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Timing of neuromuscular activation of the quadriceps and hamstrings prior to landing in high school male athletes, female athletes, and female non-athletes

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Abstract

There is a discrepancy between males and females in regards to lower extremity injury rates, particularly at the knee [Agel, J., Arendt, E.A., Bershadsky, B., 2005. Anterior cruciate ligament injury in National Collegiate Athletic Association basketball and soccer: a 13-year review. American Journal of Sports Medicine 33, (4) 524–530]. Gender differences in neuromuscular recruitment characteristics of the muscles that stabilize the knee are often implicated as a factor in this discrepancy. There is considerable research in the area of gender differences in regards to neuromuscular characteristics of the lower extremity in response to perturbation; however, most studies have been performed on the adult population only. Additionally, there is no consensus as to the gender differences that have been demonstrated. The purpose of this study was to compare muscular preactivation of selected lower extremity muscles (vastus medialis, rectus femoris, and medial/lateral hamstrings) in adolescent female basketball athletes, male basketball athletes, and female non-athletes in response to a drop landing. Subjects in the female non-athlete group recruited rectus femoris significantly slower than both the female athlete and male athlete groups (619.9 = 588.5 > 200.1 ms prior to ground contact). The female non-athlete group also demonstrated a significantly slower vastus medialis compared to the female athlete group (127.1 vs 408.1 ms), but not significantly slower than the male athlete group (127.1 vs 275.7 ms). There were no differences between female athletes and male athletes for time to initial contraction of any muscle groups. No differences were found among the groups for medial or lateral hamstring activation. This study demonstrates that physical conditioning due to basketball participation appears to affect neuromuscular recruitment in adolescents and reveals a necessity to find alternate methods of training the hamstrings for improved neuromuscular capabilities to prevent injury.

Keywords: Adolescent; Electromyography; Gender; Landing

1. Introduction

Since the passing of Title IX in 1972, the participation of women in sports has increased over 600% (Arendt et al., 1999). Over the past 25 years, there has been a direct relationship between the number of females participating in athletics and the number of reported serious sports-related injuries suffered by female athletes (Arendt et al., 1999). Traumatic knee injury, particularly to the anterior cruciate ligament (ACL), is particularly high in females athletes as compared to male athletes (Arendt and Dick, 1995; Ireland et al., 1997). A majority of these injuries are non-contact in nature, many of which occur in response to a cutting

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maneuver or during an uncontrolled landing from a jump (Arendt et al., 1999).

There has been a considerable push to understand the factors that may predispose females to non-contact ACL injuries. Several intrinsic and extrinsic factors have been examined in order to explain this discrepancy. No specific difference between genders has been identified to explain all contribution to the greater incidence of lower extremity injuries in females (Griffin et al., 2000), however, the neuromuscular function of the muscles that control the hip and knee during functional tasks is a particular extrinsic factor that has gained attention. Previous studies have examined the purported differences between males and females in regards to muscular performance and earlier activation of the quadriceps (Huston and Wojtys, 1996; Malinzak et al., 2001; Shultz et al., 2001), a conclusion that females may be quadriceps dominant (Hewett et al., 2001; Malinzak et al., 2001), how these may relate to ACL injury Griffin et al., 2000; Ireland et al., 2003, 1997; McClay Davis and Ireland, 2001), and the potential to alter these characteristics to reduce the risk of injury (Hewett et al., 1996, 1999, 2001, 2002, 2005).

An accommodation strategies paradigm has been proposed to model the relationship between a stressor and the body's response to accommodate that stressor (James et al., 2003). The body's accommodation strategies are in place to help maintain system homeostasis and to prevent injury (James et al., 2003; Riemann and Lephart, 2002a). Two different mechanisms are utilized by the individual to prevent injury. The first is a feedback mechanism, which is a reflexive response that occurs after sensory detection of the perturbation (Riemann and Lephart, 2002a). This mechanism is to identify changes that affect the system and to provide corrections. However, the feedback mechanism alone is not fast enough to provide stability and prevent collapse (Loeb and Ghez, 2000). There is also a feedforward mechanism, an anticipatory effect that occurs before sensory detection of the perturbation (Riemann and Lephart, 2002a). When the system is perturbed, there is preparatory contraction of the muscles to stiffen the joints, a protective response to prevent injury (Loeb and Ghez, 2000; Riemann and Lephart, 2002a,b). The preparatory contraction also provides stability and control of joint moments to prevent collapse, which is a performance response (Horita et al., 2002; Loeb and Ghez, 2000; Riemann and Lephart, 2002b). The overall effect of these mechanisms is efficient neuromuscular control and joint stability (Loeb and Ghez, 2000; Riemann and Lephart, 2002a).

