92		
		Post-perturbation	19.49 (10.81)	16.54 - 22.44		
	Posterior	Pre-perturbation	10.68 (5.17)	9.27 - 12.09	24.058	0.000
		Perturbation	12.09 (6.78)	10.24 - 13.94		
		Post-perturbation	21.40 (12.48)	17.99 - 24.80		
	Rotation	Pre-perturbation	10.83 (5.91)	9.22 - 12.44	14.032	0.000
		Perturbation	12.89 (8.11)	10.68 - 15.10		
		Post-perturbation	19.66 (12.08)	16.37 - 22.96		

*Significantly greater post-perturbation than pre-perturbation and perturbation phases

Table 10. Mean muscle activation by sex and perturbation for the trunk musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	F value	p-value
Left Erector Spinae	Combination	Male	3.04 (5,20)	.412	.522
		Female	3.52 (3,77)		
	Lateral	Male	2.60 (3.92)	.000	.999
		Female	2.60 (2.67)		
	Posterior	Male	2.64 (4.62)	.737	.392
		Female	2.09 (2.66)		
	Rotation	Male	2.09 (2.89)	.488	.486
		Female	2.40 (2.71)		
Right Erector Spinae	Combination	Male	6.31 (4.66)	.110	.740
		Female	6.05 (5.00)		
	Lateral	Male	5.93 (4.17)†	4.356	.038
		Female	4.63 (3.42)		
	Posterior	Male	6.41 (4.82)†	4.913	.028
		Female	4.82 (3.99)		
	Rotation	Male	5.42 (3.34)	1.490	.224
		Female	4.74 (3.57)		
Left Rectus Abdominis	Combination	Male	8.91 (10.25)	7.349	.007
		Female	14.69 (16.85)‡		
	Lateral	Male	8.42 (8.74)	10.142	.002
		Female	14.88 (16.90)‡		
	Posterior	Male	9.19 (12.58)	6.037	.015
		Female	14.89 (16.90)‡		
	Rotation	Male	5.42 (3.34)	.488	.486
		Female	4.74 (3.57)		
Right Rectus Abdominis	Combination	Male	1.87 (2.27)	6.758	.010
		Female	3.00 (3.27)‡		
	Lateral	Male	1.93 (2.39)	.699	.405
		Female	2.25 (2.28)		
	Posterior	Male	1.99 (2.59)	1.427	.234
		Female	2.53 (3.22)		
	Rotation	Male	1.92 (2.86)	2.696	.103
		Female	2.68 (2.92)		

† Significantly greater in males than females
‡ Significantly greater in females than males

Table 11. Mean muscle activation by sex and perturbation for the thigh musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	F value	p-value
Gluteus Medius	Combination	Male	10.18 (10.16)	.626	.430
		Female	11.38 (8.35)		
	Lateral	Male	9.15 (7.52)	.704	.403
		Female	10.23 (8.69)		
	Posterior	Male	9.38 (8.51)	.003	.956
		Female	9.45 (6.93)		
	Rotation	Male	8.10 (6.38)	3.645	.058
		Female	10.29 (8.20)		
Vastus Lateralis	Combination	Male	9.15 (5.69)	1.920	.168
		Female	10.44 (6.05)		
	Lateral	Male	9.21 (4.71)	.327	.568
		Female	9.65 (4.82)		
	Posterior	Male	8.98 (5.68)	.108	.742
		Female	9.27 (5.05)		
	Rotation	Male	8.19 (4.80)	2.144	.145
		Female	9.39 (5.56)		
Vastus Medialis	Combination	Male	8.61 (5.60)	.112	.739
		Female	8.32 (5.09)		
	Lateral	Male	8.80 (4.77)	1.614	.206
		Female	7.85 (4.59)		
	Posterior	Male	8.31 (5.59)	.794	.374
		Female	7.53 (5.25)		
	Rotation	Male	7.86 (5.02)	.219	.641
		Female	7.48 (5.15)		
Biceps Femoris	Combination	Male	7.44 (7.12)	.019	.891
		Female	7.28 (7.56)		
	Lateral	Male	6.43 (4.45)	1.405	.238
		Female	5.49 (5.54)		
	Posterior	Male	7.06 (5.70)†	8.084	.005
		Female	4.70 (4.34)		
	Rotation	Male	6.37 (6.16)	2.759	.099
		Female	4.90 (4.56)		
Semitendinosis	Combination	Male	5.62 (6.35)	1.718	.192
		Female	7.16 (8.59)		
	Lateral	Male	4.65 (3.57)	.264	.608
		Female	4.97 (4.35)		
	Posterior	Male	5.06 (4.54)	.211	.647
		Female	5.47 (6.78)		
	Rotation	Male	4.73 (4.41)	.652	.421
		Female	4.21 (3.30)		

† Significantly greater in males than females

Table 12. Mean muscle activation by sex and perturbation for the lower leg musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	F value	p-value
Lateral Gastrocnemius	Combination	Male	9.15 (7.23)	9.651	.002
		Female	12.60 (6.52)‡		
	Lateral	Male	9.33 (7.15)	.450	.503
		Female	9.99 (4.18)		
	Posterior	Male	9.52 (7.50)	7.078	.009
		Female	12.98 (8.98)‡		
	Rotation	Male	8.91 (6.98)	5.859	.017
		Female	11.48 (6.09)‡		
Medial Gastrocnemius	Combination	Male	12.09 (9.06)	8.229	.005
		Female	16.55 (10.63)‡		
	Lateral	Male	11.58 (8.53)	.612	.435
		Female	10.66 (5.08)		
	Posterior	Male	12.38 (9.64)	5.557	.020
		Female	15.96 (9.32)‡		
	Rotation	Male	11.72 (9.12)	4.948	.028
		Female	14.77 (7.78)‡		
Peroneus Longus	Combination	Male	29.13 (21.54)	.715	.399
		Female	32.10 (21.70)		
	Lateral	Male	29.13 (19.04)	.630	.429
		Female	31.61 (19.63)		
	Posterior	Male	28.36 (18.52)	1.743	.189
		Female	24.77 (13.07)		
	Rotation	Male	26.26 (18.33)	1.216	.272
		Female	23.26 (13.46)		
Tibialis Anterior	Combination	Male	12.26 (6.89)	19.165	.000
		Female	18.79 (12.05)‡		
	Lateral	Male	12.15 (6.26)	15.174	.000
		Female	17.69 (11.72)‡		
	Posterior	Male	12.31 (7.45)	15.289	.000
		Female	18.24 (11.85)‡		
	Rotation	Male	11.27 (6.56)	29.454	.000
		Female	19.09 (11.70)‡		

† Significantly greater in males than females
‡ Significantly greater in females than males

Table 13. Sex comparison of MAX %MVIC for the trunk musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Left Erector Spinae	Combination	Male	10.90 (20.03)	7.00 - 14.80	3.735	0.055
		Female	17.20 (18.63)	12.20 - 22.30		
	Lateral	Male	9.40 (17.94)	5.90 - 12.90	0.087	0.768
		Female	10.20 (11.38)	7.10 - 13.30		
	Posterior	Male	9.40 (20.45)	5.40 - 13.40	0.073	0.788
		Female	8.60 (11.27)	5.50 - 11.60		
	Rotation	Male	7.00 (15.75)	3.90 - 10.10	0.781	0.378
		Female	9.30 (14.29)	5.40 - 13.20		
Right Erector Spinae	Combination	Male	13.00 (10.34)	11.00 - 15.10	3.431	0.066
		Female	16.60 (13.15)	13.00 - 20.20		
	Lateral	Male	11.70 (8.78)	10.00 - 13.40	0.000	0.984
		Female	11.70 (9.17)	9.20 - 14.20		
	Posterior	Male	12.70 (10.55)	10.60 - 14.80	0.457	0.5
		Female	11.50 (9.86)	8.80 - 14.20		
	Rotation	Male	11.30 (8.36)	9.70 - 13.00	1.164	0.282
		Female	12.90 (10.15)	10.20 - 15.70		
Left Rectus Abdominis	Combination	Male	13.20 (22.96)	8.70 - 17.70	0.51	0.476
		Female	15.80 (17.90)	10.90 - 20.70		
	Lateral	Male	11.50 (16.78)	8.20 - 14.80	2.148	0.145
		Female	15.80 (17.88)	10.90 - 20.70		
	Posterior	Male	12.70 (21.97)	8.40 - 17.00	0.807	0.37
		Female	15.80 (17.90)	10.90 - 20.70		
	Rotation	Male	11.70 (16.69)	8.40 - 14.90	2.046	0.155
		Female	15.80 (17.92)	10.90 - 20.70		
Right Rectus Abdominis	Combination	Male	5.30 (7.00)	3.90 - 6.60	12.816	0.000
		Female	10.20 (9.97)‡	7.50 - 12.90		
	Lateral	Male	5.10 (7.25)	3.70 - 6.50	0.219	0.64
		Female	5.60 (5.55)	4.10 - 7.20		
	Posterior	Male	6.20 (10.54)	4.20 - 8.30	1.137	0.288
		Female	8.00 (7.95)	5.80 - 10.10		
	Rotation	Male	5.20 (8.83)	3.50 - 7.00	5.728	0.018
		Female	9.00 (10.04)‡	6.20 - 11.70		

