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Comparison of the Second Landing During a Stop Jump and Drop Vertical Jump Task: Implications for ACL Injury

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COMPARISON OF THE SECOND LANDING DURING A STOP JUMP AND DROP VERTICAL JUMP TASK:

IMPLICATIONS FOR ACL INJURY

BY

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Abstract

ACL injuries are the most frequently and debilitating knee injuries in sport. There exists a large gender disparity with female athletes tearing their ACLs at an alarmingly much higher rate (4-6) times that of their male counterpart. Two jump-landing protocols the drop vertical jump and stop jump have been studied because they represent ACL injury inciting maneuvers. These tasks have been proscribed to represent movements commonly seen in basketball, volleyball, and soccer. However, previous research has only focused on the first landing (initial deceleration) of these jump-landing protocols. The purpose of this study was to compare the differences between the drop vertical jump and stop jump during the second landing of these tasks. Nineteen female collegiate athletes were recruited to participate in this study. Three separate MANOVAs were conducted on the kinematic, kinetic, and electromyography dependent variables for both the drop vertical jump and stop jump. Within each task nine dependent variables were analyzed at initial contact and peak knee flexion. These dependent variables included knee flexion angle at initial contact, hip flexion angle at initial contact, peak knee valgus angle, peak knee extension moment, peak knee valgus moment, peak vertical ground reaction forces, hamstrings to quadriceps activation ratio (Q:H) at initial contact and peak vertical reaction forces, and peak proximal tibial anterior shear force. No significant differences were found for the kinematic, kinetic, and electromyography variables between the two jump-landing tasks. Future studies involving more participants and potentially different variables are needed to see if there are differences between during the second landing of these two jump-landing protocols

CHAPTER One: Introduction

The most frequently occurring and debilitating knee injury in sports is rupture of the anterior cruciate ligament (ACL) (Cowling & Steele, 2001). Rupture of the ACL is costly both financially, with conservative estimates of surgery and rehabilitation at $17,000-25,000 per injury, and personally with potential loss of entire seasons of sports participation, loss of scholarship funding, lowered academic performance, long term disability, and significantly greater risk of developing osteoarthritis (OA) in that knee (Hewett, Myer, & Ford, 2006). Adding to the detriment is the fact that ACL injury is often concomitant with a meniscus tear, and this type of meniscus injury is an indicated risk factor for tibiofemoral OA (Alentorn-Geli et al., 2009a). A particularly perplexing issue associated with ACL ruptures is the existence of a large gender disparity between these ACL injuries with a 4-6 fold greater incidence in female athletes compared with male athletes playing the same landing and cutting sports (Arendt & Dick, 1995; Ford, Myer, & Hewett, 2003). This increase in ACL injury in the female sports population has fueled intense examination of the mechanisms responsible for the gender disparity in these debilitating sports injuries (Hewett, Myer, & Ford et al., 2006). Despite the vast amount of research into ACL injury, the underlying mechanisms responsible for this gender disparity still remains poorly understood and very little is known about the effect of sports-specific factors on ACL injury (Renstrom et al., 2008).

Video analyses and retrospective interviews have found that the majority of ACL ruptures are noncontact in nature and range anywhere from 70-84% of all ACL injuries in both male and female athletes (Boden, Dean, Fagin, & Garret, 2000; Krosshaug et al., 2007). There is a general consensus among researchers that a majority of these non-contact ACL injuries occur during cutting, pivoting, sudden deceleration, and landing from a jump (Chappell, Kirkendall, &

