BODY KINEMATICS DURING SINGLE-LEG LANDING FROM VARYING HEIGHTS AND DISTANCES – IMPLICATIONS FOR NON-CONTACT ACL INJURIES: CASE REPORT

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Single-leg landing is seen as one of the primary mechanisms of non-contact ACL injuries during sports. The objective of this study is to determine how body kinematics varies with changes to landing heights and distances, in order to make inferences based on body kinematics to risk of non-contact ACL injuries. Spearman's correlation coefficient among selected body kinematics was determined. It was observed that the peak vertical ground reaction force (VGRF) decreased with increasing distance of landing for the male subject, but increased with increasing distance for the female subject. It was observed that knee flexion is highly correlated to landing height (ρ=0.78), and moderately correlated to distance (ρ=–0.65) for the female subject. Knee flexion moderately correlated to landing height and distance (ρ=0.65 and ρ=-0.58, respectively) for the male subject.

KEY WORDS: Ground reaction force (GRF), anterior cruciate ligament (ACL), risk factors.

INTRODUCTION: The highest incidences of ACL injuries are seen among athletes involved in single-leg landing sports such as basketball, volleyball, and soccer. Deceleration when landing from a jump on one leg is reportedly among the most serious ACL injury causing actions in sports (Yu, Kirkendall et al. 2002). Many jump landing studies have provided extensive insights into gender differences with respect to joint kinematics (Devita and Skelly 1992; McNitt-Gray, Hester et al. 2001), kinetics (Devita and Skelly 1992; Decker, Torry et al. 2003), muscle activation patterns (McNitt-Gray, Hester et al. 2001), and energy absorption strategies during landing (Devita and Skelly 1992; Decker, Torry et al. 2003). Many studies investigate two leg landing (Devita and Skelly 1992; Yu, Kirkendall et al. 2002; Decker, Torry et al. 2003), but there are a small number of studies looking at the association of single-leg landing and non-contact ACL injuries (Lephart, Ferris et al. 2002; Olsen, Myklebust et al. 2004; Nagano, Ida et al. 2007). There is still a lack of studies reporting the change in body kinematics with varying landing heights and distances for single-leg landing and further making inferences to non-contact ACL injuries. One study suggested that the knee is one part of the kinetic chain and that the trunk, hip, and ankle may also contribute to ACL injury (Griffin *et al*. 2000). The coupling between ankle, knee, hip, and trunk kinematics and the link between full body kinematics, ground reaction force (GRF), and ACL forces also requires further investigation. The objective of this study was to determine the change in the body's sagittal plane kinematics during single-leg landing tasks performed over varying landing heights and distances.

METHOD: This study was conducted in a motion analysis laboratory at the University of Ottawa. One male and one female subject with a mean (standard deviation) age of 24.5 (0.07) years, height of 1.74 (0.05) m and weight of 66.45 (0.32) kg were recruited from the student population. Inclusion criterion was good health, as well as regular participation in any kind of sport. Exclusion criterion was known history of musculoskeletal injuries to the lower extremity that could affect landing biomechanics. Informed consent was obtained from each subject as required by the university ethics review board. Retroreflective markers were placed on subjects using a customized marker set via double-sided tape. The motion capture system (Vicon MX), consisting of seven infrared video cameras, collected kinematics at a sampling rate of 250 Hz. A force plate (Kistler model 9281B) measured GRF data at a sampling rate of 1000 Hz.
A single-leg landing task entailed jump landing from a platform placed a certain height and distance from the force plate (see Table 1). The subject was instructed to stand on a landing platform with both arms placed on the hip. Maintaining this position, the subject was then

asked to stand on the dominant leg, jump forward, and land onto the force plate as naturally as possible only with the dominant leg. The order of the height and landing distance was randomized to reduce learning effects. Both subjects wore identical shoes to mitigate variability. The subject was asked to perform two trials for each combination of height and distance.

