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Gender differences exist in neuromuscular control patterns during the pre-contact and early stance phase of an unanticipated side-cut and cross-cut maneuver in 15–18 years old adolescent soccer players

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Abstract

Non-contact ACL injuries generally occur as the foot contacts the ground during cutting or landing maneuvers and the non-contact ACL injury rate is 2–8 times greater in females compared to males. To provide insight into the gender bias of this injury, this study set out to identify gender differences in the neuromuscular response of the quadriceps, hamstrings and gastrocnemii muscles in elite adolescent soccer players during the pre-contact and early stance phases of an unanticipated side-cut and cross-cut. For the early stance phase of the two maneuvers, females demonstrated greater rectus femoris activity compared to males. Throughout the pre-contact phase of the maneuvers, a rectus femoris activation difference was identified with females having an earlier and more rapid rise in muscle activity as initial ground contact approached. Females demonstrated greater lateral and medial gastrocnemii activity for the pre-contact and early stance phases of the side-cut and greater lateral gastrocnemii activity during early stance of the cross-cut. Timing of hamstring activity also differed between genders prior to foot contact. The differences suggest that the activation patterns observed in females might not be providing adequate joint protection and stability, thereby possibly having a contributing role towards increased non-contact ACL injuries in females.

Keywords: Anterior cruciate ligament (ACL); Injury; Electromyography (EMG); Gender; Pre-contact; Early stance; Side-cut; Cross-cut; Unanticipated

1. Introduction

The primary function of the anterior cruciate ligament (ACL) is to resist anterior translation and internal rotation of the tibia with respect to the femur (Markolf et al., 1995). The ACL influences overall knee joint function and stability and injury to this ligament most often occurs while performing a dynamic landing, a fast deceleration or a quick change in directions during intermittent sports such as soccer, basketball, volleyball or handball (Boden et al., 2000; Olsen et al., 2004). The event leading up to the injury is generally unanticipated in nature, with the athlete distracted and having to make split second decisions (i.e. throwing/catching a ball or avoiding an opposing player) prior to executing the actual landing or change in direction. Approximately 70–80% of all ACL injuries involve no physical contact or direct blow to the knee at the time of injury (Noyes et al., 1983) and females unfortunately have a non-contact ACL injury rate 2–8 times higher than their male counterparts (Arendt and Dick, 1995; Malone et al.,

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1993). Using the motion laboratory to analyze landing or cutting maneuvers and comparing the biomechanics and neuromuscular response between genders provides the opportunity of identifying non-contact ACL risk factors. Light guiding systems in the laboratory have also become more common and these lights force athletes to make last second decisions as to which direction to cut in the laboratory, better simulating the unanticipated nature of a true game-like scenario where the ACL is most likely to be injured (Besier et al., 2001, 2003; Ford et al., 2005; Pollard et al., 2004).

Studies addressing the biomechanics and neuromuscular response of muscles crossing the knee joint have tended to focus more on the stance phase and less on the pre-contact phase of cutting maneuvers (Ford et al., 2005; Landry et al., 2007b,c; Malinzak et al., 2001; McLean et al., 1999; Pollard et al., 2004; Sigward and Powers, 2006). Because the ACL is usually injured in early stance just after initial contact with the ground (Boden et al., 2000), focusing on the neuromuscular response and differences between genders for the period of time just prior to initial contact and during early stance should provide valuable information towards understanding both the non-contact mechanisms of ACL injuries and the gender bias associated with this injury.

A few studies have reported on the neuromuscular response of the lower limb muscles prior to foot contact for a side-cut maneuver; however, no comparisons between males and females have been made in any of these studies (Bencke et al., 2000; Besier et al., 2003; Colby et al., 2000; Simonsen et al., 2000). Zazulak et al. (2005) analyzed the pre-contact phase of a pre-planned landing maneuver and demonstrated that females had greater rectus femoris activity than males. Studies focusing on the early stance phase of cutting maneuvers are also sparse, with Sigward and Powers (2006) having one of the only studies to compare quadriceps and hamstrings activity between genders during the early stance phase (first 20% of stance) of a side-cut maneuver. While no differences between genders were reported for hamstring activity, the female athletes did have greater average quadriceps activity, normalized to maximum voluntary contractions (MVC), in comparison to the male athletes. Higher quadriceps activity is a proposed risk factor for ACL injuries because contracting the quadriceps at flexion angles less than approximately 45° can actually increase ACL strain (Arms et al., 1984).

Using elite adolescent male and female soccer players, the purpose of this study was to make gender comparisons of muscle activation waveforms for the three main muscle groups crossing the knee joint (quadriceps, hamstrings and gastrocmemii) during the pre-contact and early stance phase of an unanticipated side-cut and cross-cut maneuver. It was hypothesized that differences in the amplitude and timing of neuromuscular activity would be identified between the male and female athletes. In addition to gender differences, medial–lateral muscle site differences for each of the three muscle groups were also evaluated. The overall objective was to relate the identified differences to potential ACL injury risk factors, thereby helping to improve upon the current understanding as to why females are more prone to ACL injuries than their male counterparts.

