THREE-DIMENSIONAL KINEMATICS AND EMG OF THE LOWER LIMB OF MALE AND FEMALE ATHLETES PERFORMING A SINGLE LIMB LANDING

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The purpose of this study is to compare the time-frequency characteristic, the amplitude and the timing of recruitment of the EMG signal, as well as the three-dimensional kinematics, of the lower limb of female and male volleyball players performing a one-legged drop jump landing. Results showed that women landed with significantly higher peak knee abduction angles than men. Furthermore, peak activity of the semitendinosus, relative to initial contact (IC), occurred significantly sooner (prior to IC) for the female athletes than the male athletes (following IC). The male volleyball players' timing might be more protective to the ACL as the peak anterior tibio-femoral shear force is generated after IC. In addition, no gender differences were found for median frequency of muscle activity prior to and following IC.

KEY WORDS: ACL, injury, gender differences, neuromuscular control, landing, volleyball

INTRODUCTION: As demonstrated by previous studies (Arendt & Dick, 1995; Arendt, Agel, & Dick, 1999; Ireland & Wall, 1990; Lindenfeld, Schmitt, Hendy, Mangine, & Noyes, 1994; Malone, 1992), women injure their anterior cruciate ligament (ACL) two to eight times more frequently than their male counterparts in non contact situations, especially in sports involving many jumping/landing and planting/cutting tasks, such as soccer, basketball and volleyball (i.e. "high-risk" sports).
Most noncontact ACL injuries seen in women athletes occur by means of two main injury mechanisms: a plant-and-cut movement and a one-legged landing (Hutchinson & Ireland, 1995; Olsen, Myklebust, Engebretsen, & Bahr, 2004). In such situations, the hip is most often internally rotated and adducted, the knee is in valgus and slight flexion (20-30°) and the foot is pronated, thus causing an external rotation of the tibia (Ireland, 2000b). This so-called position of no return puts the ACL at risk of injury due partly to the fact that in full knee extension all fibres of the ACL are under tension.
Although much attention has been given to uncovering the cause of such gender discrepancy with regards to non-contact ACL injuries, the exact origin of this divergence has yet to be determined. Three types of contributory factors have however been identified: (1) anatomical; (2) hormonal; (3) neuromuscular. Firstly, women's relatively smaller ACL and intercondylar notch and their greater Q-angle are anatomical factors that are thought to possibly predispose women to a higher risk of non contact ACL injuries. Secondly, it has also been suggested that the menstrual cycle may play a role in women's increased susceptibility to ACL injuries. Lastly, women tend to display neuromuscular behaviours that predispose them to noncontact ACL injuries. The so-called "three-way neuromuscular imbalance" adequately summarizes the neuromuscular contributory factors (Hewett, Myer, & Ford, 2001): (1) Females tend to be *ligament-dominant*; (2) Women display a *quadriceps imbalance* in relation to their hamstrings; (3) Women also exhibit a *leg dominance*.
Though relative muscle activation and its timing have been examined, the time-frequency characteristic has yet to be explored. It has been demonstrated that electromyography (EMG) mean frequency is dependant of the conducting velocity during motor unit recruitment (Solomonow et al., 1990; Wakeling & Rozitis, 2004), which might identify a recruitment control strategies employed by various muscles.
Of the three types of factors, neuromuscular factors seem to be more convincing to explain the gender discrepancy with regards to non contact ACL injuries, as these have a possibility of being modified to reduce a woman's risk of injury. For this reason, additional research is needed to determine the exact cause of this increased risk experienced by women.
Consequently, the purpose of this study is to compare the time-frequency characteristic, the amplitude and the timing of recruitment of the EMG signal, as well as the three-dimensional

(3D) kinematics, of the lower limb of female and male volleyball players performing a one-legged drop jump landing. By performing a time-frequency analysis, new information regarding the neuromuscular control strategies of men and women was acquired.

METHODS: Four healthy female (age: 19.0 ± 2.0 years; height: 1.79 ± 0.02 m; mass: 69.5 ± 8.1 kg; volleyball experience: 6.75 ± 1.9 years) and three healthy male (age: 22.7 ± 3.2 years; height: 1.76 ± 0.03 m; mass: 77.7 ± 2.5 kg; volleyball experience: 7.67 ± 3.8 years) volleyball players, with a training regimen of at least three one-hour sessions per week, volunteered to participate in the study, and informed consent was obtained.