At the knee, neuromuscular recruitment patterns and recruitment velocity of the thigh muscles play a role in providing stiffness and dynamic stability at the knee (Solomonow et al., 1988). There is a preparatory and reflexive co-contraction of the quadriceps and hamstrings to stiffen the area around the joint to prevent injury (Baratta et al., 1988). The preparatory action is the neuromuscular activity before foot contact, while reflexive action is the activity after foot contact. There is a need for efficient neuromuscular control of the thigh muscles to create this dynamic joint stiffness and protective stability. There are numerous studies evaluating the neuromuscular differences between males and females. In these studies, females demonstrated muscular recruitment characteristics that may be predispositions to ACL injury, including preferential recruitment of the quadriceps over the hamstrings (Huston and Wojtys, 1996), shorter latency periods of the quadriceps (Shultz and Perrin, 1999), less muscular stiffness of the thigh muscles (Horita et al., 2002), and unbalanced quadriceps-to-hamstrings strength ratios (Hewett et al., 1996).

These previous studies that compared male and female neuromuscular capabilities have reported conflicting results. Additionally, these studies were performed on college-aged subjects. Our study was limited to a sample of male and female scholastic-age subjects and intended to identify muscular recruitment timing prior to ground contact. The purpose of our study is to compare time of initial contraction of the quadriceps and hamstrings in high school female athletes (FA), male athletes (MA), and female non-athletes (FNA) in response to a controlled landing. Female non-athletes were included in this study for comparison to female athletes and to control for training, as several studies have identified that neuromuscular training can alter performance characteristics and ACL injury rates in female athletes (Caraffa et al., 1996; Holm et al., 2004; Mandelbaum et al., 2005; Myer et al., 2006; Myklebust et al., 2003; Paterno et al., 2004). Muscle activity of the quadriceps and hamstrings was recorded by surface electromyography (sEMG) to determine recruitment order and time of initial contraction in preparation of landing from a platform. We hypothesize that the FA group and MA group would have significantly different muscular recruitment patterns and time to initial contraction of the thigh muscles when compared to each other, and also when compared to the FNA group. Specifically, it is hypothesized that female athletes will demonstrate neuromuscular characteristics that potentially predispose female athletes to knee injury.

2. Methods

2.1. Subjects

Fifty-seven, healthy high school students participated in this study which was approved by the Institutional Review Board of the Arizona School of Health Sciences (IRB). Subjects were assigned to one of three groups based on inclusion and exclusion criteria. Means and standard deviations for the group demographics were: FA [$n = 18$, age $= 14.8 \pm 1.1$ yrs, ht $= 165.4 \pm 9.4$ cm, wt $= 57.3 \pm 8.1$ kg], MA [$n = 19$, age $= 14.9 \pm 0.8$ yrs, ht $= 182.6 \pm 6.2$ cm, wt $= 77.9 \pm 11.0$ kg], and FNA [$n = 20$, age $= 15.7 \pm 1.3$ yrs, ht $= 160.7 \pm 6.9$ cm, wt $= 58.4 \pm 9.2$ kg].