2. Methods

2.1. Subjects

Twenty-one healthy male and 21 healthy female elite adolescent soccer players from the Nova Scotia Canada Games and Provincial youth soccer teams participated in this study. The means and standard deviations of age, height and body mass for the males were 17.0 ± 0.6 years, 1.77 ± 0.05 m, 69.6 ± 6.6 kg, respectively, and for the females were 16.7 ± 1.0 years, 1.65 ± 0.07 m, 60.8 ± 5.5 kg, respectively. All participants were required to be injury free at the time of testing and could not have sustained a previous major injury to either lower limb. Written consent was attained from all subjects and their respective guardians prior to testing, with ethical approval granted by the Research Ethics Board for Health and Medical Sciences at Dalhousie University.

2.2. Experimental design

A three-dimensional (3D) motion and electromyographic (EMG) analysis of the right leg was performed on three unanticipated running and cutting maneuvers in the human motion laboratory, with this article focusing on the pre-contact and early stance EMG data of the side-cut and cross-cut maneuvers only. The side-cut was performed by planting the right leg on the force platform and cutting to the left at 35–60° from the direction of approach and the cross-cut was performed by planting the right leg on the force platform and cutting to the right at 35–60° from the direction of approach, with the approach speed controlled at 3.5 ± 0.2 m/s for both maneuvers. Subjects had approximately 0.5 s to react to a 3-light guiding system that randomly cued the subjects to execute the maneuvers in an unanticipated manner. Testing continued until five trials were deemed acceptable for each maneuver based on the approach speed, cutting angle and the subject's right leg landing entirely on the force platform. Testing was performed in lycra shorts and indoor/turf soccer shoes and an ultra-thin stretchable stocking was also placed over the right leg to prevent damage and entanglement of the EMG electrode and infrared marker wires. The EMG data was captured with an eight channel surface AMT-8 EMG system (Bortec, Inc. Calgary, AB, CA) and stance information was obtained using an AMTI force platform (Advanced Medical Technology Inc. Watertown, MA, USA).

Using standardized placements measured from specific anatomical landmarks, silver/silver-chloride pellet surface electrodes (0.79 mm^2 contact area, Bortec, Inc. Calgary, AB, Canada) were attached in a bipolar configuration

(20 mm center-to-center) along the direction of the muscle fibers on shaven and alcohol cleaned skin surfaces. Electrodes were placed over the lateral gastrocnemius (LG), medial gastrocnemius (MG), rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (LH) and semitendinosus (MH), with a reference electrode placed on the tibial shaft (Hubley-Kozey et al., 2006). The raw EMG signals were captured at 1000 Hz, pre-amplified (500 times) and further amplified (bandpass 10–1000 Hz, CMRR = 115 dB (at 60 Hz), input impedance ~10 GΩ).

The pre-contact phase was defined as the 100 ms prior to foot contact and this was based on previous pre-contact EMG studies (Bencke et al., 2000; Besier et al., 2003; DeMont et al., 1999; DeMont and Lephart, 2004; Zazulak et al., 2005) and on the electromechanical delay between EMG activity and the development of muscle tension being less than 100 ms (Cavanagh and Komi, 1979). The early stance phase was represented as the first 20% of stance, similar to the work by Sigward and Powers (2006).

To amplitude normalize the EMG data collected during the cutting maneuver trials, maximum voluntary contractions (MVC) were captured after completing the maneuvers. It has been suggested that if the goal of a study is to provide information on the degree of muscle activity, then normalizing to an isometric MVC should be chosen over other methods such as the isokinetic MVC, mean or peak dynamic methods (Burden et al., 2003). While MVC normalizing EMG data can reduce the variability in the data and can allow one to compare the degree of activity between groups, it continues to be debated as to whether this technique is appropriate (Clarys, 2000; Yang and Winter, 1984). Some authors have warned against using isometric MVC normalizing techniques because for various sporting activities, you can obtain activation levels greater than 100% of the MVC (Clarys, 2000). Despite some limitations noted in the literature, however, the isometric MVC normalizing protocol was deemed to be most appropriate in this study for making gender comparisons between the muscle activation patterns during the two cutting maneuvers.

The series of isometric MVCs included extending the knee at 45° lying supine for the VL and VM, flexing the knee at 45° (supine) and 55° (prone) for the LH and MH, simultaneously flexing the hip at 90° and extending the knee at 45° to isolate the RF and plantar-flexing the ankle while standing and lying supine for the LG and MG. All MVCs were performed on a Cybex dynamometer (Lumex, Inc. Ronkonkoma, NY, USA), with the exception of the resisted standing heel rise. Each exercise was repeated twice and subjects were coached to produce a sustained and smooth maximum effort for 3 s.