‡ Significantly greater in females than males

Table 14. Sex comparison of MAX %MVIC for the thigh musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Gluteus Medius	Combination	Male	19.30 (18.84)	15.70 - 22.90	10.753	0.001
		Female	30.60 (24.00)‡	24.00 - 37.10		
	Lateral	Male	17.90 (16.90)	14.70 - 21.20	3.909	0.05
		Female	24.30 (23.18)‡	17.90 - 30.60		
	Posterior	Male	18.90 (20.02)	15.10 - 22.70	0.151	0.698
		Female	20.10 (15.68)	15.80 - 24.40		
	Rotation	Male	15.70 (13.89)	13.10 - 18.40	6.792	0.01
		Female	22.60 (18.78)‡	17.40 - 27.70		
Vastus Lateralis	Combination	Male	16.30 (11.34)	14.10 - 18.40	7.396	0.007
		Female	21.70 (13.37)‡	18.10 - 25.40		
	Lateral	Male	16.40 (9.41)	14.60 - 18.20	2.569	0.111
		Female	19.10 (11.24)	16.00 - 22.20		
	Posterior	Male	16.40 (11.19)	14.30 - 18.60	0.104	0.748
		Female	17.00 (9.47)	14.40 - 19.60		
	Rotation	Male	14.90 (9.19)	13.20 - 16.70	2.06	0.153
		Female	17.30 (11.04)	14.30 - 20.30		
Vastus Medialis	Combination	Male	15.70 (11.96)	13.40 - 18.00	0.582	0.447
		Female	17.10 (10.57)	14.30 - 20.00		
	Lateral	Male	15.60 (9.69)	13.70 - 17.40	0.078	0.781
		Female	15.10 (9.94)	12.40 - 17.80		
	Posterior	Male	15.00 (10.83)	13.00 - 17.10	0.115	0.735
		Female	14.40 (11.94)	11.10 - 17.70		
	Rotation	Male	14.20 (9.37)	12.40 - 16.00	0.02	0.887
		Female	14.40 (11.05)	11.40 - 17.40		
Biceps Femoris	Combination	Male	16.20 (14.77)	13.40 - 19.00	0.735	0.393
		Female	18.60 (20.20)	13.10 - 24.10		
	Lateral	Male	14.10 (10.86)	12.10 - 16.20	0.571	0.455
		Female	12.70 (14.03)	8.80 - 16.50		
	Posterior	Male	15.90 (13.14)†	13.40 - 18.40	10.711	0.001
		Female	9.20 (9.90)	6.50 - 11.90		
	Rotation	Male	14.90 (14.35)	12.20 - 17.70	1.552	0.215
		Female	12.00 (13.39)	8.40 - 15.70		
Semitendinosis	Combination	Male	12.80 (14.30)	10.10 - 15.60	4.699	0.032
		Female	19.40 (24.21)‡	12.80 - 26.00		
	Lateral	Male	10.70 (9.24)	9.00 - 12.50	0.182	0.67
		Female	10.00 (10.85)	7.10 - 13.00		
	Posterior	Male	11.50 (10.42)	9.50 - 13.50	0.066	0.798
		Female	12.00 (15.63)	7.80 - 16.30		
	Rotation	Male	11.10 (11.76)	8.80 - 13.30	0.183	0.669
		Female	12.00 (15.74)	7.70 - 16.30		

† Significantly greater in males than females
‡ Significantly greater in females than males

Table 15. Sex comparison of MAX %MVIC for the lower leg musculature

Muscle	Perturbation	Sex	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Lateral Gastrocnemius	Combination	Male	23.80 (16.72)	20.40 - 27.20	4.187	0.042
		Female	29.80 (18.39)‡	24.80 - 34.90		
	Lateral	Male	23.20 (15.43)	20.10 - 26.30	1.534	0.218
		Female	202.00 (114.10)	17.10 - 23.30		
	Posterior	Male	24.80 (17.90)	21.10 - 28.40	0.76	0.385
		Female	27.50 (20.38)	22.00 - 33.10		
	Rotation	Male	23.20 (15.96)	19.90 - 26.40	0.057	0.812
		Female	23.80 (17.72)	19.00 - 28.70		
Medial Gastrocnemius	Combination	Male	32.30 (20.43)	28.20 - 36.50	1.1417	0.236
		Female	36.70 (24.02)	30.20 - 43.30		
	Lateral	Male	29.40 (18.30)	25.70 - 33.20	5.634	0.19
		Female	22.70 (13.00)	19.20 - 26.30		
	Posterior	Male	32.80 (21.46)	28.50 - 37.20	0.39	0.533
		Female	35.20 (22.61)	29.00 - 41.30		
	Rotation	Male	30.80 (19.08)	26.90 - 34.60	0.135	0.714
		Female	32.10 (23.36)	25.70 - 38.40		
Peroneus Longus	Combination	Male	55.10 (34.17)	48.60 - 61.60	3.906	0.05
		Female	67.50 (43.58)‡	55.60 - 79.40		
	Lateral	Male	54.50 (31.29)	48.50 - 60.50	2.871	0.92
		Female	64.30 (40.65)	53.20 - 75.40		
	Posterior	Male	53.90 (33.71)	47.40 - 60.30	0.098	0.754
		Female	52.20 (3.49)	45.20 - 59.20		
	Rotation	Male	51.60 (33.41)	45.20 - 57.90	0.072	0.789
		Female	50.20 (26.05)	43.10 - 57.30		
Tibialis Anterior	Combination	Male	26.20 (14.20)	23.40 - 29.00	20.19	0.000
		Female	40.00 (24.21)‡	33.40 - 46.60		
	Lateral	Male	26.10 (13.21)	23.50 - 28.70	14.096	0.000
		Female	37.70 (25.26)‡	30.80 - 44.60		
	Posterior	Male	28.00 (15.84)	24.90 - 31.10	14.945	0.000
		Female	40.30 (23.56)‡	33.90 - 42.70		
	Rotation	Male	26.20 (17.53)	22.70 - 29.60	16.364	0.000
		Female	40.30 (25.80)‡	33.30 - 47.30		

† Significantly greater in males than females

‡ Significantly greater in females than males

Table 16. Sex comparison of mean time to max %MVIC for the trunk musculature

Muscle	Phase	Sex	Mean (SD) (%MVIC)	CI	F	p-value
Left Erector Spinae	Pre-perturbation	Male	0.89 (0.85)	0.81 -0.97	50.796	0.000
		Female	1.39 (1.09)‡	1.27 -1.51		
	Perturbation	Male	1.43 (1.77)	1.27 -1.59	69.439	0.000
		Female	2.91 (3.17)‡	2.56 -3.26		
	Post-perturbation	Male	5.61 (7.57)†	4.92 -6.30	4.849	0.028
		Female	4.57 (4.40)	4.08 -5.05		
Right Erector Spinae	Pre-perturbation	Male	4.35 (2.96)†	4.08 -4.62	12.628	0.000
		Female	3.65 (2.26)	3.40 -3.90		
	Perturbation	Male	4.34 (2.90)	4.08 -4.60	2.515	0.113
		Female	4.69 (3.16)	4.34 -5.04		
	Post-perturbation	Male	8.33 (5.99)	7.79 -8.88	0.271	0.603
		Female	8.55 (5.56)	7.94 -9.17		
Left Rectus Abdominis	Pre-perturbation	Male	8.29 (8.25)	7.54 -9.04	77.110	0.000
		Female	16.32 (17.01)‡	14.44 -18.21		
	Perturbation	Male	8.54 (8.96)	7.73 -9.36	68.761	0.000
		Female	16.31 (17.01)‡	14.42 -18.20		
	Post-perturbation	Male	10.29 (14.35)	8.98 -11.59	28.522	0.000
		Female	16.32 (17.01)‡	14.43 -18.21		
Right Rectus Abdominis	Pre-perturbation	Male	1.04 (1.22)	0.93 -1.15	38.216	0.000
		Female	1.79 (2.14)‡	1.55 -2.03		
	Perturbation	Male	1.19 (1.36)	1.06 -1.31	100.645	0.000
		Female	2.82 (3.10)‡	2.48 -3.17		
	Post-perturbation	Male	3.63 (4.59)	3.21 -4.05	2.294	0.130
		Female	4.11 (4.04)	3.66 -4.56		