Inclusion criteria for the FA and MA groups required that each subject was a participating member of the high school freshman, junior varsity, or varsity basketball teams. Exclusion criteria required that each subject had no reported history of serious knee injury, and was free from any acute injury to the back or lower extremity for at least two weeks prior to testing. It was also required that subjects have no history of participation in any type of ACL injury prevention program. Exclusion criteria for the FNA group followed these same criteria. Additionally, it was required that the FNA subjects must not have participated in an organized exercise program or had not exercised on a regular basis in the last two years. This included any self-directed exercise program, such as jogging, running, hiking, swimming, or weight room/fitness center activities. Subjects who met the inclusion and exclusion criteria were asked to participate. The subjects who agreed received an informed consent, also approved by the IRB for use in this study. For subjects under the age of 18, a parent/guardian co-signed the consent form.

2.2. Instrumentation

The EMG data was collected from four muscles: rectus femoris (RF), vastus medialis (VM), lateral hamstrings (LH), and medial hamstrings (MH) of each subject's right leg. The skin over the bellies of these muscles was prepared for electrode placement by shaving and cleaning the area with 70% isopropyl alcohol. Self-adhesive Ag/AgCl bipolar, dual surface electrodes (Noraxon USA, Inc., Scottsdale, AZ) were placed over the preparation sites in line with the muscle fibers. The electrodes were 4 cm × 2.2 cm with an interelectrode distance of 2 cm. A single reference electrode was placed over the tibial tuberosity. The electrodes were attached to leads pre-amplified with the high-pass filter set at 10 ± 1 Hz of the cutoff. The data were collected at 1000 Hz by a MyoSystem 1400 Surface EMG System (Noraxon USA, Inc., Scottsdale, AZ). The test was carried out for 6 s to allow for five full seconds of data collection and the data smoothed by taking the root mean square with a 20 ms window. The time to initial contraction was based on two standard deviations above baseline, as previously described (Shultz et al., 2000, 2001) that was recorded during the quiet period before the drop jump. A force-sensitive foot-switch was attached to the sole of the subject's right shoe at the head of the 1st metatarsal and the heel, and footswitch information was processed by a Norswitch System Contact Switch (Noraxon USA, Inc., Scottsdale, AZ) which was synchronized to the EMG system. The footswitch was used to determine initial ground contact and onset of muscle activity for each trial was referenced to that point of initial ground contact. Initial ground contact was the defined as the initial instant in time when the testing foot first came into contact with the ground.

2.3. Procedures

A previously described testing protocol (Devita and Skelly, 1992) was used in the collection of the landing data. The subject stood in a balanced position near the front edge of the 32 cm platform with the foot of the testing leg completely off the platform and suspended over the floor with the heel of that foot resting against the front of the platform (Fig. 1). This placed the subject's center of mass as far forward as possible in an attempt to limit horizontal motion. The subject's weight was supported fully on the platform by the non-testing leg. To initiate movement, the subject weight-shifted forward and dropped vertically, while attempting to land in a balanced position on the testing leg. Subjects were instructed to 'fall' from the platform without jumping or lowering their body prior to leaving the platform. At landing, the subject held that position for five seconds (Fig. 2).