2.3. Data processing and statistical analysis

All EMG data was bias corrected, converted to μV, full-wave rectified and low pass filtered at 6 Hz using a zero lag 4th order Butterworth filter in Matlab (The MathWorks, Inc. Natick, MA, USA). A 100 ms moving window algorithm identified maximum EMG amplitudes for each muscle individually from the MVC normalization exercises and these maximums were then used to amplitude normalize the cutting EMG data (Hubley-Kozey et al., 2006). Ensemble average waveforms for a subject's seven muscle sites were obtained by averaging three to five trials for each of the running and cutting maneuvers. The 100 ms pre-contact phase and early stance (first 20%) phase for every subject's ensemble average waveforms were represented separately by 101 data points.

The ensemble average EMG waveforms were analyzed using the multivariate analysis technique of Principal Component Analysis (PCA), which has emerged as a popular and proven tool for analyzing biomechanical (Deluzio et al., 1997; Landry et al., 2007a; Wrigley et al., 2005) and neuromuscular (Hubley-Kozey et al., 2006; Wootten et al., 1990) waveform data. For both the pre-contact and early stance phases of each maneuver, four separate PC analyses were carried out on the waveform data with both gender and medial–lateral muscle site comparisons being performed on the gastrocnemii (LG and MG), hamstrings (LH and MH) and quadriceps (VL and VM) and only gender comparisons being performed on the RF. PCA can be summarized as a technique that uses the variability in an original set of waveform data to orthogonally transform the data into a new data set where waveform features such as local maximums, overall waveform magnitudes, amplitudes and phase shifts (timing) can be identified simultaneously. Each individual waveform in the analysis gets scored (PC score) based on the similarity it has to the specific waveform features identified using PCA and then statistical comparisons are carried out on these PC scores.

For the two cutting maneuvers, Student *t*-tests were used to test for gender differences ($p < 0.05$) in the PC scores of the RF activation waveforms for both the pre-contact and early stance phases. A 2-factor mixed-model ANOVA with Tukey adjusted post-hoc pairwise comparisons was used to simultaneously test for gender (between group) and medial–lateral site (within group) differences in the PC scores of the quadriceps (VL and VM), hamstrings (LH and MH) and gastrocnemii (LG and MG) muscle groups for the two phases of the two maneuvers. All statistical tests were performed in Matlab and Minitab (Minitab, Inc. State College, PA, USA).

3. Results

The male and female EMG ensemble average waveforms, expressed as a percent of MVC, show both the pre-contact and early stance phases of the cutting maneuvers in Figs. 1 and 2. In all the ensemble average plots, the pre-contact phase is expressed in ms and the early stance phase is expressed as percent stance. For plotting purposes, the early stance phase was scaled appropriately