Data Collection Procedures: Following skin preparation and surface electrode (Kendall Meditrace ® 133, Ag/AgCl) positioning on the targeted muscles (i.e. medial and lateral gastrocnemius, vastus lateralis and medialis, biceps femoris and semitendinosus), the athletes performed three isometric maximum voluntary contractions (MVC) against a resistance provided by the investigator for each movement: knee flexion, knee extension and ankle plantar flexion. Reflective markers were then placed on the participants to measure knee flexion/extension, abduction/adduction and internal/external rotation by means of a modified Cleveland Clinic Marker Set. A foot switch was also positioned beneath the forefoot of the participant's landing foot (i.e. right). Subsequent to the recording of the athlete standing in a neutral position, the latter performed five one-legged drop jump landings from a 40.5-cm high box, always using his/her right leg. Data was acquired with four digital cameras (JVC DVL 9800) and a Bortec AMT-8 (Bortec Biomedical Ltd., Calgary, AB, Canada), a eight-channel EMG system – directly connected to the SIMI Reality Motion Systems GmbH (Unterschleissheim, Germany), sampling at a speed of 60 Hz and 1000 Hz, respectively. Data was also collected from a photoelectric cell positioned at the edge of the box, in order to identify the event of "take-off".

Data Analysis Procedures: Three-dimensional coordinates of the markers by means of DLT was obtained from SIMI Motion and subsequently imported in a custom MatLab program for quantification of knee flexion, abduction and external rotation angles during the pre-stance and stance phases. The peak and range of the kinematics values were then obtained for each athlete. Using raw EMG data, the onset and peak value of muscle activation was obtained. Furthermore, the mean of the median frequency for the pre-stance and stance phases was calculated from the raw data. The integral for the pre-stance and stance phases were then obtained from the filtered (highpass, 10 Hz; 2nd order lowpass, 6 Hz) and normalized (MVC) EMG data. The pre-stance phase was defined as the time between the muscle activation onset and the initial contact (IC). In turn, the stance phase was defined as the phase subsequent and equal in duration to the pre-stance phase.

Statistics: Using SPSS statistical analysis software (SPSS for Windows, version 11.5, SPSS Science Inc. Chicago, IL), one-way ANOVAs were used to determine the presence of significant differences between genders with regards to the kinematic variables. As for the EMG variables, 2 (gender) x 6 (muscle) mixed-model ANOVAs were performed. An alpha level of 0.05 was used to determine statistical significance. The partial eta squared (η^2), an effect-size measure was also calculated. For ANOVAs, η^2 values of 0.01 represent small differences; 0.06 moderate differences; and 0.14 large differences.

RESULTS AND DISCUSSION: No significant differences between genders were found with regards to demographics (age, height, mass and volleyball experience). Table 1 summarizes results for 3D knee kinematics found for male and female volleyball players executing a one-legged drop jump. Of interest, results from one-way ANOVAs showed that women displayed a significantly higher peak knee abduction angle than men ($p = 0.05$, $\eta^2 = 0.57$). This is in accordance with the literature (Ford, Myer, & Hewett, 2003), which demonstrates that women tend to land with greater knee valgus angles than men. Results also showed a tendency for women to execute the landing task with greater knee abduction angles at initial contact ($p=0.13$, $\eta^2 = 0.40$) and over a greater range of this angle ($p = 0.16$, $\eta^2 = 0.35$). Although these differences were not significant, the effect sizes are very large indicating that the lack of significance is most likely due to the small sample sizes. In addition, the female athletes displayed a tendency for greater peak and range of knee flexion angles in comparison with the male athletes. These results contradict the literature, which states that women tend to execute landing tasks with smaller knee flexion angles than that of men (Salci, Kentel, Heycan, Akin, & Korkusuz, 2004).

Table 1 Gender comparison (mean (SD)) of 3D knee angles during a one-legged drop jump.