† Significantly greater in males than females

‡ Significantly greater in females than males

Table 17. Sex comparison of mean time to max %MVIC for the thigh musculature

Muscle	Phase	Sex	Mean (SD) (%MVIC)	CI	F	p-value
Gluteus Medius	Pre-perturbation	Male	7.41 (9.84)	6.51 -8.30	1.600	0.206
		Female	8.23 (7.21)	7.43 -9.03		
	Perturbation	Male	7.72 (10.07)	6.80 -8.64	13.971	0.000
		Female	10.34 (8.91)‡	9.35 -11.33		
	Post-perturbation	Male	12.11 (10.73)	11.14 -13.09	4.524	0.034
		Female	13.78 (10.71)‡	12.59 -14.97		
Vastus Lateralis	Pre-perturbation	Male	7.03 (4.29)	6.64 -7.42	4.664	0.031
		Female	7.77 (5.24)‡	7.19 -8.35		
	Perturbation	Male	7.05 (4.18)	6.67 -7.43	30.001	0.000
		Female	8.95 (5.52)‡	8.34 -9.57		
	Post-perturbation	Male	10.88 (6.58)	10.28 -11.48	20.229	0.000
		Female	13.07 (6.82)‡	12.32 -13.83		
Vastus Medialis	Pre-perturbation	Male	6.66 (4.70)	6.23 -7.09	0.658	0.418
		Female	6.37 (5.13)	5.80 -6.94		
	Perturbation	Male	6.62 (4.42)	6.21 -7.02	0.858	0.355
		Female	6.93 (5.05)	6.37 -7.49		
	Post-perturbation	Male	9.75 (6.01)	9.20 -10.29	0.826	0.364
		Female	10.16 (6.43)	9.44 -10.87		
Biceps Femoris	Pre-perturbation	Male	3.98 (3.49)†	3.67 -4.30	45.434	0.000
		Female	2.43 (2.58)	2.15 -2.72		
	Perturbation	Male	4.05 (3.01)	3.78 -4.33	7.016	0.008
		Female	4.90 (5.81)‡	4.25 -5.54		
	Post-perturbation	Male	12.01 (8.77)†	11.21 -12.81	15.926	0.000
		Female	9.56 (7.89)	8.68 -10.43		
Semitendinosis	Pre-perturbation	Male	3.98 (3.49)†	3.67 -4.30	45.434	0.000
		Female	2.43 (2.58)	2.15 -2.72		
	Perturbation	Male	4.05 (3.01)	3.78 -4.33	7.016	0.008
		Female	4.90 (5.81)‡	4.25 -5.54		
	Post-perturbation	Male	12.01 (8.77)†	11.21 -12.81	15.926	0.000
		Female	9.56 (7.89)	8.68 -10.43		

† Significantly greater in males than females

‡ Significantly greater in females than males

Table 18. Sex comparison of mean time to max %MVIC for the lower leg musculature

Muscle	Phase	Sex	Mean (SD) (%MVIC)	CI	F	p-value
Lateral Gastrocnemius	Pre-perturbation	Male	6.85 (4.32)	6.43 -7.28	7.176	0.008
		Female	7.70 (3.73)‡	7.27 -8.13		
	Perturbation	Male	7.76 (4.96)	7.27 -8.25	67.133	0.000
		Female	11.09 (5.64)‡	10.44 -11.75		
	Post-perturbation	Male	15.30 (9.53)	14.36 -16.23	0.591	0.442
		Female	15.88 (9.96)	14.72 -17.03		
Medial Gastrocnemius	Pre-perturbation	Male	8.71 (5.75)	8.14 -9.27	0.117	0.733
		Female	8.85 (5.05)	8.27 -9.44		
	Perturbation	Male	9.77 (5.75)	9.20 -10.33	47.307	0.000
		Female	13.26 (7.55)‡	12.38 -14.14		
	Post-perturbation	Male	21.54 (11.17)	20.44 -22.63	1.174	0.279
		Female	20.57 (12.12)	19.16 -21.97		
Peroneus Longus	Pre-perturbation	Male	17.05 (14.64)	15.72 -18.39	0.430	0.512
		Female	17.77 (15.35)	16.07 -19.47		
	Perturbation	Male	18.09 (11.91)	17.01 -19.18	80.924	0.000
		Female	28.36 (19.92)‡	26.15 -30.57		
	Post-perturbation	Male	41.54 (23.25)	39.42 -43.66	3.758	0.053
		Female	38.42 (20.11)	36.19 -40.65		
Tibialis Anterior	Pre-perturbation	Male	9.71 (8.36)	8.94 -10.47	18.692	0.000
		Female	12.63 (10.49)‡	11.47 -13.80		
	Perturbation	Male	9.35 (6.95)	8.72 -9.99	110.415	0.000
		Female	16.25 (11.36)‡	14.99 -17.51		
	Post-perturbation	Male	15.85 (9.39)	14.99 -16.70	120.884	0.000
		Female	26.16 (16.70)‡	24.31 -28.01		

† Significantly greater in males than females

‡ Significantly greater in females than males

Table 19. Mean muscle activation by knee position and perturbation for the trunk musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Left Erector Spinae	Combination	Bent	3.29 (4.78)	2.21 - 4.36	0.038	0.845
		Straight	3.43 (4.67)	2.38 - 4.49		
	Lateral	Bent	2.84 (3.95)	1.95 - 3.73	0.261	0.610
		Straight	2.56 (2.96)	1.89 - 3.22		
	Posterior	Bent	2.50 (4.14)	1.56 - 3.43	0.001	0.971
		Straight	2.52 (3.85)	1.65 - 3.39		
	Rotation	Bent	2.27 (2.63)	1.68 - 2.86	0.016	0.900
		Straight	2.33 (3.05)	1.64 - 3.02		
Right Erector Spinae	Combination	Bent	6.50 (4.28)	5.54 - 7.47	0.026	0.871
		Straight	6.38 (5.14)	5.22 - 7.54		
	Lateral	Bent	6.05 (4.03)	5.14 - 6.96	2.058	0.153
		Straight	5.17 (3.63)	4.35 - 5.98		
	Posterior	Bent	6.34 (4.84)	5.25 - 7.43	1.003	0.318
		Straight	5.62 (4.13)	4.69 - 6.55		
	Rotation	Bent	5.89 (3.63)*	5.07 - 6.71	4.323	0.039
		Straight	4.79 (2.97)	4.12 - 5.46		
Left Rectus Abdominis	Combination	Bent	11.57 (13.04)	8.63 - 14.51	0.014	0.907
		Straight	11.83 (14.36)	8.59 - 15.07		
	Lateral	Bent	11.21 (12.60)	8.37 - 14.05	0.063	0.802
		Straight	11.74 (13.69)	8.65 - 14.83		
	Posterior	Bent	11.34 (13.22)	8.36 - 14.32	0.271	0.603
		Straight	12.58 (16.34)	8.89 - 16.26		
	Rotation	Bent	11.09 (12.64)	8.24 - 13.94	0.190	0.664
		Straight	11.99 (13.01)	9.05 - 14.92		
Right Rectus Abdominis	Combination	Bent	2.41 (2.57)	1.83 - 2.99	0.004	0.952
		Straight	2.44 (3.01)	1.76 - 3.11		
	Lateral	Bent	2.01 (1.91)	1.57 - 2.44	0.524	0.470
		Straight	2.28 (2.73)	1.66 - 2.89		
	Posterior	Bent	2.18 (2.60)	1.59 - 2.77	0.249	0.618
		Straight	2.41 (3.16)	1.70 - 3.12		
	Rotation	Bent	2.19 (2.77)	1.56 - 2.81	0.271	0.603
		Straight	2.43 (3.08)	1.74 - 3.13		