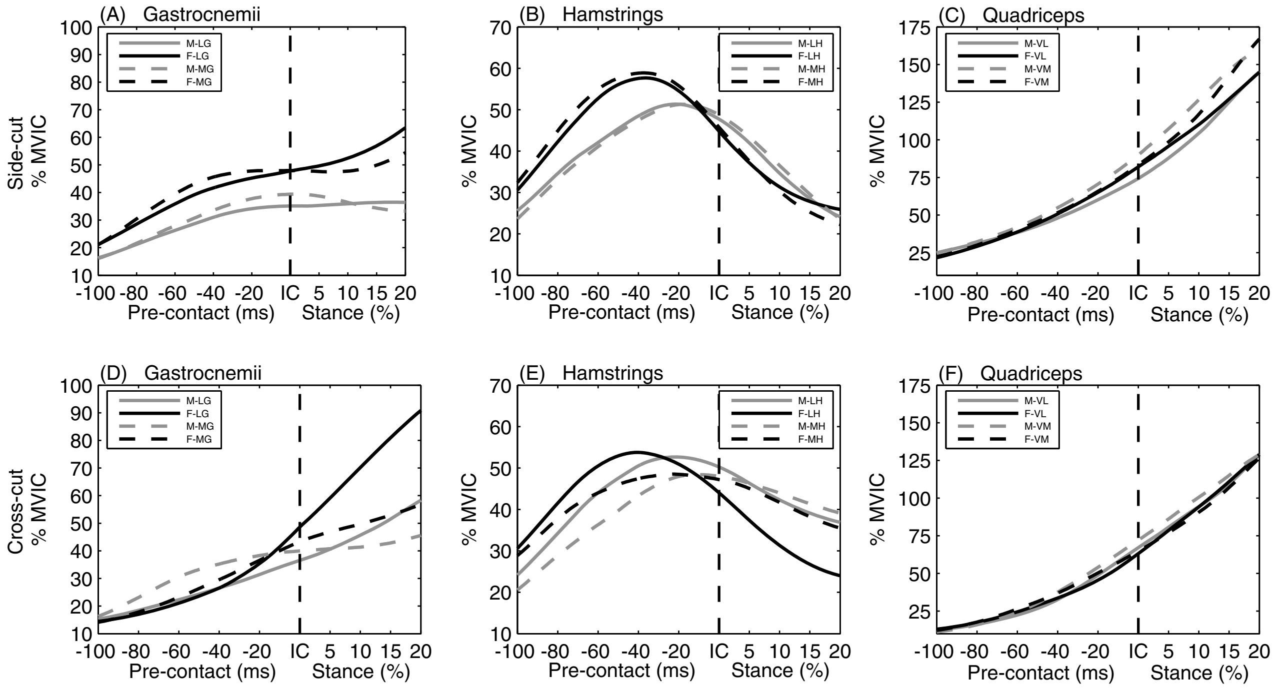

Fig. 1. Male (M) and female (F) mean activation waveforms for the gastrocnemii, hamstrings and quadriceps showing the pre-contact and early stance phases of the two cutting maneuvers. Side-cut waveforms (A–C) plotted in first row and cross-cut waveforms (D–F) plotted in second row, with gastrocnemii (LG and MG) along first column (A and D), hamstrings (LH and MH) along second column (B and E) and quadriceps (VL and VM) along third column (C and F) for both maneuvers. Pre-contact phase expressed in ms (−100 ms to instant of contact (IC)) and early stance phase expressed as % stance (IC to 20%).

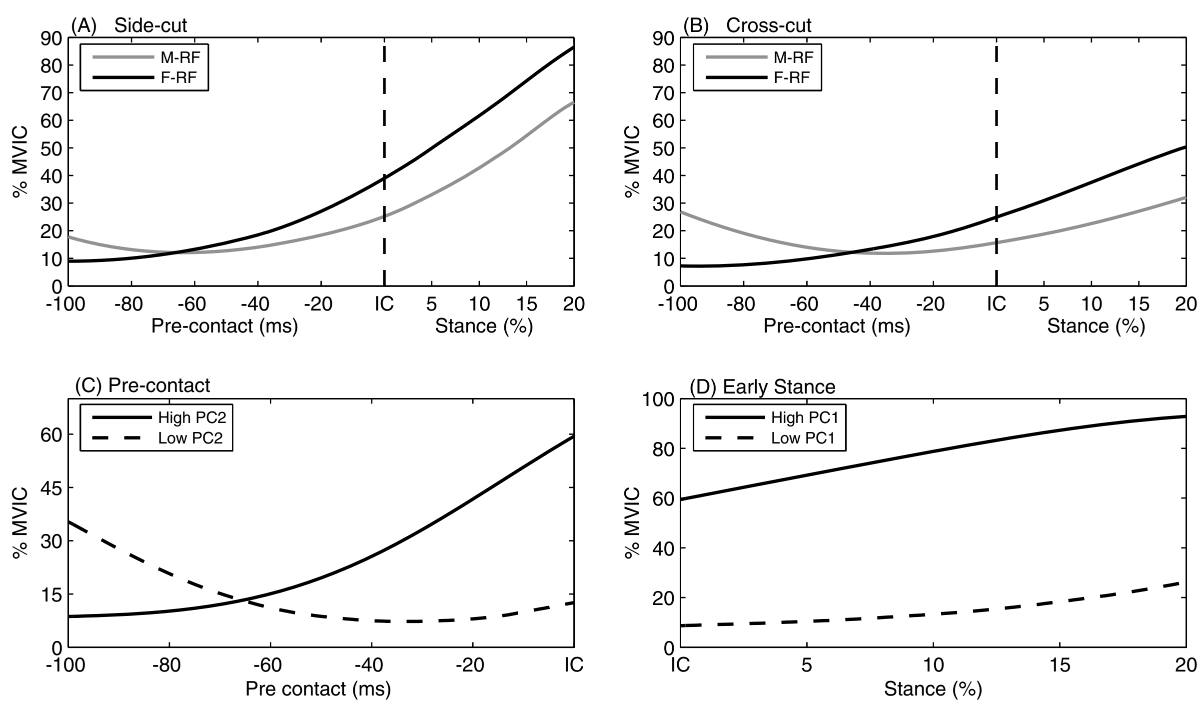

Fig. 2. Male (M) and female (F) mean activation waveforms for the RF showing the pre-contact and early stance phases of the two cutting maneuvers and waveforms of individuals with high and low PC1 and PC2 scores. Mean RF activation waveforms for the side-cut (A) and cross-cut (B). Pre-contact RF waveforms for an individual with a high and low PC2 score (C). Early stance waveforms for an individual with a high and low PC1 score (D).

in the plots to visually coincide with the pre-contact phase. For both the pre-contact and early stance phases of the cutting maneuvers, the first two PCs from each muscle group analysis (gastrocnemii, hamstrings, quadriceps and RF) explained a minimum of 97.6% of the total variance in the amplitude and timing (phase shift) of the muscle activa-