Garrett 2002; Ford et al., 2003; Hewett & Bahr, 2007; Yu, Lin, & Garret, 2006). Focusing on these playing scenarios, Alentorn-Geli et al. (2009a) identified numerous risk factors for non-contact ACL injury and categorized them into 2 groups: non-modifiable and modifiable. Non-modifiable risk factors include anatomical risk factors and hormonal risk factors. Anatomical risk factors that have been proposed include increased Q-angle, narrower femoral notch, and increased hypermobility or laxity in female athletes. Few, if any, anatomical variables, however, has been directly correlated with an increased risk of noncontact ACL injury (Alentorn-Geli et al., 2009a). There has been significant research focus on the effects of sex hormone relationships to ACL injury. The increase in estrogen seen during the pre-ovulatory phase of the menstrual cycle has been purported to increase anterior knee laxity (Zazulak et al., 2006), decrease ACL tensile stiffness (Woodhouse et al., 2007), and decrease neuromuscular function (Sarwar, Niclos, Rutheford, 1996). However, literature provides conflicting evidence, which has prevented a strong consensus to be reached on whether ACL injury risk is associated with specific sex hormone fluctuation (Alentorn-Geli et al., 2009a). There is no conclusive evidence that anatomical or hormonal risk factors are directly correlated with an elevated risk of ACL injury in female athletes. Furthermore, most of these factors are congenital factors and are not easily controlled so they will not be analyzed in this study.

Emphasis has turned to modifiable risk factors which include both biomechanical and neuromuscular mechanisms that predispose an athlete to ACL injury because these aspects can be altered or improved with feedback and proper intervention (Alentorn-Geli et al., 2009a). Numerous studies have examined gender differences in lower extremity mechanics during athletic tasks consistently reporting that females exhibit: decreased hip and knee flexion angles, increased knee valgus angles, increased quadriceps activation, and decreased hamstring muscle activation; all factors have been suggested to increase strain on the ACL (Blackburn & Padua, 2008; Chappell et al., 2002; Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Ford et al., 2003; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Myer, Ford, & Hewett, 2005; Pollard, Sigward, & Power, 2009). Identification of these ACL injury risk factors has lead to neuromuscular training programs designed to prevent ACL injury and modify ACL injury risk factors (Alentorn-Geli et al., 2009b). While many studies on these programs have reported success in improving potential ACL injury risk factors, ACL injury numbers continue to be high (Agel, Arendt, & Bershadsky, 2005). ACL numbers may continue to be high due to a lack of sport-specific motion analysis studies and neuromuscular training programs incorporating factors intrinsic to each individual sport. ACL loading studies for jumping and landing maneuvers have analyzed landing mechanics during either drop vertical jumps or stop jumps. Focus has concentrated on these jump-landing tasks because they are purported to mimic playing situations commonly seen in a variety of sports including handball, volleyball, soccer, and basketball (Chappell et al., 2002). While the movements that occur during these sports leading to ACL injury are similar, the sports themselves are very different in nature and have factors intrinsic to their sport that could affect ACL loading characteristics. The stop jump task protocol established by Chappell et al. (2002) consists of an approach typically ranging from 2 to 5 steps, a two-footed landing with countermovement arm swing (landing phase), followed by a two-footed takeoff for maximum height (takeoff phase). The drop vertical jump protocol established by Hewett et al. (2005) consists of a subject dropping directly down off a box (31 cm) and immediately performing a maximum vertical jump, raising both arms as if they were jumping for a basketball rebound. Thus both jump landing studies consist of two separate landings: 1) an initial deceleration landing, and 2) landing after performance of a maximum vertical jump. Two drop jump studies (Ford et al., 2005; Smith et al., 2007) and one stop jump study (Onate et al., 2005), incorporated the use of a basketball overhead so that the athletes jump maximally, catch the ball, and then land. However, these studies only analyzed the initial landing (deceleration before jump), and not the second landing after the maximal jump with the basketball in the athlete's hand. Landing after grabbing a rebound in basketball, spiking a ball in volleyball, or heading a ball in soccer are examples dynamic functional activity in which the athlete has a tendency to concentrate on attending to the ball rather than concentrating on their mechanics upon landing. During basketball, female high school athletes injure their ACL more often while jumping or landing (60%) (Piasecki, Spindler, Warren, Andrish, & Parker, 2003). Specifically, Powell and Barber-Foss (2000) found that rebounding the basketball was the cause of the majority of injuries to female basketball players. Steele and Brown (1999) postulated that the upper-limb motion required to catch a ball may interfere with muscle coordination during dynamic tasks, such as an abrupt landing, thereby compromising the preprogrammed synchrony of the lower-limb muscles required to ensure that the integrity of the ACL is maintained (Cowling & Steele, 2001).