* Significantly higher in bent vs straight knee condition

Table 20. Mean muscle activation by knee position and perturbation for the thigh musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Gluteus Medius	Combination	Bent	11.70 (10.70)	9.34 - 14.07	1.958	0.164
		Straight	9.63 (7.96)	7.87 - 11.39		
	Lateral	Bent	10.39 (7.91)	8.64 - 12.14	1.639	0.202
		Straight	8.79 (8.08)	7.00 - 10.57		
	Posterior	Bent	10.21 (8.22)	8.40 - 12.03	1.704	0.194
		Straight	8.60 (7.49)	6.95 - 10.26		
	Rotation	Bent	9.78 (7.81)	8.05 - 11.50	1.926	0.167
		Straight	8.20 (6.57)	6.75 - 9.65		
Vastus Lateralis	Combination	Bent	10.49 (5.66)	9.24 - 11.74	3.154	0.078
		Straight	8.87 (5.97)	7.55 - 10.19		
	Lateral	Bent	10.61 (4.02)*	9.72 - 11.50	11.425	0.001
		Straight	8.17 (5.10)	7.04 - 9.30		
	Posterior	Bent	11.10 (4.99)	10.00 - 12.20	25.431	0.000
		Straight	7.10 (5.10)	5.97 - 8.23		
	Rotation	Bent	10.32 (5.01)*	9.21 - 11.43	18.117	0.000
		Straight	7.05 (4.76)	6.00 - 8.10		
Vastus Medialis	Combination	Bent	9.48 (5.38)*	8.29 - 10.67	5.540	0.020
		Straight	7.51 (5.24)	6.35 - 8.67		
	Lateral	Bent	10.26 (4.33)*	9.30 - 11.22	29.348	0.000
		Straight	6.57 (4.34)	5.61 - 7.53		
	Posterior	Bent	10.27 (5.18)*	9.13 - 11.42	34.131	0.000
		Straight	5.71 (4.74)	4.66 - 6.76		
	Rotation	Bent	9.62 (5.04)*	8.50 - 10.73	26.703	0.000
		Straight	5.80 (4.34)	4.84 - 6.76		
Biceps Femoris	Combination	Bent	7.30 (7.12)	5.73 - 8.88	0.016	0.899
		Straight	7.45 (7.48)	5.80 - 9.10		
	Lateral	Bent	6.41 (5.43)	5.21 - 7.61	0.885	0.348
		Straight	5.68 (4.38)	4.71 - 6.65		
	Posterior	Bent	6.04 (5.33)	4.87 - 7.22	0.019	0.892
		Straight	6.16 (5.31)	4.98 - 7.33		
	Rotation	Bent	5.96 (5.68)	4.70 - 7.21	0.177	0.674
		Straight	5.59 (5.54)	4.36 - 6.81		
Semitendinosis	Combination	Bent	5.85 (6.51)	4.41 - 7.29	0.471	0.494
		Straight	6.64 (8.15)	4.84 - 8.45		
	Lateral	Bent	4.80 (3.58)	4.01 - 5.59	0.003	0.954
		Straight	4.76 (4.22)	3.83 - 5.70		
	Posterior	Bent	4.95 (5.65)	3.70 - 6.20	0.394	0.531
		Straight	5.50 (5.46)	4.29 - 6.71		
	Rotation	Bent	4.45 (3.81)	3.61 - 5.30	0.039	0.844
		Straight	4.58 (4.19)	3.65 - 5.50		

* Significantly higher in bent vs straight knee condition

Table 21. Mean muscle activation by knee position and perturbation for the lower leg musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence Interval	F value	p-value
Lateral Gastrocnemius	Combination	Bent	11.37 (6.59)	9.85 - 12.89	0.004	0.950
		Straight	11.44 (6.90)	9.85 - 13.03		
	Lateral	Bent	10.45 (5.58)	9.16 - 11.73	0.028	0.867
		Straight	10.29 (5.82)	8.95 - 11.63		
	Posterior	Bent	11.69 (7.99)	9.85 - 13.53	0.027	0.870
		Straight	11.91 (8.04)	10.06 - 13.76		
	Rotation	Bent	10.48 (6.36)	9.02 - 11.94	0.278	0.599
		Straight	11.03 (6.38)	9.56 - 12.50		
Medial Gastrocnemius	Combination	Bent	14.05 (8.64)	12.06 - 16.04	1.581	0.211
		Straight	16.00 (10.23)	13.64 - 18.35		
	Lateral	Bent	11.33 (6.76)	9.78 - 12.89	1.889	0.171
		Straight	12.87 (6.91)	11.28 - 14.46		
	Posterior	Bent	13.65 (9.14)	11.55 - 15.75	3.046	0.083
		Straight	16.24 (9.05)	14.16 - 18.32		
	Rotation	Bent	13.23 (8.34)	11.31 - 15.15	1.328	0.251
		Straight	14.77 (8.04)	12.92 - 16.62		
Peroneus Longus	Combination	Bent	30.13 (22.12)	25.24 - 35.02	0.004	0.951
		Straight	30.34 (21.16)	25.66 - 35.02		
	Lateral	Bent	30.86 (19.44)	26.56 - 35.16	0.289	0.591
		Straight	29.23 (19.11)	25.01 - 33.46		
	Posterior	Bent	27.70 (16.79)	23.99 - 31.42	0.263	0.609
		Straight	26.35 (16.80)	22.64 - 30.06		
	Rotation	Bent	24.65 (16.53)	21.00 - 28.31	0.142	0.707
		Straight	25.65 (16.98)	21.89 - 29.40		
Tibialis Anterior	Combination	Bent	14.90 (9.38)	12.79 - 17.02	0.166	0.684
		Straight	14.28 (9.85)	12.06 - 16.50		
	Lateral	Bent	14.45 (9.03)	12.42 - 16.49	0.349	0.555
		Straight	13.61 (8.78)	11.63 - 15.59		
	Posterior	Bent	15.52 (11.27)	12.97 - 18.06	0.948	0.332
		Straight	13.95 (8.66)	12.00 - 15.90		
	Rotation	Bent	15.31 (10.88)	12.85 - 17.76	1.283	0.259
		Straight	13.51 (8.81)	11.52 - 15.50		

* Significantly higher in bent vs straight knee condition

Table 22. Knee position comparison of MAX %MVIC for the trunk musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Left Erector Spinae	Combination	Bent	12.20 (18.31)	8.00 - 16.30	0.34	0.561
		Straight	14.00 (21.13)	9.20 - 18.80		
	Lateral	Bent	10.10 (16.34)	6.40 - 13.80	0.126	0.723
		Straight	9.20 (15.63)	5.70 - 12.70		
	Posterior	Bent	9.10 (18.91)	4.90 - 12.20	0.001	0.979
		Straight	9.10 (16.69)	5.30 - 13.40		
	Rotation	Bent	7.70 (13.18)	4.70 - 10.60	0.01	0.921
		Straight	7.90 (17.15)	4.00 - 11.80		
Right Erector Spinae	Combination	Bent	14.30 (11.15)	11.80 - 16.80	0.005	0.944
		Straight	14.20 (11.86)	11.50 - 16.90		
	Lateral	Bent	12.70 (9.10)	10.60 - 14.80	1.957	0.164
		Straight	10.70 (8.61)	8.80 - 12.70		
	Posterior	Bent	12.80 (10.32)	10.50 - 15.10	0.411	0.522
		Straight	11.70 (10.32)	9.40 - 14.10		
	Rotation	Bent	12.80 (9.35)	10.70 - 14.90	1.504	0.222
		Straight	11.00 (8.65)	9.00 - 12.90		
Left Rectus Abdominis	Combination	Bent	14.00 (20.89)	9.30 - 18.80	0.001	0.976
		Straight	14.10 (21.87)	9.20 - 19.10		
	Lateral	Bent	12.50 (15.09)	9.10 - 15.90	0.159	0.691
		Straight	13.60 (19.22)	9.20 - 17.90		
	Posterior	Bent	12.80 (16.77)	9.00 - 16.60	0.339	0.561
		Straight	14.70 (23.99)	9.30 - 20.10		
	Rotation	Bent	12.70 (17.59)	8.70 - 16.70	0.075	0.784
		Straight	13.50 (16.87)	9.70 - 17.30		
Right Rectus Abdominis	Combination	Bent	7.00 (8.19)	5.10 - 8.80	0.001	0.979
		Straight	6.90 (8.75)	5.00 - 8.90		
	Lateral	Bent	4.90 (5.53)	3.60 - 6.10	0.575	0.449
		Straight	5.70 (7.70)	4.00 - 7.40		
	Posterior	Bent	6.60 (9.60)	4.50 - 8.80	0.059	0.808
		Straight	7.00 (9.91)	4.80 - 9.30		
	Rotation	Bent	5.90 (8.57)	4.00 - 7.80	0.66	0.418
		Straight	7.10 (10.79)	4.80 - 9.40		