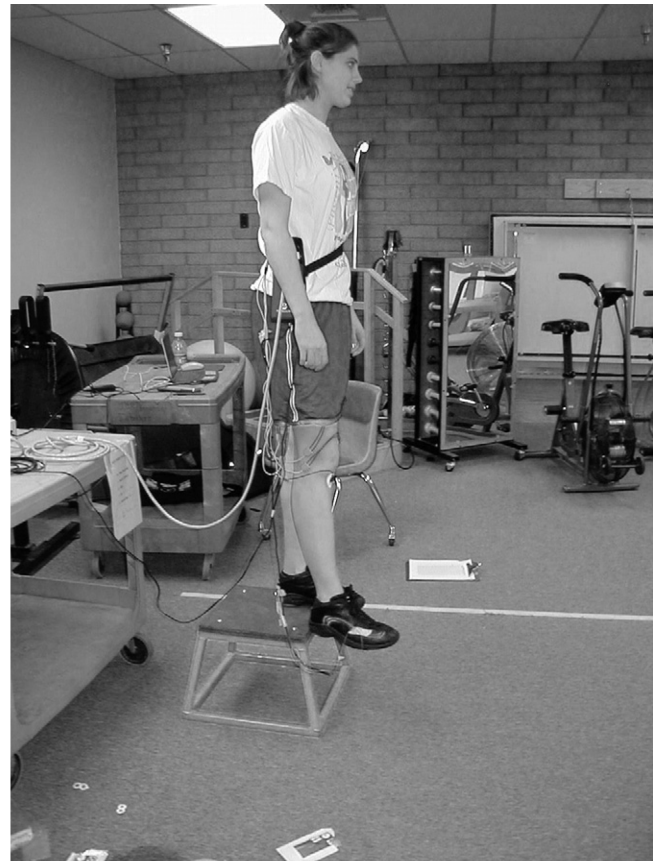

Fig. 1. The initial position for the drop landing procedure.

The subject was allowed to practice the technique until the movement could be performed appropriately and consistently. At beginning of each trial, with the subject in position, a quiet period during which there was no discernable muscle activity was recorded and used as baseline. Each subject performed three trials, which were visually monitored to assure that the technique was performed correctly. Failed trials were discarded and repeated. For each subject, the two trials with least variation were averaged for data analysis.

2.4. Statistical analysis

A mixed model repeated measures analysis of variance, with group (FA, MA, and FNA) membership as the between-subjects factor and muscle (VM, RF, MH, and LH) as the within-subjects factor was performed using SPSS (version 10.0 for Windows; SPSS, Inc., Chicago, Il). Tukey's post-hoc analyses were on performed on significant findings. All analyses were performed at the α-level of $P < .05$.

3. Results

We observed a significant group by muscle interaction ($P < .001$). Subjects in the FNA group recruited RF significantly later than both the FA and MA groups (200.1 ± 75.3 vs 619.8 ± 79.3 and 588.5 ± 77.3 ms prior to ground contact). All results are presented as means ± SEM. The FNA group also demonstrated a significantly later VMO compared to the FA group

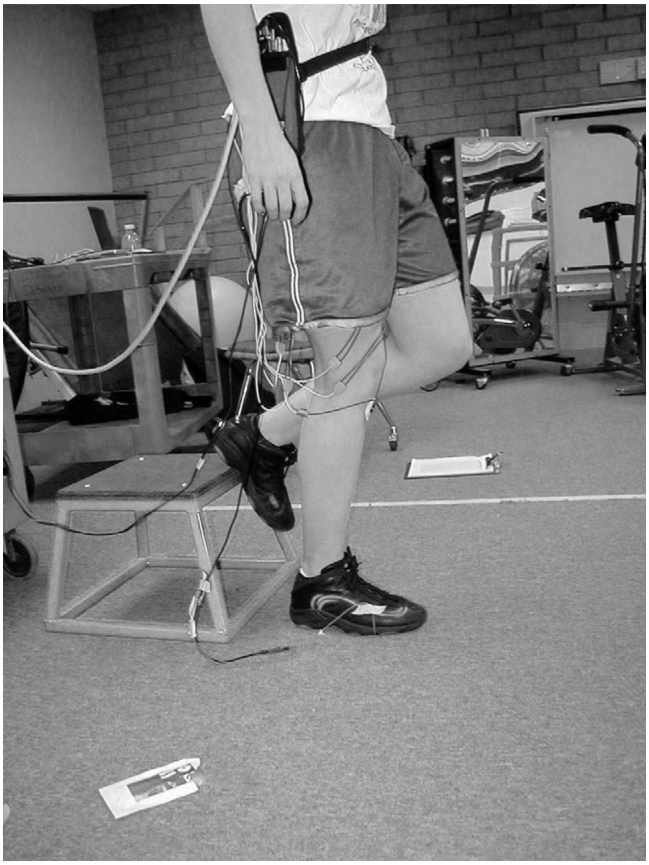

Fig. 2. The final position for the drop landing task.

(127.1 ± 48.6 vs 408.1 ± 51.1 ms prior to ground contact), but not significantly later than MA.