A. Statement of the Problem

The drop vertical jump and stop jump are 2 land-and-jump maneuvers believed to be associated with risk factors for noncontact ACL injury, but only 1 previous study has examined the kinetics and kinematics of both jumping tasks in the same patient population (Chappell & Limpisvasti, 2008). These jump-landing protocols (drop vertical jump and stop jump) have been proscribed to represent a variety of movement tasks seen in a several different sports including volleyball, handball, soccer, and basketball. However, these protocols have only measured ACL injury risk factors during the first landing (initial deceleration) of the task. An analysis of ACL injury risk factors during the second landing (after performance of maximal jump) is needed.

B. Purpose of the Study

The purpose of this research study is to compare the lower extremity biomechanics and neuromuscular firing patterns associated with ACL injury between two jump-landing tasks during the second landing. Kinetic, kinematic, and electromyography measures were compared during the second landing of the stop jump and drop vertical jump.

C. Significance of the Study

Stop jump and drop vertical jump landing studies have failed to assess ACL injury risk factors during the second landing. In various sports this second landing may be altered as the athlete has to concentrate on attending to a sport-specific ball. Neuromuscular training programs have been shown to be effective; however the majority of these programs have not incorporated sport-specific actions such as landing after catching a ball. If neuromuscular training programs can train the lower extremity to safely and effectively land, while focused on a different task such as catching a ball, then our neuromuscular training programs would be enhanced and hopefully reduce the high number of ACL injuries still seen today.

D. Research Hypothesis

It was hypothesized that there would be significant differences in landing mechanics between stop jump and drop vertical jump tasks during the second landing.

E. Variables

During these two jump-landing tasks, knee flexion angle at initial contact, hip flexion angle at initial contact, peak knee valgus angle, peak knee valgus moment, peak knee extension moment, neuromuscular activation ratio of the quadriceps and hamstrings at initial contact and peak vertical ground reaction force, peak vertical ground reaction forces, and peak proximal anterior tibial shear force were measured during the second landing (descending after maximal jump).

F. Limitations

Subjects were allowed to wear their own type of athletic footwear. Activities performed outside prior to testing were not controlled and may have influenced the variables being measured. Basketball players in this study may have had an advantage compared to soccer and volleyball players in terms of familiarity of movement as they regularly perform vertical jumps, grab a basketball, and successfully land. The speed of the approach run in the stop jump was not controlled for and could have varied between subjects.

G. Delimitations

This study was limited to female NCAA Division II athletes at Barry University consisting of 10 soccer, 6 basketball, and 3 volleyball players and cleared to participate. Instructions for the two jump-landing tasks were provide by only the primary investigator in the study. All testing protocols took place in the biomechanics laboratory.

H. Assumptions

It was assumed that all athletes were in good health and were motivated to complete the jump-landing tasks as they would in the same manner as a practice or game setting. The participants in this study fully understood the directions for each task given before testing began.

I. Definition of Terms

Anterior Cruciate Ligament: Anterior portion of two cruciate ligaments essential for normal function of the knee joint and affect both the stability and mobility of the joint. It attaches proximally to the lateral epicondyle of the femur and follows an anterior-medial-oblique pathway to attach to intercondylar fossa of the tibia. The ACL acts primarily to prevent forward translation of the tibia relative to the femur, and also prevents hyperextension and stabilizes the knee against tibia rotation.