*Significantly greater in bent knee condition than straight

Table 23. Knee position comparison of MAX %MVIC for the thigh musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Gluteus Medius	Combination	Bent	25.00 (23.61)	19.70 - 30.20	1.325	0.251
		Straight	21.10 (18.69)	17.00 - 25.20		
	Lateral	Bent	22.10 (19.60)	17.80 - 26.50	1.901	0.17
		Straight	18.00 (19.05)	13.70 - 22.20		
	Posterior	Bent	21.20 (19.25)	17.00 - 25.50	1.735	0.19
		Straight	17.40 (17.94)	13.40 - 21.40		
	Rotation	Bent	19.90 (17.48)	16.00 - 23.70	2.211	0.139
		Straight	16.20 (14.14)	13.00 - 19.30		
Vastus Lateralis	Combination	Bent	19.30 (11.66)	16.70 - 20.80	1.524	0.219
		Straight	16.90 (12.85)	14.00 - 19.70		
	Lateral	Bent	18.90 (8.75)*	17.00 - 20.80	4.06	0.046
		Straight	15.70 (11.12)	13.30 - 18.20		
	Posterior	Bent	19.60 (9.94)*	17.40 - 21.80	13.538	0,000
		Straight	13.70 (10.51)	11.30 - 16.00		
	Rotation	Bent	18.00 (9.68)*	15.90 - 20.10	9.097	0.003
		Straight	13.40 (9.59)	11.30 - 15.60		
Vastus Medialis	Combination	Bent	17.80 (11.78)	15.20 - 20.40	3.376	0.068
		Straight	14.50 (11.05)	12.10 - 17.00		
	Lateral	Bent	18.20 (8.64)*	16.20 - 20.10	13.807	0,000
		Straight	12.70 (10.07)	10.50 - 14.90		
	Posterior	Bent	18.50 (10.98)*	16.10 - 20.90	19.58	0,000
		Straight	11.10 (10.18)	8.90 - 13.40		
	Rotation	Bent	17.40 (10.11)*	15.10 - 19.60	17.311	0,000
		Straight	11.20 (8.75)	9.20 - 13.10		
Biceps Femoris	Combination	Bent	16.00 (15.21)	12.60 - 19.30	0.656	0.419
		Straight	18.10 (18.19)	14.10 - 22.10		
	Lateral	Bent	14.60 (13.00)	11.70 - 17.40	0.917	0.34
		Straight	12.70 (10.88)	10.30 - 15.20		
	Posterior	Bent	13.50 (12.29)	10.80 - 16.20	0.021	0.885
		Straight	13.80 (12.83)	11.00 - 16.60		
	Rotation	Bent	14.20 (14.05)	11.10 - 17.30	0.063	0.802
		Straight	13.70 (14.16)	10.60 - 16.80		
Semitendinosis	Combination	Bent	13.70 (16.16)	10.20 - 17.30	0.773	0.381
		Straight	16.30 (20.42)	11.80 - 20.80		
	Lateral	Bent	10.60 (9.11)	8.50 - 12.60	0.007	0.932
		Straight	10.40 (10.46)	8.10 - 12.70		
	Posterior	Bent	10.90 (11.72)	8.30 - 13.50	0.706	0.402
		Straight	12.50 (12.97)	9.60 - 15.40		
	Rotation	Bent	11.20 (12.91)	8.40 - 14.10	0.035	0.852
		Straight	11.60 (13.51)	8.60 - 14.60		

*Significantly greater in bent knee condition than straight

Table 24. Knee position comparison of MAX %MVIC for the lower leg musculature

Muscle	Perturbation	Knee position	Mean (SD) (%MVIC)	95% Confidence internal	F	Sig.
Lateral Gastrocnemius	Combination	Bent	27.00 (18.52)	22.80 - 31.30	0.541	0.463
		Straight	24.90 (16.52)	21.10 - 28.70		
	Lateral	Bent	22.10 (13.32)	19.00 - 25.20	0.001	0.98
		Straight	22.10 (15.02)	18.70 - 25.60		
	Posterior	Bent	26.00 (19.43)	21.50 - 30.50	0.028	0.867
		Straight	25.50 (18.30)	21.30 - 29.70		
	Rotation	Bent	22.50 (15.07)	19.00 - 26.00	0.459	0.499
		Straight	24.30 (17.97)	20.20 - 28.50		
Medial Gastrocnemius	Combination	Bent	32.50 (20.96)	27.70 - 37.30	0.643	0.424
		Straight	35.30 (22.69)	30.10 - 40.60		
	Lateral	Bent	25.50 (16.52)	21.70 - 29.30	1.233	0.269
		Straight	28.60 (17.15)	24.60 - 32.50		
	Posterior	Bent	31.30 (22.27)	26.20 - 36.40	1.776	0.185
		Straight	36.10 (21.28)	31.20 - 41.00		
	Rotation	Bent	29.70 (20.27)	25.00 - 34.40	0.817	0.368
		Straight	32.80 (21.06)	27.90 - 37.60		
Peroneus Longus	Combination	Bent	58.40 (38.30)	49.90 - 66.80	0.085	0.771
		Straight	60.10 (37.69)	51.80 - 68.40		
	Lateral	Bent	59.00 (35.27)	51.20 - 66.80	0.218	0.641
		Straight	56.50 (34.64)	48.80 - 64.10		
	Posterior	Bent	51.00 (32.69)	47.80 - 62.30	0.513	0.475
		Straight	51.50 (29.68)	45.00 - 58.10		
	Rotation	Bent	50.00 (30.61)	43.20 - 56.70	0.218	0.641
		Straight	52.20 (31.67)	45.20 - 59.20		
Tibialis Anterior	Combination	Bent	31.90 (19.52)	27.50 - 36.30	0.348	0.556
		Straight	30.10 (19.30)	25.70 - 34.40		
	Lateral	Bent	31.40 (20.47)	26.80 - 36.00	0.753	0.387
		Straight	28.80 (17.51)	24.80 - 32.70		
	Posterior	Bent	34.40 (22.27)	29.40 - 39.40	1.868	0.174
		Straight	30.10 (16.57)	26.40 - 33.90		
	Rotation	Bent	32.60 (23.25)	27.40 - 37.90	0.816	0.368
		Straight	29.50 (20.17)	24.90 - 34.00		

*Significantly greater in bent knee condition than straight

Table 25. Knee position comparison of mean time to max %MVIC by phase for the trunk musculature

Muscle	Phase	Knee	Mean (SD)	CI	F	p-value
Left Erector Spinae	Pre-perturbation	Bent	1.07 (0.94)	0.98 - 1.17	0.263	0.608
		Straight	1.11 (1.02)	1.01 - 1.21		
	Perturbation	Bent	1.95 (2.37)	1.71 - 2.18	0.831	0.362
		Straight	2.11 (2.70)	1.84 - 2.38		
	Post-perturbation	Bent	5.26 (6.74)	4.59 - 5.92	0.090	0.764
		Straight	5.12 (6.24)	4.49 - 5.74		
Right Erector Spinae	Pre-perturbation	Bent	4.47 (2.95)†	4.17 - 4.76	17.387	0.000
		Straight	3.66 (2.40)	3.42 - 3.90		
	Perturbation	Bent	4.85 (3.21)†	4.53 - 5.17	12.035	0.001
		Straight	4.11 (2.75)	3.83 - 4.38		
	Post-perturbation	Bent	8.87 (5.96)†	8.28 - 9.46	4.652	0.031
		Straight	7.97 (5.65)	7.41 - 8.53		
Left Rectus Abdominis	Pre-perturbation	Bent	11.28 (12.67)	10.03 - 12.54	0.286	0.593
		Straight	11.79 (13.62)	10.43 - 13.15		
	Perturbation	Bent	11.33 (12.70)	10.07 - 12.59	0.546	0.460
		Straight	12.04 (14.04)	10.63 - 13.44		
	Post-perturbation	Bent	12.36 (14.43)	10.93 - 13.79	0.421	0.516
		Straight	13.09 (17.00)	11.39 - 14.79		
Right Rectus Abdominis	Pre-perturbation	Bent	1.30 (1.58)	1.14 - 1.45	0.632	0.427
		Straight	1.39 (1.80)	1.21 - 1.57		
	Perturbation	Bent	1.75 (2.10)	1.54 - 1.96	1.331	0.249
		Straight	1.95 (2.61)	1.69 - 2.21		
	Post-perturbation	Bent	3.64 (3.83)	3.26 - 4.02	1.358	0.244
		Straight	4.01 (4.88)	3.52 - 4.50		