Table 1
Configuration of trials

Landing distance (m)	Landing Height (m)		
	0.2	**0.4**	**0.6**
0.3	Trial 1	Trial 4	Trial 7
0.5	Trial 2	Trial 5	Trial 8
0.7	Trial 3	Trial 6	Trial 9

Data analysis: Marker trajectories and analog data were imported into Visual3D and low-pass filtered using a second-order bidirectional Butterworth filter at 6 Hz and 25 Hz, respectively. One trial was selected from the better of two trials where any trial that showed obvious missing marker trajectories was deemed unacceptable. The landing phase was determined as 0.8 s prior to peak VGRF and 0.6 s post peak VGRF. The full-body kinematics were determined at peak VGRF. The resultant GRFs were normalized by body weight.

RESULTS: It was observed that an increase in landing height led to an increase in peak VGRF for both the male and female subjects (see Fig 1). However, an increase in landing distance led to a decrease in peak VGRF for the male subject, but interestingly it led to an increase in peak VGRF for the female subject. Using Spearman's correlations, it was determined that ankle flexion was highly correlated to landing distance for both genders ($\rho=-0.75, -0.90$) and weakly correlated to landing height ($\rho=0.01, 0.3$) (see Fig 2). Knee flexion was highly correlated to landing height ($\rho=0.78$) and moderately correlated to distance ($\rho=-0.65$) for the female subject (see Fig.2). But, for the male subject, knee flexion was moderately correlated to landing height and distance ($\rho=0.65$, $\rho=-0.58$, respectively) (see Fig.2). There was a weak correlation ($\rho<0.30$) between both hip and trunk flexion and landing height and distance for both subjects (see Fig 3). In addition, peak VGRF was moderately and negatively correlated to ankle flexion ($\rho=-0.67$) for the female subject, while it was moderately and positively correlated ($\rho=0.57$) for the male subject (see Fig 4). As well, knee flexion was moderately correlated to peak VGRF ($\rho=0.67$) for the male subject, but weakly correlated for the female subject ($\rho<0.38$) (see Fig 4).

DISCUSSION: An *in vivo* study by Cerulli *et al*. (Cerulli, Benoit et al. 2003) reported that maximum ACL strain occurred at peak VGRF for a single-leg landing task suggesting that GRF may be a predictor for establishing the risk of ACL injuries. Landing with high impact forces may also be a risk factor for ACL injuries (Devita and Skelly 1992; Chappell, Yu et al. 2002; Decker, Torry et al. 2003). These studies also found that increasing knee flexion at initial foot contact with the ground may decrease impact forces and knee loading during landing. Our results agree with these findings and also suggest that increasing distance of landing places the female athlete at increased risk of ACL injury given knee flexion decreases with increasing landing distance. On the other hand, with increased height of landing both subjects demonstrated an accompanying increase in knee flexion to perhaps assist in dampening the forces upon impact. Further, an increase in distance led to an increase in peak VGRF, decreased ankle plantiflexion, decreased knee flexion, and lower trunk flexion angles for the female subject; factors known to increase the risk of non-contact ACL injuries. Our results suggest that in order to alleviate the risk of non-contact ACL injury, the female subject should perhaps land with more ankle plantiflexion, as well as more knee and trunk flexion. One possible explanation for the higher magnitude in peak VGRF for the male subject (see Fig.1) is the muscular activity during landing, which can modify GRFs upon impact (Lees 1981).

Even though the literature reports that an increase in hip and trunk flexion may reduce the risk of non-contact ACL injuries (Olsen, Myklebust et al. 2004; Hashemi, Chandrashekar et al. 2007; Blackburn and Padua 2008), this study failed to find any correlation between these values and landing height, distance or even peak VGRF. However, this study is in agreement with the study by Yu *et al*. (Yu, Lin et al. 2006), which showed that hip flexion does not necessarily reduce impact forces upon landing. Further, our results are in agreement with the study by Devita and Skelly (Devita and Skelly 1992), which showed that the ankle and knee were primarily responsible for reducing the body's kinetic energy upon landing. The main limitation of this study was that it is a case report. In addition, the study was conducted in a laboratory environment that was different from what the subjects would have been familiar. Further limitations of this study include, but are not limited to, failure to capture the effect of muscle activities and lack of adequate warm-up.

