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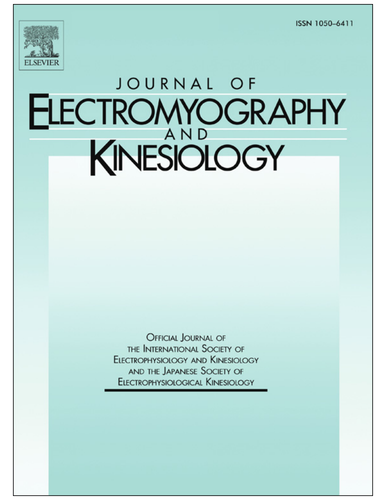

Quadriceps and hamstrings prelanding myoelectric activity during landing from different heights among male and female athletes

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QUADRICEPS AND HAMSTRINGS PRELANDING MYOELECTRIC ACTIVITY DURING LANDING FROM DIFFERENT HEIGHTS AMONG MALE AND FEMALE ATHLETES

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INTRODUCTION

Anterior cruciate ligament (ACL) tear is a serious injury occurring among athletes involved in sports that include jump-landing and cutting tasks. ACL tear usually happens in the first 50 ms after initial ground contact during the landing phase of the jump task or during change of direction (Koga et al. , 2010, Krosshaug et al. , 2007).

ACL injury is more common among female athletes than male athletes (Powell and Barber-Foss, 2000). One of the theories that have been proposed as explanations for this sex disparity is that female athletes preferentially activate their quadriceps compared to the hamstrings, potentially causing anterior tibial translation that increases the stress within the ACL (quadriceps dominance theory) (Hewett et al. , 2010, Pappas et al. , 2012). The ACL prevents anterior translation of the tibia relative to the femur; thus, excessive quadriceps forces would increase the strain within the ACL. The co-contraction of knee flexors and extensors is important in preventing the knee from assuming a dangerous position during landing (Yeadon et al. , 2010), by providing joint stability(Hirokawa et al. , 1991).

The quadriceps dominance theory has been supported by previous research that found female athletes after menarche to increase quadriceps strength more than hamstrings strength(Ahmad et al. , 2006), and that female athletes with lower knee flexion and higher knee extension strength are at greater risk of tearing the ACL (Myer et al. , 2009). Other studies have shown that female recreational athletes performing landing and cutting tasks prepare for landing with increased activity of the quadriceps compared to male subjects (Chappell et al. , 2007, Landry et al. , 2009). Finally, the importance of preparatory

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hamstrings activity was supported by the findings of a study (Bryant et al. , 2009) showing that among ACL-deficient athletes, higher pre-activation of the hamstrings is associated with higher knee functionality. But probably the most direct evidence comes from a prospective study that demonstrated that female athletes who exhibit greater quadriceps and lower hamstrings myoelectric activity in the prelanding phase of athletic activities are more likely to suffer an ACL tear (Zebis et al. , 2009).

Furthermore, the height of the jump-landing task in drop-jump maneuvers may influence muscle activity around the knee joint. When landing height increased from 1 m to 1.5 m and 2 m, myoelectric activity of the quadriceps and hamstrings increased during both the prelanding and landing phases (Arampatzis et al. , 2003). As increasing the height of the jump-landing task leads to an increase in the vertical ground reaction force, this condition elicits higher risk for an ACL injury (Ali et al. , 2012). Despite of the evidence linking preparatory activity of the knee musculature and the height of landing to ACL injury, to the authors' knowledge there are currently no studies that investigated the effect of sex and height on prelanding myoelectric activity. Two recent studies (Ali, Robertson, 2012, Ali et al. , 2013) investigated these effects on kinetics and kinematics but not on muscle activity. Other investigators (Peng et al. , 2011) included EMG on a study of different heights but did not report prelanding myoelectric activity or differences between males and females. Prelanding myoelectric activity may be important as ACL tears occur early in the landing phase, and thus muscle preactivation may be a more effective mechanism for protection from knee injury. Ford et al (Ford et al. , 2011) investigated the effect of increasing height on prelanding myoelectric activity but on female athletes only. Thus, there is a need for a study that investigates sex differences in the prelanding activity of athletes when landing from different heights.