†Significantly greater in bent knee condition than straight

‡ Significantly greater in straight knee condition than bent

Table 26. Knee position comparison of mean time to max %MVIC by phase for the thigh musculature

Muscle	Phase	Knee	Mean (SD)	CI	F	p-value
Gluteus Medius	Pre-perturbation	Bent	8.36 (10.25)†	7.34 - 9.37	3.868	0.050
		Straight	7.11 (7.17)	6.39 - 7.83		
	Perturbation	Bent	9.54 (9.94)†	8.56 - 10.53	4.950	0.026
		Straight	8.00 (9.39)	7.06 - 8.94		
	Post-perturbation	Bent	13.90 (10.79)†	12.83 - 14.97	8.631	0.003
		Straight	11.65 (10.59)	10.59 - 12.71		
Vastus Lateralis	Pre-perturbation	Bent	9.50 (4.39)†	9.06 - 9.93	213.379	0.000
		Straight	5.13 (3.94)	4.74 - 5.52		
	Perturbation	Bent	9.79 (4.47)†	9.34 - 10.23	156.348	0.000
		Straight	5.82 (4.39)	5.38 - 6.26		
	Post-perturbation	Bent	13.04 (6.22)†	12.42 - 13.66	29.104	0.000
		Straight	10.47 (7.04)	9.77 - 11.18		
Vastus Medialis	Pre-perturbation	Bent	9.14 (4.80)†	8.67 - 9.62	316.684	0.000
		Straight	3.90 (3.28)	3.57 - 4.22		
	Perturbation	Bent	9.08 (4.54)†	8.63 - 9.54	263.915	0.000
		Straight	4.37 (3.49)	4.02 - 4.72		
	Post-perturbation	Bent	11.66 (6.22)†	11.04 - 12.28	68.846	0.000
		Straight	8.14 (5.62)	7.57 - 8.70		
Biceps Femoris	Pre-perturbation	Bent	3.40 (3.08)	3.09 - 3.71	0.142	0.707
		Straight	3.31 (3.40)	2.97 - 3.65		
	Perturbation	Bent	4.33 (4.08)	3.92 - 4.73	0.187	0.666
		Straight	4.46 (4.66)	4.00 - 4.93		
	Post-perturbation	Bent	11.24 (8.35)	10.41 - 12.07	0.525	0.469
		Straight	10.80 (8.67)	9.93 - 11.66		
Semitendinosis	Pre-perturbation	Bent	3.40 (3.08)	3.09 - 3.71	0.142	0.707
		Straight	3.31 (3.40)	2.97 - 3.65		
	Perturbation	Bent	4.33 (4.08)	3.92 - 4.73	0.187	0.666
		Straight	4.46 (4.66)	4.00 - 4.93		
	Post-perturbation	Bent	11.24 (8.35)	10.41 - 12.07	0.525	0.469
		Straight	10.80 (8.67)	9.93 - 11.66		

†Significantly greater in bent knee condition than straight

Table 27. Knee position comparison of mean time to max %MVIC by phase for the lower leg musculature

Muscle	Phase	Knee	Mean (SD)	CI	F	p-value
Lateral Gastrocnemius	Pre-perturbation	Bent	7.09 (4.09)	6.66 - 7.52	0.576	0.448
		Straight	7.33 (4.13)	6.89 - 7.77		
	Perturbation	Bent	8.83 (5.11)	8.30 - 9.37	2.342	0.126
		Straight	9.48 (5.87)	8.85 - 10.10		
	Post-perturbation	Bent	14.89 (9.46)	13.90 - 15.89	3.132	0.077
		Straight	16.20 (9.93)	15.14 - 17.26		
Medial Gastrocnemius	Pre-perturbation	Bent	7.38 (4.71)	6.88 - 7.88	48.808	0.000
		Straight	10.20 (5.81)‡	9.57 - 10.82		
	Perturbation	Bent	9.64 (6.06)	9.00 - 10.28	41.013	0.000
		Straight	12.86 (7.10)‡	12.10 - 13.62		
	Post-perturbation	Bent	19.41 (10.63)	18.30 - 20.53	15.901	0.000
		Straight	22.90 (12.25)‡	21.59 - 24.21		
Peroneus Longus	Pre-perturbation	Bent	17.18 (15.36)	15.66 - 18.70	0.093	0.761
		Straight	17.51 (14.49)	16.06 - 18.95		
	Perturbation	Bent	22.03 (16.60)	20.38 - 23.67	0.131	0.718
		Straight	22.45 (16.27)	20.83 - 24.08		
	Post-perturbation	Bent	40.39 (22.16)	38.19 - 42.59	0.019	0.892
		Straight	40.17 (22.02)	37.97 - 42.38		
Tibialis Anterior	Pre-perturbation	Bent	11.43 (10.22)	10.42 - 12.45	2.682	0.102
		Straight	10.33 (8.43)	9.49 - 11.18		
	Perturbation	Bent	12.58 (10.01)	11.59 - 13.58	1.709	0.191
		Straight	11.69 (9.16)	10.77 - 12.60		
	Post-perturbation	Bent	20.83 (14.67)	19.37 - 22.28	2.771	0.096
		Straight	19.19 (12.84)	17.90 - 20.47		

‡ Significantly greater in straight knee condition than bent

Table 28. Comparison by perturbation of Mean and Max %MVIC

Phase	Perturbation	Mean (SD) (%MVIC)	F	p-value	Max (SD) (%MVIC)	F	p-value
Pre-perturbation	Combination	7.07 (7.57)	0.196	0.899	11.24 (11.84)	0.275	0.844
	Lateral	7.21 (7.58)			11.31 (11.75)		
	Posterior	7.26 (7.65)			11.56 (12.24)		
	Rotation	6.98 (7.19)			10.98 (11.47)		
Perturbation	Combination	9.06 (9.92)	1.196	0.310	23.95 (25.21) [a]	6.758	0.000
	Lateral	8.52 (9.59)			19.79 (22.18)		
	Posterior	8.29 (8.58)			20.19 (21.25)		
	Rotation	8.21 (8.30)			18.96 (20.07)		
Post-perturbation	Combination	15.78 (14.80) [b]	5.039	0.002	31.47 (26.13) [b,c]	3.391	0.017
	Lateral	13.86 (13.24)			27.78 (24.08)		
	Posterior	14.35 (13.55)			28.97 (25.32)		
	Rotation	13.00 (12.52)			27.70 (24.38)		

[a] significantly higher combo vs other 3

[b] significantly higher combination vs rotation

[c] significantly higher combination vs lateral

Table 29. Mean time to max muscle activation by perturbation and phase for the trunk musculature