Drop Vertical Jump: Common jump-landing protocol used in ACL research; subject drops of a box (31 cm in height) onto two force plates and immediately performs a maximum vertical jump.

Dynamic Knee Valgus: Combination of hip adduction and hip internal rotation, tibial abduction, and foot eversion resulting in a knock-kneed appearance.

Ground Reaction Forces: Force exerted by the ground on a body in contact with it

Kinematics: The study of motion without regard to its causes; velocity, speed, acceleration, angular displacement and so on.

Kinetics: The study of the causes of motion; forces and moments of force and their characteristics such as work, energy, impulse, momentum, power and so on.

Knee Abduction: Also referred to knee valgus; occurs when the lateral aspect of the knee joint compresses and the medial aspect of the knee joint opens up.

Latency Period: Interval between stimulus and reaction

Moment: The turning effect of a force on a body

Neuromuscular Control: Unconscious activation of dynamic restraints (muscles) surrounding a joint in response to a stimuli

Proximal Tibial Anterior Shear Force: Shear force acting on the proximal tibia causing it to translate anteriorly relative to the femur.

Stop Jump: Common jump-landing protocol in ACL research; the task consists of an approach typically ranging from 2 to 5 steps, a two-footed landing with countermovement arm swing (landing phase), followed by a two-footed takeoff for maximum height (takeoff phase)

Tibial Rotation: Proximal segment of the tibia rotates internally or externally relative to the distal portion of the femur

Valgus: The alignment in which the angle between the proximal and distal segments opens laterally

Valgus collapse: Situation where the knee collapses medially from excessive valgus motion and/or tibial rotation.

<u>Chapter Two: Literature Review</u>

This study will analyze biomechanical and neuromuscular aspects that have been highly correlated with ACL loading and injury during a stop jump and drop vertical jump. Specifically main outcome measures will be analyzing knee flexion angle, hip flexion angle, knee valgus angle, knee valgus moment, knee extension moment, neuromuscular activation of the quadriceps and hamstrings, vertical ground reaction forces, and proximal anterior tibial shear force. The literature review will discuss the mechanisms and risk factors correlated with ACL injury, movement tasks associated with ACL injury, and sport-specific factors intrinsic to basketball that may contribute to ACL injury.

A. ACL Structure and Function

The ACL is a dense connective tissue that is essential for normal function of the knee joint and affects both the stability and mobility of the knee. The ACL stabilizes the knee joint, prevents abnormal movements, and steers the movement of the knee (Bicer et al., 2009). The ACL acts primarily to prevent forward translation of the tibia relative to the femur. In addition, sectioning studies have shown that the ACL also prevents hyperextension and stabilizes the knee against tibia rotation (Bicer et al., 2009)

B. Mechanisms of ACL Injury

The majority of research into ACL ruptures has been concentrated on determining the mechanisms and risk factors for ACL injury and discovering the reasons for the great gender disparity. While the precise mechanism of ACL injury is not universally agreed on, it is accepted that 2 general mechanisms exist: contact and noncontact (Krosshaug et al., 2007). Myklebust et al. (2003) defined contact ACL injury as any injury that occurs as a result of player-to-player (body-to-body) contact, and non-contact ACL injury as an injury that occurs in the absence of any player-to-player contact (Hewett et al., 2006). As noted above, non-contact ACL injuries are believed to account for as high as 84% of all ACL related injuries. This has led researchers to concentrate on playing scenarios that emulate non-contact ACL injuries.

Determining the mechanisms of non-contact ACL injuries is based on several methodological approaches: Interviews with injured players, video analysis, clinical studies (where clinical joint damage is studied to understand the mechanism of the injury), in vivo studies (measuring ligament strain or forces to understand ligament loading patterns), cadaver studies, mathematical modeling, and simulation of injury situations or measurements/estimation from close to injury situations (Alentorn-Geli et al., 2009a).