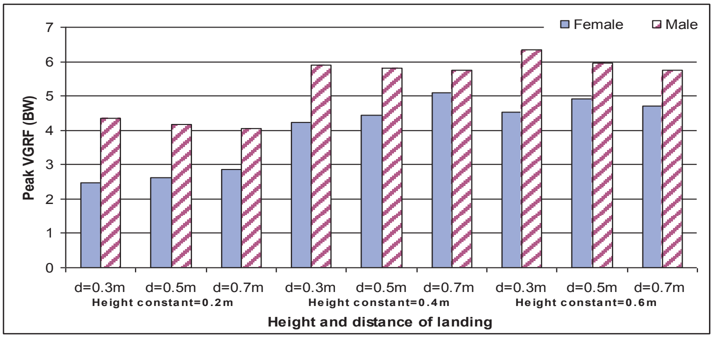

Figure 1: Variation in peak VGRF with landing height & distance

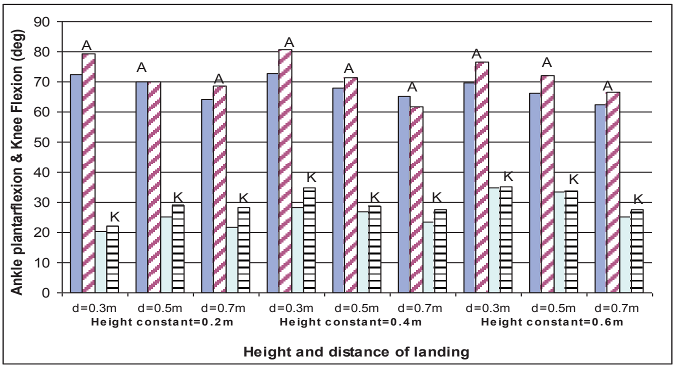

Figure 2: Variation in ankle plantiflexion (A) and knee flexion (K) with landing height & distance: solid=female; hatched=male

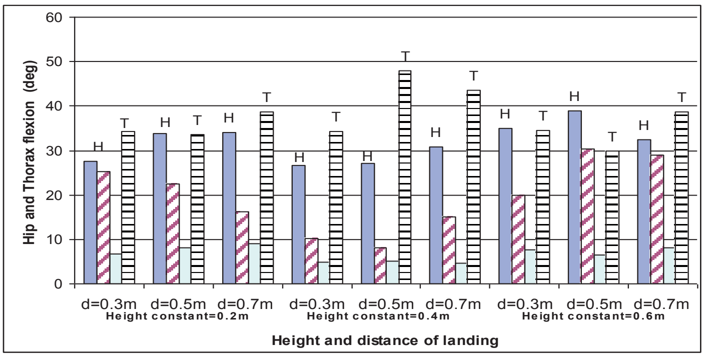

Figure 3: Variation in hip flexion (H) and thorax flexion (T) with landing height & distance: solid=female; hatched=male

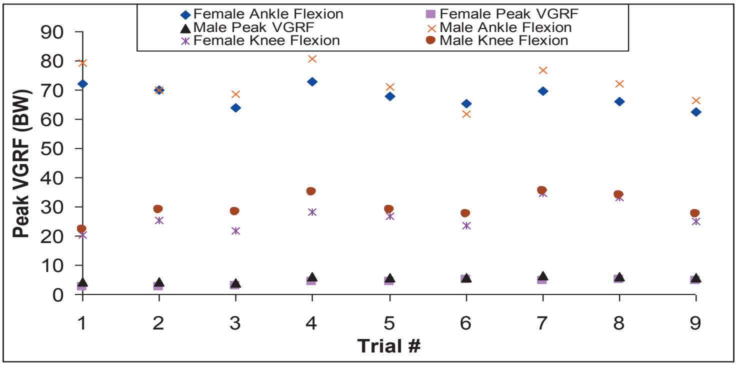

Figure 4: Variation between peak VGRF and ankle/knee flexion as landing height & distance increases

CONCLUSION: It was inferred from the results of this study that the distance of landing will more likely lead to an increased risk of non-contact ACL injury than height of landing, especially for the female subject. In addition, the ankle and knee flexion may be better able to attenuate the ground reaction force over increasing height and distance compared to an increase in hip and trunk flexion. Finally, risk factors to non-contact ACL injury during single-leg landing for male and female subjects may be different from each other, and consequently, different methods of prevention may be advised. These findings should be approached within the limitations of this study, and cannot be generalized especially since non-contact ACL injuries likely occur when several extreme conditions or risk factors happen concurrently.

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