Significant main effects were also found for group ($P < .001$) and muscle ($P < .001$). The MA and FA groups demonstrated an overall earlier muscle activation than the FNA group prior to ground contact (269.5 ± 31.8 and $297.3 \pm 32.7 > 109.1 \pm 31.0$ ms). Post-hoc analysis of the main effect for muscle demonstrated earlier RF activation compared to VM, MH, LH and earlier VM activation compared to MH and LH prior to ground contact ($469.5 \pm 44.7 > 270.3 \pm 28.8 > 79.5 \pm 15.7 = 82.0 \pm 15.2$ ms). No differences were found between groups for MH or LH activation. All results are detailed in Fig. 3.

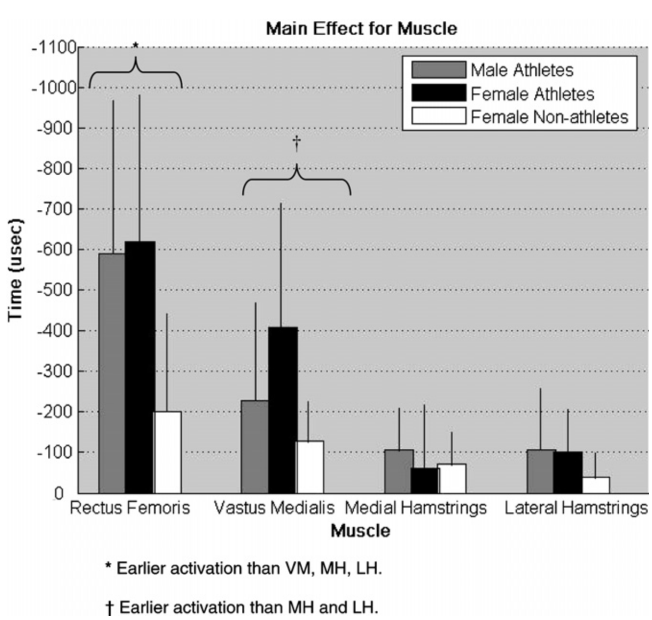

Fig. 3. Individual results of the group by muscle interaction and the main effects for muscle group are presented.

4. Discussion

The purpose of this study was to compare neuromuscular characteristics of the muscles that stabilize the knee in response to a controlled landing in male athletes, female athletes, and female non-athletes. It was hypothesized that the FA group and MA group would have significantly different muscular recruitment patterns and time to initial contraction of the thigh muscles when compared to each other, and also when compared to the FNA group. These hypotheses were based on the conflicting results of several studies (Griffin et al., 2000; Hewett et al., 2001, 1996; Horita et al., 2002; Huston and Wojtys, 1996; Ireland et al., 1997, 2003; Malinzak et al., 2001; McClay Davis and Ireland, 2001; Shultz and Perrin, 1999; Shultz et al., 2001) that examined muscle activation patterns for stabilization at the knee.

Our hypothesis that MA and FA would exhibit earlier time of initial contraction than FNA was confirmed. Both the MA and FA groups recruited RF significantly earlier in relation to initial ground contact than the FNA group. Our results support pre-existing theories that training will result in earlier muscle activation (Chimera et al., 2004; Hewett et al., 1999; Wilkerson et al., 2004). We conclude that it is likely that physical conditioning for basketball improves the neuromuscular response time of RF, as there were no statistical differences seen between male athletes and female athletes, and both athlete groups recruited the RF significantly faster than the FNA group. These findings do differ from studies of reflexive neuromuscular activation in response to landing or a perturbation that have found females tend to activate the quadriceps earlier than males (Huston and Wojtys, 1996; Malinzak et al., 2001; Shultz et al., 2001). Due to the nature of the game, training for basketball may improve the preactivation capabilities of the quadriceps, resulting in a quicker anticipation of landing and recognition of the stabilization needed to protect the knee upon landing, while leaving the hamstrings relatively unconditioned.