Table 1
Gender and medial–lateral muscle site comparisons of gastrocnemii muscle activation PC waveforms for the pre-contact and early stance phase of the cutting maneuvers

Maneuver	PC	Feature described by PC	Pre-contact phase				Early stance phase			
			Gender comparison *p*-value		Med–Lat site comparison *p*-value		Gender comparison *p*-value		Med–Lat site comparison *p*-value	
Side-cut	PC1	Amplitude	Med site	**0.04**	Male	0.95	Med site	**0.007**	Male	0.99
			Lat site	**0.03**	Female	0.87	Lat site	**0.002**	Female	0.59
	PC2	Timing/phase shift	Med site	0.99	Male	0.93	Med site	0.16	Male	0.19
			Lat site	0.83	Female	0.99	Lat site	0.18	Female	0.21
Cross-cut	PC1	Amplitude	Med site	0.82	Male	0.40	Med site	0.61	Male	0.98
			Lat site	0.96	Female	0.99	Lat site	**0.006**	Female	0.056
	PC2	Timing/phase shift	Med site	0.49	Male	0.99	Med site	0.92	Male	0.17
			Lat site	0.22	Female	0.87	Lat site	0.71	Female	0.054

Repeated measures ANOVA used on PC scores for each phase, with Tukey adjusted post-hoc pairwise comparisons. Significant differences in bold ($p < 0.05$). Med = medial, Lat = lateral.

tion waveforms. PC1 captured the overall amplitude of the waveforms during each task and phase and PC2 captured a feature related to the timing (phase shift) of the waveforms that was quite similar across all the analyzed maneuvers, phases and muscle groups.

For all the separate analyses, an individual waveform having a high PC1 score corresponded to a large overall muscle activation amplitude and a low PC1 score corresponded to a small activation amplitude throughout the phase (pre-contact or early stance) being analyzed (Fig. 2D). With respect to the second PC, a waveform with a high PC2 score generally had a smaller activation amplitude early in the phase followed by an increase in amplitude as the phase progressed. A low PC2 score generally corresponded to a waveform that had an amplitude that decreased or remained relatively constant for the progression of either the pre-contact or early stance phase (Fig. 2C).

While medial–lateral muscle site differences were not found, significant gender differences were captured for the hamstrings (LH and MH), gastrocnemii (LG and MG) and RF during the pre-contact and early stance phases of the side-cut and cross-cut. No significant differences, related to either the amplitude or timing (phase shift), were captured for the quadriceps (VL and VM) throughout either phase of the maneuvers. For both the side-cut and cross-cut, two female VM waveforms and three male MG waveforms had to be removed from the analysis because adequate signal quality was not obtained during the MVC normalization exercises.

3.1. Gastrocnemii activation waveforms

The ensemble average muscle activation waveforms for the gastrocnemii (Fig. 1A and D) were analyzed and the identified differences in PC scores varied across the two phases and two maneuvers (Table 1 and Fig. 3). For the side-cut, only amplitude differences (PC1) were captured with the females having larger activation amplitudes compared to males for both the LG and MG throughout the duration of both the pre-contact (LG, $p = 0.03$; MG, $p = 0.04$, Figs. 1A and 3A) and early stance phases (LG, $p = 0.002$; MG, $p = 0.007$, Figs. 1A and 3B). The only difference detected for the cross-cut was a gender difference in the overall amplitude of the LG during early stance, with females experiencing greater muscle activation amplitudes than males throughout the entire early stance phase ($p = 0.006$, Figs. 1D and 3D).

3.2. Hamstring activation waveforms

Similar to the gastrocnemii analyses, PC1 captured the hamstring activation amplitude throughout the duration of each phase and PC2 was associated with a timing (phase shift) for both the pre-contact and early stance phases (Fig. 2C and D). The only hamstring differences captured for the side-cut and cross-cut were gender differences in the timing (phase shift) of the activation waveforms (PC2) during the pre-contact phase of the two maneuvers (Table 2 and Figs. 1B, E and 4). Females tended to experience peak activity sooner than males, with greater hamstring activity earlier in the pre-contact phase compared to males. As ground contact approached, however, females tended to be experiencing a substantial reduction in hamstring activity whereas males were just reaching peak activity. This difference between genders was statistically significant at the MH site for the side-cut ($p = 0.01$, Figs. 1B and 4A) and at the LH site for the cross-cut ($p = 0.04$, Figs. 1E and 4B) only, with gender differences being of comparable magnitude but statistically insignificant for both the LH site of the side-cut ($p = 0.14$) and the MH site of the cross-cut ($p = 0.07$). A lack of adequate power (side-cut LH power = 0.18; cross-cut MH power = 0.23) does makes it difficult, however, to confidently conclude that these two differences do not exist.