Muscle	Phase	Perturbation	Mean (SD)	95% Confidence Interval
Left Erector Spinae	Pre-perturbation	Combination	1.10 (0.98)	0.96 - 1.23
		Lateral	1.04 (0.95)	0.97 - 1.22
		Posterior	1.13 (1.10)	1.40 - 1.83
		Rotation	1.09 (0.91)	4.05 - 5.38
	Perturbation	Combination	3.19 (3.55)[a,b,c]	0.91 - 1.18
		Lateral	1.71 (1.98)	2.69 - 3.68
		Posterior	1.62 (1.52)	1.25 - 1.89
		Rotation	1.57 (2.25)	2.65 - 3.93
	Post-perturbation	Combination	8.26 (8.36)[a,b,c]	0.98 - 1.29
		Lateral	4.72 (4.69)	1.43 - 1.99
		Posterior	3.29 (4.52)	7.09 - 9.43
		Rotation	4.41 (6.49)	3.50 - 5.33
Right Erector Spinae	Pre-perturbation	Combination	4.12 (2.77)	3.73 - 4.51
		Lateral	3.87 (2.54)	3.76 - 4.59
		Posterior	4.11 (2.58)	3.88 - 4.64
		Rotation	4.17 (2.97)	6.99 - 8.52
	Perturbation	Combination	4.78 (3.33)	3.51 - 4.22
		Lateral	4.22 (2.75)	4.32 - 5.25
		Posterior	4.26 (2.67)	4.19 - 5.10
		Rotation	4.65 (3.22)	7.19 - 8.43
	Post-perturbation	Combination	11.50 (7.21)[a,b,c]	3.75 - 4.48
		Lateral	7.76 (5.43)	3.83 - 4.61
		Posterior	7.81 (4.38)	10.49 - 12.51
		Rotation	6.56 (4.57)	5.92 - 7.21
Left Rectus Abdominis	Pre-perturbation	Combination	11.34 (12.94)	9.53 - 13.16
		Lateral	11.85 (13.30)	9.47 - 13.04
		Posterior	11.69 (13.79)	9.81 - 13.80
		Rotation	11.26 (12.62)	10.45 - 14.58
	Perturbation	Combination	11.49 (12.93)	9.97 - 13.74
		Lateral	11.91 (13.45)	9.67 - 13.30
		Posterior	11.81 (14.06)	9.66 - 13.38
		Rotation	11.52 (13.16)	10.77 - 15.85
	Post-perturbation	Combination	12.94 (16.37)	9.73 - 13.64
		Lateral	12.51 (14.60)	10.00 - 13.81
		Posterior	13.31 (17.90)	10.65 - 15.24
		Rotation	12.13 (13.93)	10.16 - 14.10
Right Rectus Abdominis	Pre-perturbation	Combination	1.35 (1.70)	1.11 - 1.59
		Lateral	1.26 (1.43)	1.14 - 1.59
		Posterior	1.40 (1.99)	1.48 - 2.07
		Rotation	1.37 (1.62)	2.61 - 3.37
	Perturbation	Combination	2.22 (2.89)[a]	1.06 - 1.46
		Lateral	1.58 (2.00)	1.82 - 2.63
		Posterior	1.77 (2.08)	1.48 - 2.15
		Rotation	1.81 (2.36)	2.90 - 4.21
	Post-perturbation	Combination	5.07 (5.31)[a,b,c]	1.12 - 1.68
		Lateral	2.99 (2.67)	1.29 - 1.86
		Posterior	3.56 (4.61)	4.33 - 5.81
		Rotation	3.65 (4.24)	3.05 - 4.25

a. significantly higher combination vs lateral
b. significantly higher combination vs posterior
c. significantly higher combination vs rotation

Table 30. Mean time to max muscle activation by perturbation and phase for thigh musculature				
Muscle	Phase	Perturbation	Mean (SD)	95% Confidence Interval
Gluteus Medius	Pre-perturbation	Combination	8.32 (13.03)	6.50 - 10.15
		Lateral	7.12 (6.06)	6.84 - 9.18
		Posterior	7.49 (6.20)	7.01 - 9.49
		Rotation	8.01 (8.28)	11.50 - 14.78
	Perturbation	Combination	9.73 (12.24)	6.26 - 7.98
		Lateral	8.56 (8.90)	8.01 - 11.44
		Posterior	8.25 (8.75)	7.37 - 9.73
		Rotation	8.55 (8.36)	10.14 - 13.06
	Post-perturbation	Combination	15.75 (11.50)[b,c]	6.61 - 8.37
		Lateral	13.14 (11.60)	7.30 - 9.82
		Posterior	11.60 (10.30)	14.13 - 17.36
		Rotation	10.60 (8.68)	9.37 - 11.83
Vastus Lateralis	Pre-perturbation	Combination	7.50 (5.01)	6.80 - 8.20
		Lateral	7.10 (4.54)	6.70 - 7.99
		Posterior	7.37 (4.69)	7.13 - 8.46
		Rotation	7.34 (4.60)	11.37 - 12.98
	Perturbation	Combination	8.16 (5.32)	6.46 - 7.74
		Lateral	7.55 (4.65)	7.42 - 8.91
		Posterior	7.79 (4.68)	7.10 - 8.43
		Rotation	7.76 (4.74)	9.77 - 11.61
	Post-perturbation	Combination	14.01 (7.71)[a,b,c]	6.70 - 8.03
		Lateral	12.17 (5.68)[e]	6.89 - 8.20
		Posterior	10.69 (6.50)	12.93 - 15.09
		Rotation	10.14 (6.33)	9.25 - 11.03
Vastus Medialis	Pre-perturbation	Combination	6.60 (5.03)	5.90 - 7.31
		Lateral	6.35 (4.77)	5.86 - 7.22
		Posterior	6.67 (4.95)	6.03 - 7.32
		Rotation	6.54 (4.81)	9.83 - 11.50
	Perturbation	Combination	6.96 (4.85)	5.67 - 7.02
		Lateral	6.48 (4.57)	6.28 - 7.64
		Posterior	6.68 (4.55)	6.18 - 7.53
		Rotation	6.86 (4.80)	8.12 - 9.78
	Post-perturbation	Combination	11.48 (6.85)[b,c]	5.97 - 7.37
		Lateral	10.66 (5.92)[d,e]	5.84 - 7.13
		Posterior	8.95 (5.84)	10.52 - 12.44
		Rotation	8.53 (5.60)	7.74 - 9.32
Biceps Femoris	Pre-perturbation	Combination	3.37 (3.30)	2.91 - 3.83
		Lateral	3.24 (3.18)	3.14 - 4.16
		Posterior	3.17 (2.80)	3.31 - 4.42
		Rotation	3.65 (3.63)	10.06 - 12.02
	Perturbation	Combination	5.31 (5.40)[a,b]	2.79 - 3.69
		Lateral	4.07 (3.94)	4.55 - 6.06
		Posterior	3.86 (3.89)	3.76 - 4.88
		Rotation	4.32 (3.95)	8.00 - 9.86
	Post-perturbation	Combination	16.71 (10.91)[a,b,c]	2.77 - 3.56
		Lateral	11.04 (6.91)[d,e]	3.51 - 4.63
		Posterior	8.93 (6.56)	15.18 - 18.24
		Rotation	7.29 (5.30)	6.54 - 8.04
Semitendinosis	Pre-perturbation	Combination	3.37 (3.30)	2.91 - 3.83
		Lateral	3.65 (3.63)	3.14 - 4.16
		Posterior	3.86 (3.89)	3.31 - 4.42
		Rotation	3.17 (2.81)	10.06 - 12.02
	Perturbation	Combination	5.31 (5.40)[a,b]	2.79 - 3.69
		Lateral	4.07 (3.94)	4.55 - 6.06
		Posterior	3.86 (3.89)	3.76 - 4.88
		Rotation	4.32 (3.95)	8.00 - 9.86
	Post-perturbation	Combination	16.71 (10.91)[a,b,c]	2.77 - 3.56
		Lateral	11.04 (6.91)[d,e]	3.51 - 4.63
		Posterior	8.93 (6.56)	15.18 - 18.24
		Rotation	7.29 (5.30)	6.54 - 8.04

a. significantly higher combination vs lateral
b. significantly higher combination vs posterior
c. significantly higher combination vs rotation
d. significantly higher lateral vs posterior
e. significantly higher lateral vs rotation

Table 31. Mean time to max muscle activation by perturbation and phase for lower leg musculature