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The aim of this study was to investigate the prelanding myoelectric activity of the hamstrings and quadriceps of recreational athletes of both sexes performing jump-landing tasks from different heights.

METHODS

Fifteen male and 15 female recreational athletes consented to participate in the study [mean (standard-deviation) for male and female, respectively; age: 28.9 (4) vs. 28.4 (6) years, height: 182 (7) vs. 167 (6) cm, body mass: 81 (11) vs. 59 (6) kg]. The inclusion criteria included participation in recreational sports that involved jump-landing activities at least twice per week for a minimum of 45 min per practice session. Participants were excluded if they had received specialized training in jumping and landing techniques such as through participation in injury prevention programs, gymnastics or dance. All participants were right leg dominant as determined by the answer the question about their preferred leg to kick a ball. Participants were informed of the study protocol and all risks and possible harms as described in the consent form. Ethics approval was obtained by the NYU School of Medicine.

Electromyographic (EMG) measurements were in reference to the right lower extremity. EMG data were collected at 1200 Hz sampling rate with a Noraxon Myosystem 1400 (Noraxon USA, Inc., Scottsdale, AZ). The electrodes were disposable, surface, passive electrodes (Blue Sensor, Ambu, Inc., Linthicum, MD). The skin was prepared according to

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SENIAM recommendations and the surface electrodes were placed on the vastus medialis, rectus femoris, biceps femoris and medial hamstrings between the motor point and the distal tendon in order to improve intra and inter-subject comparison reliability consistently with recent guidelines (Hermens et al. , 2000). Two electrodes were placed on each muscle at a 20 mm distance and parallel to muscle fiber orientation while athletic tape was used to fixate the electrodes and decrease movement artefact (Hermens, Freriks, 2000). The settings for EMG data collection were at 10-500Hz for the hardware filter, at 100 MOhm for input impedance, at 100 dB min at 50 Hz for the common rejection ratio and at 1000 for the gain. EMG data were full wave rectified and enveloped by filtering through a 2nd order low pass Butterworth filter with a 6 Hz cut-off frequency. EMG data were extracted for two time points: at 10ms before landing and the average of the 100ms before landing. EMG was then amplitude normalized to the maximum linear-enveloped EMG of each muscle (Arampatzis, Morey-Klapsing, 2003) during the landing phase of the 20cm landing task.

Kinematic data were collected with the use of eight Eagle cameras (Motion Analysis Corp. Santa Rosa, CA) and reflective markers were placed as per the “Helen Hayes system” (Richards, 2002). The software for data collection was the EvaRT 4.0 (Motion Analysis Corp. Santa Rosa, CA). In this project, kinematic data were only used to calculate the hip and knee flexion angles at landing. Additionally, participants landed on a force plate (OR6-5, AMTI, Watertown, MA) embedded flush with the laboratory floor that was used to determine the beginning of the landing cycle. The analog signals were digitized with an A/D board (SCB-100, National Instruments, Austin, TX). Kinetic, kinematic and EMG data were time synchronized and stored on a personal computer.

The athletes were allowed two practice jumps from each height and then performed three bilateral drop jumps from each height (20 and 40 cm platform in a randomized order). They were instructed to drop directly down off the box and land with both legs on a force plate. The effect of the arms was minimized by asking the participants to keep their arms crossed against their chest (Hagins et al. , 2007). No additional instructions on the landing technique

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were provided to avoid a coaching effect. Trials were repeated when they were judged as non-acceptable (such as when participants lost their balance). EMG measurements during landing tasks have been previously shown to be reliable (ICC>0.8) (Fauth et al. , 2010).

A 2 x 2 mixed MANOVA was performed to evaluate the effect of height (20 vs. 40cm) and sex on prelanding normalized myoelectric activity (NEMG) followed by post-hoc univariate ANOVAs and pairwise tests when statistical significance was detected. The level was *a priori* set at 0.05. Knee and hip flexion immediately at initial contact were also assessed to insure that any NEMG differences were not due to the joints being at different flexion angles.