3.3. Quadriceps activation waveforms

No differences were captured for the VM and VL muscle sites (Fig. 1C and F), however, several RF differences were identified for both maneuvers (Table 3 and Fig. 2). A timing difference (PC2) was detected for the RF during the pre-contact phase of the side-cut ($p = 0.01$, Fig. 2A

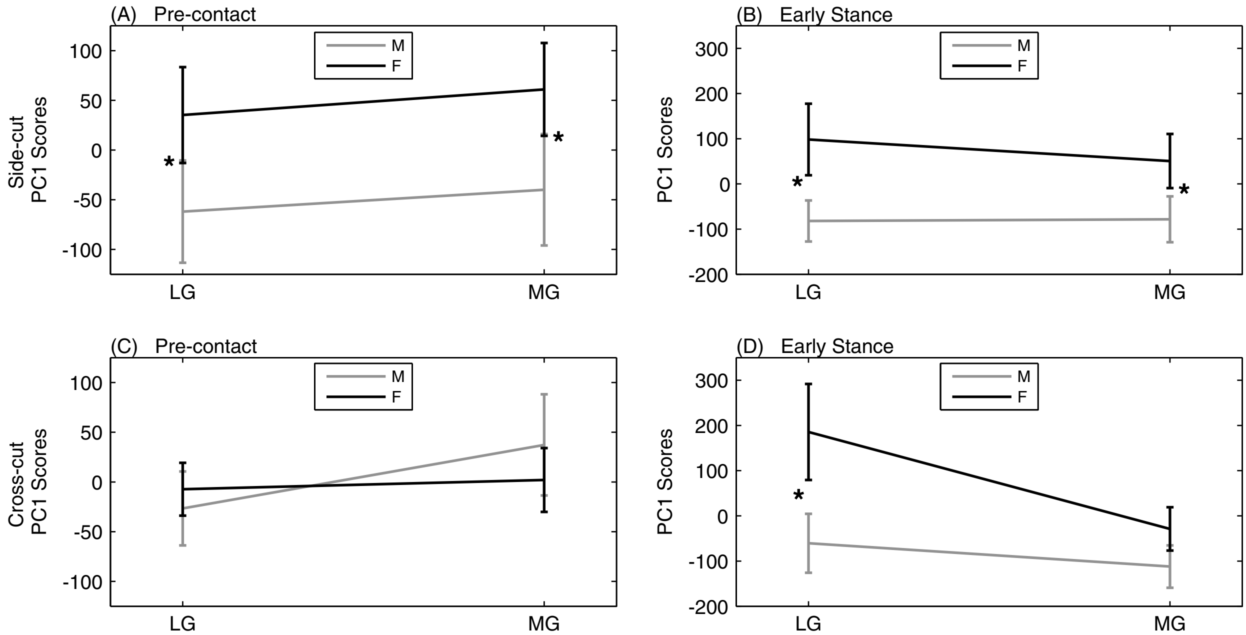

Fig. 3. PC1 score means for the male (M) and female (F) gastrocnemii (LG and MG) for the two cutting maneuvers. Mean PC1 scores along with standard error of the means for the (A) pre-contact and (B) early stance phases of the side-cut maneuver and (C) pre-contact and (B) early stance phases of the cross-cut maneuver. * indicates a significant gender difference for the indicated muscle site (lateral or medial) ($p < 0.05$).

Table 2
Gender and medial–lateral muscle site comparisons of hamstring muscle activation PC waveforms for the pre-contact and early stance phase of the cutting maneuvers

Maneuver	PC	Feature described by PC	Pre-contact phase				Early stance phase			
			Gender comparison *p*-value		Med–Lat site comparison *p*-value		Gender comparison *p*-value		Med–Lat site comparison *p*-value	
Side-cut	PC1	Amplitude	Med site	0.32	Male	0.99	Med site	0.56	Male	0.99
			Lat site	0.41	Female	0.98	Lat site	0.87	Female	0.99
	PC2	Timing/phase shift	Med site	**0.01**	Male	0.96	Med site	0.99	Male	0.99
			Lat site	0.14	Female	0.95	Lat site	0.27	Female	0.27
Cross-cut	PC1	Amplitude	Med site	0.69	Male	0.49	Med site	0.99	Male	0.99
			Lat site	0.92	Female	0.78	Lat site	0.11	Female	0.13
	PC2	Timing/phase shift	Med site	0.066	Male	0.78	Med site	0.96	Male	0.76
			Lat site	**0.04**	Female	0.63	Lat site	0.29	Female	0.11

Repeated measures ANOVA used on PC scores for each phase, with Tukey adjusted post-hoc pairwise comparisons. Significant differences in bold ($p < 0.05$). Med = medial, Lat = lateral.

and C) and cross-cut ($p = 0.01$, Fig. 2B and C) maneuvers. At 100 ms prior to foot contact with the ground, females generally had less RF activity than males but as foot contact approached, females tended to increase their RF activity to a greater extent and therefore at contact, females were activating their RF to a higher percentage of MVC compared to males (Fig. 2A–C). For the entire early stance phase, an amplitude difference (PC1) was captured for both maneuvers, with females having a greater activation amplitude than males for the side-cut ($p = 0.02$, Fig. 2A and D) and cross-cut ($p = 0.005$, Fig. 2B and D).