Muscle	Phase	Perturbation	Mean (SD)	95% Confidence Interval
Lateral Gastrocnemius	Pre-perturbation	Combination	7.50 (4.42)	6.84 - 8.16
		Lateral	6.95 (4.28)	6.69 - 7.85
		Posterior	7.10 (3.85)	8.53 - 10.10
		Rotation	7.27 (3.85)	11.05 - 13.42
	Perturbation	Combination	10.58 (6.44)[a,c]	6.30 - 7.59
		Lateral	7.92 (4.48)	9.62 - 11.54
		Posterior	9.31 (5.17)	7.94 - 9.57
		Rotation	8.75 (5.40)	17.09 - 20.66
	Post-perturbation	Combination	17.20 (9.39)[a,c]	6.51 - 7.68
		Lateral	12.23 (7.85)	7.24 - 8.59
		Posterior	18.87 (11.78)[f,g]	15.81 - 18.60
		Rotation	13.82 (7.93)	12.62 - 15.01
Medial Gastrocnemius	Pre-perturbation	Combination	8.88 (5.44)	8.07 - 9.69
		Lateral	8.68 (5.57)	8.10 - 9.73
		Posterior	8.58 (5.52)	11.23 - 13.22
		Rotation	8.91 (5.37)	12.79 - 15.20
	Perturbation	Combination	12.79 (8.18)[a,c]	7.84 - 9.52
		Lateral	9.10 (5.13)	11.57 - 14.00
		Posterior	12.23 (6.55)[f]	9.80 - 11.70
		Rotation	10.75 (6.29)	23.55 - 27.00
	Post-perturbation	Combination	25.58 (13.18)[a,c]	7.75 - 9.42
		Lateral	14.00 (8.01)	8.32 - 9.87
		Posterior	25.27 (11.41)[f,g]	23.62 - 27.54
		Rotation	19.57 (8.85)[h]	18.24 - 20.91
Peroneus Longus	Pre-perturbation	Combination	17.75 (15.11)	15.63 - 19.87
		Lateral	16.89 (17.19)	15.89 - 19.58
		Posterior	16.98 (14.13)	17.92 - 21.38
		Rotation	17.74 (13.06)	46.65 - 53.46
	Perturbation	Combination	25.48 (18.36)[b,c]	14.45 - 19.32
		Lateral	24.10 (18.86)[d,e]	22.90 - 28.05
		Posterior	19.65 (12.18)	17.59 - 21.72
		Rotation	19.66 (14.60)	32.34 - 36.99
	Post-perturbation	Combination	48.07 (22.71)[b,c]	14.97 - 18.99
		Lateral	50.06 (24.05)[d,e]	21.43 - 26.77
		Posterior	34.67 (16.37)[g]	44.88 - 51.25
		Rotation	28.21 (16.06)	25.94 - 30.48
Tibialis Anterior	Pre-perturbation	Combination	12.07 (9.82)	9.75 - 12.35
		Lateral	11.20 (8.83)	9.99 - 12.86
		Posterior	12.11 (8.58)	10.89 - 13.33
		Rotation	13.17 (10.96)	17.99 - 21.47
	Perturbation	Combination	21.81 (14.45)	9.30 - 11.96
		Lateral	19.73 (12.32)	10.69 - 13.45
		Posterior	19.98 (14.27)	11.62 - 14.72
		Rotation	18.50 (13.98)	17.96 - 22.01
	Post-perturbation	Combination	12.07 (9.82)	9.21 - 11.66
		Lateral	11.20 (8.83)	9.95 - 12.45
		Posterior	12.11 (8.58)	19.79 - 23.83
		Rotation	13.17 (10.96)	16.53 - 20.48

a. significantly higher combo vs lat
b. significantly higher combo vs post
c. significantly higher combo vs rot
d. significantly higher lat vs post
e. significantly higher lat vs rot
f. significantly higher post vs lat
g. significantly higher post vs rot
h. significantly higher rot vs lat

Table 32. Mean EMG effect size by muscle, perturbation, sex, knee position and phase for the trunk musculature.

Muscle	Perturbation	Sex	η_p^2	Knee position	η_p^2	Phase	η_p^2
Left Erector Spinae	Combination	Male	0,056	Bent	0,001	Pre-perturbation	
		Female		Straight		Perturbation	0,199
						Post-perturbation	
	Lateral	Male	0,005	Bent	0,002	Pre-perturbation	0,227
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,003	Bent	0,000	Pre-perturbation	0,162
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,010	Bent	0,000	Pre-perturbation	0,187
		Female		Straight		Perturbation	
						Post-perturbation	
Right Erector Spinae	Combination	Male	0,003	Bent	0,001	Pre-perturbation	0,313
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,027	Bent	0,020	Pre-perturbation	0,214
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,032	Bent	0,012	Pre-perturbation	0,210
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,008	Bent	0,042	Pre-perturbation	0,209
		Female		Straight		Perturbation	
						Post-perturbation	
Left Rectus Abdominis	Combination	Male	0,134	Bent	0,000	Pre-perturbation	0,000
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,143	Bent	0,000	Pre-perturbation	0,000
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,144	Bent	0,000	Pre-perturbation	0,000
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,130	Bent	0,000	Pre-perturbation	0,000
		Female		Straight		Perturbation	
						Post-perturbation	
Right Rectus Abdominis	Combination	Male	0,076	Bent	0,000	Pre-perturbation	0,150
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,010	Bent	0,003	Pre-perturbation	0,166
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,016	Bent	0,002	Pre-perturbation	0,155
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,023	Bent	0,002	Pre-perturbation	0,116
		Female		Straight		Perturbation	
						Post-perturbation	

Table 33. Mean EMG effect size by muscle, perturbation, sex, knee position and phase for the thigh musculature.

Muscle	Perturbation	Sex	η_p^2	Knee position	η_p^2	Phase	η_p^2
Gluteus Medius	Combination	Male	0,006	Bent	0,012	Pre-perturbation	0,071
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,004	Bent	0,012	Pre-perturbation	0,077
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,000	Bent	0,018	Pre-perturbation	0,069
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,021	Bent	0,016	Pre-perturbation	0,060
		Female		Straight		Perturbation	
						Post-perturbation	
Vastus Lateralis	Combination	Male	0,016	Bent	0,032	Pre-perturbation	0,166
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,001	Bent	0,091	Pre-perturbation	0,182
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,000	Bent	0,179	Pre-perturbation	0,183
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,006	Bent	0,119	Pre-perturbation	0,130
		Female		Straight		Perturbation	
						Post-perturbation	
Vastus Medialis	Combination	Male	0,006	Bent	0,043	Pre-perturbation	0,130
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,036	Bent	0,184	Pre-perturbation	0,121
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,014	Bent	0,211	Pre-perturbation	0,116
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,015	Bent	0,161	Pre-perturbation	0,077
		Female		Straight		Perturbation	
						Post-perturbation	
Biceps Femoris	Combination	Male	0,000	Bent	0,000	Pre-perturbation	0,342
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,010	Bent	0,018	Pre-perturbation	0,367
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,089	Bent	0,002	Pre-perturbation	0,341
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,034	Bent	0,004	Pre-perturbation	0,288
		Female		Straight		Perturbation	
						Post-perturbation	
Semitendinosus	Combination	Male	0,012	Bent	0,004	Pre-perturbation	0,255
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,000	Bent	0,000	Pre-perturbation	0,336
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,000	Bent	0,002	Pre-perturbation	0,260
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,019	Bent	0,001	Pre-perturbation	0,258
		Female		Straight		Perturbation	
						Post-perturbation	

Table 34. Mean EMG effect size by muscle, perturbation, sex, knee position and phase for the leg musculature.

Muscle	Perturbation	Sex	η_p^2	Knee position	η_p^2	Phase	η_p^2
Lateral Gastrocnemius	Combination	Male	0,027	Bent	0,002	Pre-perturbation	0,333
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,012	Bent	0,000	Pre-perturbation	0,270
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,016	Bent	0,001	Pre-perturbation	0,290
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,007	Bent	0,003	Pre-perturbation	0,279
		Female		Straight		Perturbation	
						Post-perturbation	
Medial Gastrocnemius	Combination	Male	0,029	Bent	0,018	Pre-perturbation	0,400
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,071	Bent	0,016	Pre-perturbation	0,352
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,016	Bent	0,035	Pre-perturbation	0,486
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,010	Bent	0,011	Pre-perturbation	0,376
		Female		Straight		Perturbation	
						Post-perturbation	
Peroneus Longus	Combination	Male	0,006	Bent	0,000	Pre-perturbation	0,282
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,006	Bent	0,002	Pre-perturbation	0,297
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,025	Bent	0,002	Pre-perturbation	0,248
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,022	Bent	0,002	Pre-perturbation	0,261
		Female		Straight		Perturbation	
						Post-perturbation	
Tibialis Anterior	Combination	Male	0,103	Bent	0,002	Pre-perturbation	0,202
		Female		Straight		Perturbation	
						Post-perturbation	
	Lateral	Male	0,062	Bent	0,005	Pre-perturbation	0,181
		Female		Straight		Perturbation	
						Post-perturbation	
	Posterior	Male	0,104	Bent	0,017	Pre-perturbation	0,284
		Female		Straight		Perturbation	
						Post-perturbation	
	Rotation	Male	0,169	Bent	0,015	Pre-perturbation	0,217
		Female		Straight		Perturbation	
						Post-perturbation	