We also observed a difference among the three groups in regards to the VM. FA demonstrated a significantly faster time to initial contraction of the VM compared to FNA. FA also demonstrated a faster time to initial contraction of the VM when compared to MA, however this difference was not significant. MA demonstrated a faster time to initial contraction compared to FNA; this difference was also not significant. This was the only observed difference between the male and female athlete groups. Previous studies have concluded that males and females diverge in their neuromuscular capabilities during adolescence (Hewett et al., 2004) and that collegiate males and females rely on different techniques for stabilizing the knee in response to perturbation (Shultz and Perrin, 1999). After the growth spurt, it had been proposed that males tend to improve in strength and coordination, while females do not "recover" from growth spurt awkwardness (Hewett et al., 2004). The difference in VM preactivation times among our three was the only observation which may support the theory of diverging knee stabilization strategies. Whether the differences seen in our study between the FA and MA groups in regards to VMO contraction are actually the result of developmental differences is unknown.

No significant difference was observed by group or muscle in regards to the LH and MH muscles which also may be a result of the nature of conditioning for basketball. Basketball requires considerable concentric and eccentric activity of the quadriceps, while requiring relatively little work from the hamstrings and leaving that muscle group untrained by comparison. By testing only basketball athletes, there is the possibility that the results are a consequence of the type of athlete tested, and that athletes from another sport may have different results. Further research must be conducted to determine how the nature of certain sports contributes to the overtraining of certain muscle groups and how that affects injury rates. EMG testing of the thigh muscles in athletes in other sports may provide additional insight.

Our hypothesis that male and female athletes would demonstrate different recruitment patterns when compared to female non-athletes was not confirmed. All groups demonstrated the same recruitment patterns. There was no difference among the groups in regards to muscle activation pattern; all groups preactivated the quadriceps first. In the post-hoc between-muscle comparison, we observed that RF was activated significantly faster than all other muscle groups, and that VM was activated significantly faster than the LH and MH groups. The testing protocol has been used previously (Devita and Skelly, 1992) and also allowed for standardized testing procedures; however, it is possible the testing protocol put the quadriceps at a mechanical advantage, resulting in shorter time-to-initial-contraction for that muscle group. In the starting test position, the quadriceps may have been slightly preshortened; this could decrease the response time for the quadriceps (Trontelj, 1993) and the muscle group would have the ability to contract earlier.

5. Limitations

Based on the results of this study, it seems that physical conditioning may improve pre-landing recruitment response. We also conclude that neuromuscular and kinematic differences between males and females as seen in other studies may be due to factors other than preactivation of the stabilizing musculature. Time to muscle preactivation alone is probably not a risk factor for ACL injury in physically conditioned female athletes; the female ACL injury epidemic is most likely multi-factorial (Huston et al., 2000). While we can comment on the time to initial contraction, we cannot make any conclusions about the magnitude of the muscular responses. There may be considerable differences in the strength of contraction for each muscle and this was not controlled for in this study. Time to muscle contraction that actually imposes a counteracting force on the torques associated with landing could not be determined based on the data collection strategies utilized in this study. This study only looked at the preactivity of the muscles in response to landing, however future studies should include measures of amplitude to identify whether the magnitude of activation differs between groups or sports.

6. Conclusions

While it has been proposed that neuromuscular characteristics may, in part, explain the discrepancy of ACL injury rates between males and females, the similarities between MA and FA in regard to muscle activation times in our study can not alone explain the vast differences in the incidence of ACL injury in females as compared to males. It is unknown whether the earlier, however, non-significant preactivation of the VM witnessed in the FA group would place more stress on the ACL and therefore explain, in part, the discrepancy in ACL injury incidence in regards to gender.

6.1. Clinical significance

One goal of research in this area is to establish a potential causal relationship between neuromuscular characteristics and the increased incidence of ACL injuries in females. Amongst the intrinsic and extrinsic factors that are often used to explain the increased rate of knee injuries in females, neuromuscular performance is a factor that may be potentially altered and improved (Hewett et al., 1999; Wilkerson et al., 2004). To implement effective ACL injury prevention programs, a full understanding of the problem is needed. This study does demonstrate the potential for improving reaction time before the actual landing as physical conditioning appears to affect neuromuscular recruitment in adolescents. It also reveals a necessity to find alternate methods of training the hamstring muscles for improved neuromuscular capabilities as they were apparently not affected by conditioning for scholastic basketball. Directed conditioning of the hamstrings in order to prevent ACL injuries seems efficacious.

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