The National Collegiate Athletics Association (NCAA) Injury Surveillance System performed a 16 year sample (1989-2004) and found, ranked as a *percentage* of ACL injuries on a team compared with all injuries on that team, female sports dominate the list (women's soccer, women's lacrosse, women's gymnastics and women's basketball). For the age group slightly younger than college level (14–18 years), the rate of non-contact ACL injuries in soccer was twice as high in females as in males. For basketball the rate of injury in the younger female age group is the highest—nearly four times that of males (Renstrom et al., 2008).

Several video analyses and retrospective interviews were conducted to help determine the mechanism and playing scenario of a non-contact ACL tear by capturing the movement leading up to injury. These studies have concluded that the most common playing scenarios precluding a non-contact ACL injury include: change of direction or cutting maneuvers combined with deceleration, landing from a jump in or near full extension, and pivoting with knee near full extension and a planted foot (Boden et al., 2000; Krosshaug et al., 2007; Olsen, Mykelbust, Engebretsen, & Bahr, 2004). These movements cause a combination of dynamic loads that place high loads on the soft tissues and supporting structures of the knee (Chaudhari, Hearn, & Andriacchi, 2005). Video analyses agree that in most cases the injury occurred immediately after initial contact with the ground (within 40 milliseconds) during landing maneuvers with the knee near or at full extension (Krosshaug et al., 2007). Teitz (2001) also indicated that most often the center of mass of the body was behind and away from the base of support. Thus, there is mounting evidence that the most common non-contact injury mechanism of injury in female athletes occurs during a deceleration task with high knee internal extension torque combined with dynamic valgus rotation with the body weight shifted over to the injured leg and the plantar surface of the foot fixed flat on the playing surface (Boden et al., 2000; Krosshaug et al., 2007; Olsen et al., 2000;). Interestingly, both male and female athletes may demonstrate similar body alignment during competitive play without succumbing to an ACL injury, thus, it is crucial to determine the underlying risk factors that contribute to an increased propensity for this high-risk position (Alentorn-Geli et al., 2009a).

C. ACL Injury Risk Factors

Numerous risk factors predisposing an individual to non-contact ACL injury have been purported and include non-modifiable and modifiable risk factors. Non-modifiable risk factors include anatomical risk factors and hormonal risk factors. Anatomical risk factors that have been proposed include increased Q-angle, narrower femoral notch, ACL size and increased hyper-mobility or laxity of the knee in female athletes. There is no conclusive evidence that any of these non-modifiable risk factors are directly correlated with an elevated risk of ACL injury in female athletes. Furthermore, most of these factors are congenital factors and are not easily controlled (Hewett et al. 2007), so they will not be discussed in this study.

1. Biomechanical Risk Factors

Biomechanics of playing actions are necessary to understand the pathomechanics of ACL injuries and to offer effective prevention programs, prompting the majority of research focused on modifiable factors since these can be improved through proper feedback and instruction (Alentorn-Geli et al., 2009b).

i. Sagittal Plane Biomechanics

Sagittal plane biomechanics were initially thought to be the main culprit for ACL injury and thus have yielded many studies on sagittal plane trunk, hip, knee, and ankle angles when performing jump-landing and cutting maneuvers (Quatman, Quatman-Yates, & Hewett, 2010). As the joints of the lower extremity flex during landing, more kinetic and potential energy is absorbed by dynamic restraints (muscles) and thus results in less energy being transferred to passive restraints (ligaments and bones) (Devita & Skelly, 1992).

The reported effects of gender on knee flexion angle vary. Several motion analysis studies have found females exhibit less knee flexion during landing, jumping, and cutting tasks compared with males (Chappell, et al., 2007; Hewett & Bahr, 2007; Krosshaug et al., 2007; Olsen et al., 2004; Yu, Lin, & Garrett, 2006). In addition, interview and video observational studies indicate that the knee is at low (0-30°) knee flexion angles during ACL injury events (Boden et al., 2000; Krosshaug et al., 2007). However, several motion analysis studies show no sex differences or even greater knee flexion in females during landing and cutting tasks (Ford et al., 2005; Pollard, Davis, & Hamil, 2004).