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RESULTS

Significant main effects for height ($p<0.001$) and sex ($p=0.038$) but not for the interaction of height *x* sex ($p=0.359$) were found. Post-hoc tests revealed that with the increased height prelanding NEMG of the rectus and vastus medialis were increased ($p\leq0.033$) by 15-20% (Figure 1) but no changes were found for the NEMG of the hamstrings ($p\geq0.123$) (Figure 2). Females exhibited higher preactivation of the medial hamstrings ($p\leq0.006$) but there was no sex effect on any of the other muscles ($p\geq0.139$). There were no differences in knee or hip flexion angle between heights or between males and females ($p\geq0.185$).

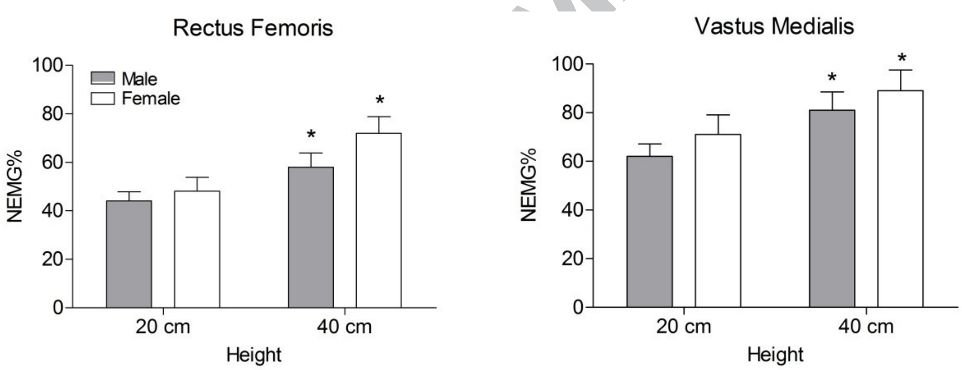

Figure 1. Prelanding NEMG of rectus femoris and vastus medialis increased when height changed from 20 cm to 40 cm. * indicates statistical significant difference compared to 20 cm height. No differences were observed between male and female.

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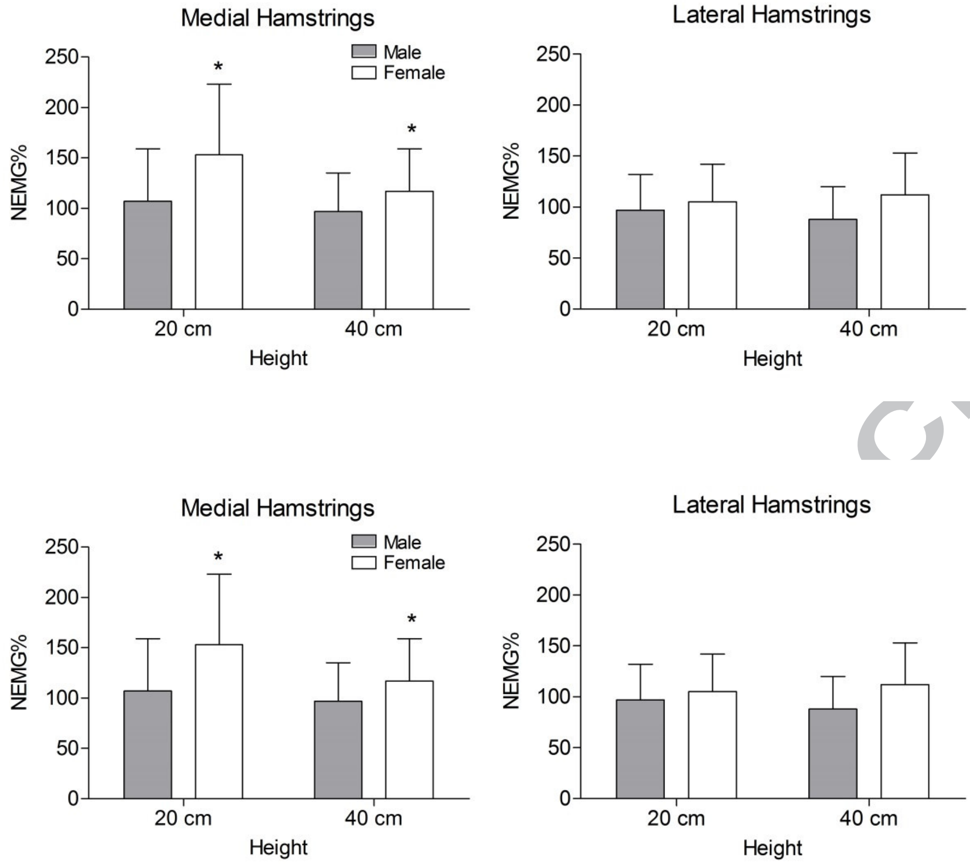