4. Discussion

Amplitude and timing differences in neuromuscular activity were identified between genders for the major muscle groups crossing the knee joint during the pre-contact and early stance phases of two unanticipated cutting maneuvers. Focusing on the musculature response during the early stance phase of cutting or landing maneuvers is important because most non-contact ACL injuries occur during this period and the musculature surrounding the knee has an important role in joint stability and protecting the knee's ligamentous structures (Goldfuss et al., 1973). The muscular response prior to making contact with the ground (pre-contact phase) also has relevance to ACL injuries and how the body activates the musculature during this phase influences the knee's ability to absorb and dissipate forces, thereby helping to avoid injury to ligaments such as the ACL.

Of the three quadriceps muscles analyzed in this study, the RF was the only muscle that demonstrated gender

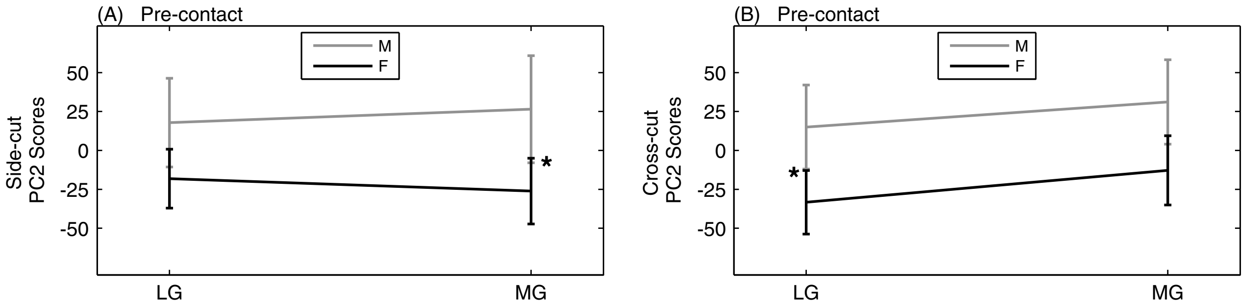

Fig. 4. PC2 score means for the male (M) and female (F) hamstrings (LH and MH) for the two cutting maneuvers. Mean PC2 scores along with the standard error of the means for the (A) side-cut and (B) cross-cut maneuvers during the pre-contact phase. * indicates a significant gender difference ($p < 0.05$).

Table 3
PC score gender means, standard error of the means and gender comparisons of the RF muscle activation PC waveforms for the pre-contact and early stance phase of the cutting maneuvers

Maneuver	PC	Feature described by PC	Gender comparison *p*-value					
			Pre-contact phase			Early stance phase		
			PC score means (SEM)			PC score means (SEM)		
			Male	Female	*p*-Value	Male	Female	*p*-Value
Side-cut	PC1	Amplitude	−22.8 (17.8)	22.8 (24.4)	0.14	−91.5 (31.8)	91.5 (65.9)	**0.02**
	PC2	Timing/phase shift	−24.5 (16.9)	24.5 (8.4)	**0.01**	4.9 (12.5)	−4.9 (8.6)	0.51
Cross-cut	PC1	Amplitude	36.2 (42.0)	−36.2 (9.3)	0.10	−74.3 (16.1)	74.3 (53.5)	**0.005**
	PC2	Timing/phase shift	−25.3 (9.0)	25.3 (17.4)	**0.01**	−4.9 (5.9)	4.9 (5.2)	0.096

Student *t*-tests used to test for differences between genders in the PC scores for the RF waveforms. Statistically significant differences in bold ($p < 0.05$).

differences during the pre-contact and early stance phases of the cutting maneuvers. Contracting the quadriceps at relatively small knee flexion angles can strain the ACL by pulling the tibia anteriorly (Arms et al., 1984) and while it remains unclear if this force alone can injure the ACL, the greater RF activation during early stance in combination with other external loads could increase the risk for injury to the ACL during a non-contact scenario. A plausible explanation for finding gender differences for the RF and not the VL or VM is the RF is the only biarticulate muscle of the four quadriceps and the increased activity may be required more for controlling the hip than the knee. A kinematic and kinetic analysis of the same cutting maneuvers by our group (Landry et al., 2007b,c) was able to show that females generate smaller hip flexion angles throughout the entire stance phase compared to males. Cutting or landing in a less erect posture can reduce the loads at the knee and thereby possibly help protect the ACL (Gauffin and Tropp, 1992; Huston et al., 2001; Malinzak et al., 2001). The increased RF activity in females could be required to help increase hip flexion and thereby avoid the potentially more dangerous erect posture. Gender differences in the timing of RF activity also existed during the pre-contact phase, with females having an earlier and more rapid rise in activity just prior to ground contact. This finding suggests that female athletes have a different neuromuscular feed forward process with respect to how this muscle is pre-activated prior to the foot making contact with the ground during the cutting maneuvers.