Variable	Females	Males	p-value	Partial eta squared	Observed power
Angle (°) at initial contact					
Knee flexion	13.53 (4.9)	12.55 (5.8)	0.82	0.01	0.06
Knee abduction	2.04 (1.4)	0.03 (1.5)	0.13	0.40	0.32
Knee external rotation	2.60 (5.7)	2.49 (2.2)	0.98	0.00	0.05
Peak angle (°)					
Knee flexion	63.04 (9.1)	49.99 (13.7)	0.19	0.32	0.24
Knee abduction	8.00 (2.9)	2.72 (2.5)	0.05*	0.57	0.55
Knee external rotation	5.57 (5.1)	4.50 (2.8)	0.76	0.02	0.06
Range of angle (°)					
Knee flexion	53.77 (6.1)	41.42 (7.9)	0.07	0.53	0.48
Knee abduction	7.83 (2.7)	2.85 (2.5)	0.16	0.35	0.27
Knee external rotation	11.97 (3.2)	14.51 (1.7)	0.27	0.24	0.18

Furthermore, results from 2 (gender) x 6 (muscle) mixed-model ANOVAs showed no significant gender by muscle interactions. However, several tendencies were present as the effect sizes for time of onset ($p = 0.19$, $\eta^2 = 0.25$) and peak ($p= 0.14$, $\eta^2 = 0.27$) muscle activity relative to initial contact (IC), muscle activation post-IC ($p= 0.35$, $\eta^2 = 0.96$) and median frequency pre- ($p = 0.49$, $\eta^2 = 0.16$) and post- ($p=0.08$, $\eta^2 = 0.99$) IC were very large. Once again, the effect sizes show that the differences were large; however the observed statistical power was low due to small sample sizes. Consequently, several one-way ANOVAs were performed to follow-up these tendencies. Follow-up results showed that peak activity of the semitendinosus (ST), relative to IC, occurred significantly sooner for the female athletes (-42 ± 54 ms) than the male athletes (78 ± 113 ms), $p = 0.12$, $\eta^2 = 0.42$. Specifically, women's peak ST activity occurred prior to IC, whereas men's peak occurred after IC (see Figure 1), indicating that the male volleyball players might display a timing of peak ST activity more protective to the ACL as peak anterior tibio-femoral shear force is generated after IC (Cowling & Steele, 2001). There was also a tendency for women (-74 ± 22 ms) to exhibit a vastus lateralis (VL) onset timing closer in time to IC than men (-117 ± 27 ms), $p=0.06$, $\eta^2 = 0.53$. Since the quadriceps are known to be an antagonist to the ACL, especially when the knee is close to full extension, this timing of VL activation displayed by the female participant might be deemed less protective to their ACL. Additionally, no significant gender differences were found for the median frequency of muscle activity. There was, however a tendency for women to display a higher median frequency for biceps femoris ($p = 0.25$, $\eta^2 = 0.25$) and medial gastrocnemius ($p = 0.17$, $\eta^2 = 0.35$) than men just prior to IC. It was, nevertheless noticed that one of the male participants displayed relatively low median frequency values for all muscle activity. This could have been the cause of the observed gender discrepancy. As median frequency has never been compared among gender in relation to ACL injuries, it becomes quite difficult to interpret this result. Consequently, this topic needs further investigating.

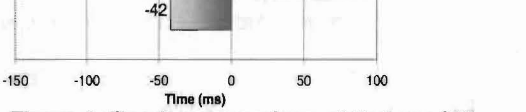

Figure 1 Gender comparison of timing of VL onset and peak ST, relative to IC.

CONCLUSION: Consequently, the results of this study confirm that women tend to land with greater knee valgus angles then men. However, the women in this study displayed greater knee flexion angles, which contradict previous research. Furthermore, these female volleyball players displayed neuromuscular control strategies that may be less protective to the ACL, which could in turn partially explain their higher susceptibility to ACL injuries. No gender differences were found with respect to median frequency of muscle activation. Nonetheless, neuromuscular training programs should continue to be designed to focus on reducing gender discrepancy with regards to knee kinematics and muscle activation patterns displayed in this present study. Future research should measure these variables under unanticipated conditions, which would better reproduce circumstances of ACL injuries.

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