Figure 2. Prelanding NEMG of medial and lateral hamstrings did not change when height changed from 20 cm to 40 cm. Females exhibited higher prelanding NEMG of the medial hamstrings than males. * indicates statistical significant between males and females.

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DISCUSSION

Here we investigated the prelanding NEMG of the hamstrings and quadriceps of recreational male and female athletes performing jump-landing tasks from two different heights. Our key findings are that: a) feedforward changes occur in the NEMG activity of the knee muscles when increasing the height of a landing task, and b) female athletes demonstrate higher recruitment of the medial hamstrings than their male counterparts.

While the quadriceps preactivates to a greater extent when increasing the jump height from 20 to 40 cm, the hamstrings may not follow the same pattern. This may create an imbalance in the anterior-posterior shear forces as the quadriceps cause anterior translation that is not counteracted by posterior translation forces of the hamstrings. It may have implications for the mechanism of injuries as ACL prevents anterior translation of the tibia (Amis, 2012). This finding is in agreement with previous studies reporting that in female athletes quadriceps activity but not hamstrings activity increases with increasing height during the prelanding (Ford, Myer, 2011) and landing phases (Peng, Kernozek, 2011). Thus, combining the findings of the present study with those of the previous two studies allows for a complete picture of the effect of increasing height on muscle activity; quadriceps activity increases prior to and during the landing phases but hamstrings activity remains unchanged in female and male athletes.

ACL injuries frequently occur immediately after landing and therefore muscle preactivation may be more effective in preventing excessive forces within the ACL than muscle recruitment after landing has initiated. Increased hamstrings muscle stiffness better resists

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anterior tibial shear forces which may in turn prevent ACL injuries (Blackburn et al. , 2013). Our findings are particularly important in light of evidence demonstrating that muscle preactivation during athletic maneuvers is modifiable. Through specific neuromuscular training it is possible to increase the activity of the semitendinosus muscle in the prelanding phase of athletic maneuvers (Zebis et al. , 2008).

The second finding is that female athletes demonstrate higher recruitment of the medial hamstrings. Previous research has suggested a multitude of factors that are different between males and females during the performance of athletic maneuvers and may explain the sex disparity; knee valgus angle and moment (Carson and Ford, 2011, Pappas et al. , 2007b), side to side asymmetries (Ford et al. , 2003, Pappas and Carpes, 2012), vertical ground reaction forces (Pappas et al. , 2007a) have been previously demonstrated to differ between males and females. The findings of the present study are in agreemnt with a recent study on 11-year old male and female soccer players (Kipp et al. , in press) that also reported that female athletes demonstrate higher preactivation of the medial hamstrings than males. This may be due to the higher knee laxity among females (Trimble et al. , 2002), which requires greater levels of hamstrings preactivation to avoid excessive anterior translation of the tibia in respect to the femur during landings tasks. Thus, it may be a protective mechanism among females who as a group are at higher risk for ACL injury than males.