Sagittal plane translation movements are also important to consider, since the ACL is a major stabilizing ligament of the knee that provides approximately 85% of the total restraint in the knee joint to anterior tibial translation (Quatman, Quatman-Yates, & Hewett, 2010). Many cadaveric, imaging and physical exam studies demonstrate that ACL-deficient knees have significantly more anterior tibial translation compared with ACL-intact conditions (Quatmann et al., 2010). Both *in vivo* and *in vitro* studies demonstrate that the total range for anterior/posterior tibial displacement is greater at 30° than 90° of knee flexion, which indicates that the knee joint has the potential to translate further anteriorly at shallow knee flexion angles (Quatman et al., 2010)

Several studies support anterior tibial shear as a mechanism for ACL injury (Quatman et al., 2010). Anterior shear forces in the knee cause the tibia to translate anteriorly relative to the femur and to load the ACL (Kulas, Hortobagyi, & Devita, 2010). The external anterior force acting on the proximal tibia is a result of attempting to accelerate the body forward (Chaudhari et al., 2005). This anterior force may be generated by the subject to balance, after the initial deceleration of the body but before the knee reaches its maximum flexion angle (Chaudhari et al., 2005). This force must be balanced by internal forces generated by the hamstring muscles and soft tissues such as the ACL to prevent anterior tibial translation (Chaudhari et al., 2005). Berns, Hull, and Peterson (1992) and Markolf, Burchfield, and Shapiro (1995) found that anterior shear force at the proximal tibia is the major ACL loading mechanism and that the ACL loading is reduced as the knee flexion angle is increased (Alentorn-Geli et al., 2009a). Garrett and Yu (2007) reported that non-contact ACL injuries occur when an anterior shear force generates large forces at the proximal tibia, leading to excessive tension force on ACL. Magnetic Resonance Imaging (MRI) studies after ACL injury demonstrate that tibial bone bruises are located more posteriorly than femoral condylar bone bruises and it has been speculated that this is a result of the tibia shifting anteriorly relative to the femur during the injury (Quatman et al., 2010). In vivo arthroscopic studies demonstrate that the ACL is a primary restraint to anterior shear loading and abnormal anterior tibial translation relative to the femur is a clinical measure used to determine ACL deficiency (Quatman et al., 2010). However, if the mechanism was solely an anterior shear, the bone bruise patterns on MRI after ACL injury would most likely be located along the medial tibial plateau as well as the tibial plateau. Since the bone bruises are usually located laterally, lateral compression or internal/external tibial rotation of the joint also likely occurred during these injuries (Quatman et al., 2010).

It was postulated that decreased hip flexion angles at landing places the ACL at a greater risk of injury, because a greater peak landing force is transmitted to the knee (Alentorn-Geli et al., 2009a). Yu et al. (2006) found that female athletes who exhibited smaller hip and knee flexion angles at the initial foot contact with the ground and maximum knee flexion angle at the end of the landing, landed with greater impact forces.

Previous studies have demonstrated a significant relationship between peak ground reaction forces and knee injury (Devita & Skelly, 1992) particularly to ACL loading (Shelburne, Pandy, Anderson, & Torry, 2004). The impact on the lower extremity passive restraints, such as the ACL, increases as the peak vertical ground reaction forces increase (McNitt-Gray, 1991). Peak vertical ground reaction forces may elaborate internal loads that may cause injury if not sufficiently distributed or attenuated by the musculoskeletal system (Devita & Skelly, 1992). Yu et al., (2006) found that the greater the hip and knee flexion angular velocity at initial contact during the landing of a stop-jump task, the lesser posterior and vertical ground reaction forces. This is important because the greater posterior and greater vertical ground reaction forces, the greater peak proximal tibia anterior shear force and peak knee extension moment and thus ACL loading during landing (Yu et al., 2006). Thus, it is believed that large hip and knee flexion angles at initial contact with the ground do not necessarily reduce the impact force during landing, but active hip and knee flexion motions do (Yu et al., 2006).