Contracting the hamstrings can increase joint stability and the hamstrings can also act as an ACL agonist at larger knee flexion angles (More et al., 1993; Renstrom et al., 1986). Pre-activating the hamstrings prior to experiencing the stressful load during ground contact helps protect the integrity of the knee joint and surrounding structures (DeMont and Lephart, 2004). It would appear that this pre-contact activity of the hamstrings is of particular importance during unanticipated maneuvers, where a reduction in the response time can lead to a lack of appropriate postural adjustments and an increase in the loads experienced at the knee joint (Besier et al., 2003). While gender differences were not identified in the pre-contact amplitude of hamstring activity, potential important differences related to the timing of hamstring activity were captured between genders using the PCA technique. Peak hamstring activity occurred sooner for females compared to males for the MH during the side-cut and LH during the cross-cut. The other two hamstring muscle sites (LH for the side-cut; MH for the cross-cut) had comparable gender differences but these differences only approached statistical significance and lacked adequate power for confidently concluding that they did not exist. Peak hamstring activity tended to occur on average within 60 ms of ground contact and with the electrical–mechanical delay of muscles being approximately 50–100 ms, it would suggest that maximum hamstring contraction is occurring close to ground contact to decelerate the forward progression of the tibia and to help stabilize the knee. The earlier peak activity observed in females could be causing this muscle group to maximally contract a bit sooner than needed to properly stabilize the knee and adequately protect the ACL from being injured after ground contact. There is no question that proper timing for activating the hamstrings is important for protecting the ACL and future studies should continue to focus on the importance of the hamstrings for protecting the structures of the knee joint during different unanticipated sporting scenarios when the ACL is most likely to be injured.

While the role of the hamstrings and quadriceps has been discussed extensively throughout the literature with respect to knee joint stability and ACL injuries (Ahmad et al., 2006), the function of the gastrocnemii at the knee joint has garnered much less attention in the literature. Some researchers have suggested that the gastrocnemii help flex the knee and provide stability to the joint (Huston and Wojtys, 1996; Lass et al., 1991) and others have shown that contracting this muscle group can increase ACL strain (Fleming et al., 2001; O'Connor, 1993). Gastrocnemii pre-activity has been compared between genders for downhill running and differences have been reported (DeMont and Lephart, 2004). Gastrocnemii pre-activity has also been assessed in female ACL-deficient, ACL-reconstructed and control groups during functional activities such as walking, running, hopping and landing. Differences were reported for the LG only and while differences varied across activities, it was concluded that the gastrocnemii muscle group most likely has a role related to knee joint stability and the ACL (DeMont et al., 1999).

Non-contact ACL injuries in an Australian football population have been shown to be more prevalent during a side-cut in comparison to a cross-cut (Cochrane et al., 2007) and our gastrocnemii gender differences were most evident for the side-cut maneuver. The higher gastrocnemii activity observed in females during the pre-contact and early stance phases of the side-cut may be required by the females to enhance joint stability but at the same time could be placing the ACL under greater strain, thereby increasing the risk of ligament damage in the female population. The main role of the gastrocnemii appears to be later in stance when the ankle needs to be plantar-flexed during the propulsion phase of the cut but because gender differences exist prior to initial contact and during early stance when ACL injuries are most likely to occur, it is thought that the gastrocnemii could have an important influence on protecting the knee and ACL while executing these demanding activities.

5. Conclusion

This study is one of the first studies to simultaneously identify amplitude and timing differences in neuromuscular activity between genders during the pre-contact and/or early stance phase of unanticipated cutting maneuvers using PCA. The adolescents in this study were between the ages of 15–18 years of age and while it is difficult to say whether or not there were slight differences in the degree of pubertal maturation between the males and females, the gender bias in non-contact ACL injuries is prevalent at this age group and therefore justifies the importance of focusing on these athletes. Comparing the male and female elite adolescent soccer players, amplitude differences in the RF and gastrocnemii as well as timing differences in the hamstring activation waveforms were identified and described with respect to being potential risk factors for non-contact ACL injuries. These results suggest that female athletes are performing unanticipated cutting maneuvers with different neuromuscular control strategies compared to male athletes and these neuromuscular patterns could have a contributing role to the greater female ACL injury rate. Understanding neuromuscular control strategies and implementing preventative training programs targeting these control strategies could potentially help reduce the incidence of ACL injuries, particularly in the female athletic population.

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