The current methodological design has some limitations. EMG provides valuable information on mucle activation, however, it has inherent limitations. Probably the most important is that the information it provides on myolelectric activity cannot easily be translated to muscle force. Additionally, normalization methods vary widely between authors, therefore, limiting comparisons between studies. The bilateral landing task we tested is commonly used in

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biomechanical studies as it is easy to standardize, however, unilateral landings may more relevant for ACL injury. A study comparing unilateral and bilateral landings found that NEMG increases for quadriceps and hamstrings mucles during the unilateral tasks but in a similar pattern for males and females (Pappas, Hagins, 2007a). Thus, we speculate that even though the amplitude of NEMG would be higher during the prelanding phase from a unilateral landing, the effect of sex and height would probably be the same as in the current study. Finally, we only measured EMG of the dominant leg; side-to-side asymmetries in muscle activity may have provided additional, clinically-relevant information.

CONCLUSIONS

This study showed that increasing the height of drop landing tasks is associated with increased NEMG of the quadriceps but not the hamstrings in recreational athletes. Female athletes exhibited higher activity of the medial hamstrings compared to their male counterparts.

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Morgana is a last year Physiotherapy student at the Federal University of Pampa (Brazil). Her research interests include the neuromechanics of lower extremity, particularly in the prevention of knee injuries in sports involving jump-landing tasks. She is currently supported by a FAPERGS research fellowship. During the development of this research Morgana was the recipient of the International Travel Grant Program from the International Society of Biomechanics (ISB).

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Evangelos Pappas

Dr. Evangelos Pappas trained as a physiotherapist in Thessaloniki, Greece before pursuing a Master's in Orthopaedic Physical Therapy at Quinnipiac University and a PhD in Orthopaedic Biomechanics at New York University in the USA. Prior to coming to the University of Sydney, Dr. Pappas taught for 11 years at Long Island University-Brooklyn Campus in kinesiology, clinical decision making and musculoskeletal pathology and physiotherapy. His excellence in teaching was recognized by his nomination for the Newton award for excellence in teaching. Dr. Pappas joined the University of Sydney as a Senior Lecturer in 2013 where he continues to lecture in the areas of musculoskeletal physiotherapy, and particularly as it relates to the upper and lower extremities.

Dr. Pappas is also active in musculoskeletal research. His research has been funded by the National Institutes of Health and intramural grants. He has presented his work in more than 50 national and international conferences and he has been interviewed on the radio as an expert on knee injuries. His publications appear in top journals in the fields of physiotherapy, sports medicine and biomechanics. One of his publications received the T. David Sisk award for best review paper from "Sports Health"; a leading multidisciplinary journal in sports medicine. In addition, Dr. Pappas has served on the research subcommittee of the awards committee of the American Physical Therapy Association.

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Keywords: anterior cruciate ligament; knee injury; muscle activity; sport injury; EMG

Abstract: ACL tear is a major concern among athletes, coaches and sports scientists. More than taking the athlete away from training and competition, ACL tear is a risk factor for early-onset of knee osteoarthritis, and, therefore addressing strategies to avoid such injury is pertinent not only for competitive athletes, but for all physically active subjects. Imbalances in the prelanding myoelectric activity of the hamstrings and quadriceps muscles have been linked to ACL injuries. We investigated the effect of landing from different heights on prelanding myoelectric activity of the hamstrings and quadriceps muscles in recreational athletes. Thirty recreational athletes (15 male and 15 female) performed three bilateral drop jumps from two different heights; 20 cm and 40 cm while myoelectric activity of the vastus medialis, rectus femoris, biceps femoris and medial hamstrings were collected. When increasing the height of drop landing tasks prelanding normalized myoelectric activity of the quadriceps was increased by 15-20% but no significant changes were found for the hamstrings. Female athletes exhibited higher activity of the medial hamstrings compared to their male counterparts. We concluded that increasing the height of drop landing tasks is associated with increased myoelectric activity of the quadriceps but not the hamstrings in recreational athletes. These differences in muscle activity may be related to increased risk for ACL injury when the height is increased. Female athletes demonstrated higher recruitment of the medial hamstrings.

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