Blackburn and Padua (2008) demonstrated that increased trunk flexion during landing reduced landing forces and quadriceps activity, thus potentially reducing the force imparted to the ACL. The authors also indicated that trunk flexion during landing also increases knee and hip flexion, resulting in a less erect landing posture (Blackburn & Padua, 2008). In combination, these findings support emphasis on trunk and hip flexion during landing as part of ACL injury-prevention programs (Alentorn-Geli, 2009a)

Gross and Nelson (1988) found forefoot strike landings can reduce skeletal transients by 50% compared to rearfoot landings. Forefoot landings increase joint range of motion and therefore the time during which the body is brought to rest. Self and Paine (2001) showed that landing technique with the largest plantar-flexion position at ground contact demonstrated the most shock absorption and reduction of the peak vertical ground reaction force (Alentorn-Geli et al., 2009a). It was recently demonstrated by Cortes et al. (2007) that landing with the rear foot (dorsiflexed ankle) was associated with less hip and knee flexion at peak vertical GRF than forefoot landing (plantarflexed ankle) (Alentorn-Geli et al., 2009a). Cortes et al., (2007) also found the maximum knee flexion angle with forefoot landing technique was significantly higher than rear foot technique. Maximum force transferred to the knee would be at peak vertical ground reaction force; therefore a forefoot landing technique may minimize peak vertical ground reaction forces (Alentorn-Geli et al., 2009a). Burkhart et al. (2008) reported that an athlete who landed with an increased heel to flat-foot loading mechanism was more likely to sustain a non-contact ACL injury. However, no significant differences have been observed between male and females in ankle and foot landing technique (Alentorn-Geli et al. 2009a).

ii. Frontal Plane Biomechanics

The frontal plane theory mechanism has become a recent topic of debate with over 80% of studies supporting frontal plane mechanisms as a contributor to ACL injury (Quatman et al., 2010). Of particular interest has been the amount of valgus angle and valgus moment experienced at the knee during athletic tasks. Hewett et al. (2006) define dynamic knee valgus as the combination of hip adduction and internal rotation, tibial abduction, and foot eversion. The amount of valgus during a landing maneuver suggests an inability of an athlete's musculature to control ground reaction forces (Cowley, Ford, Myer, Kernozek, & Hewett, 2006). As a result ligaments may absorb the additional forces and overreliance on the ligaments to control motion may constitute a greater risk factor for ACL injury (Cowley et al., 2006). Valgus collapse, a commonly reported scenario for ACL injury, is a situation where the knee collapses medially from excessive valgus motion at the knee and/or internal/external tibial rotation (Krosshaug et al., 2007). Video analyses studies found that dynamic valgus collapse was a common ACL injury mechanism among basketball players with females demonstrating a 5.3 fold higher relative risk of abduction collapse during ACL injury compared with males (Krosshaug et al., 2007).

Physiologic dynamic valgus torques on the knee can significantly increase anterior tibial translation and load on the ACL several-fold (Hewett et al., 2006). Knee abduction moments, which directly contribute to lower extremity dynamic valgus and thus high ACL forces and tension throughout the range of knee flexion, predicted ACL injury risk with 73% sensitivity and 78% specificity (Hewett, Myer, & Ford, 2005). Knee abduction angle was more than 8 degrees greater in an ACL injured group than uninjured during a jump-landing task. In the ACL injured group, knee abduction angle correlated to peak vertical ground reaction forces (Hewett et al., 2005). Hewett et al. (2005) concluded that high knee abduction motion and torque are both common sex differences during athletic movements and predictors of future ACL injury risk (Hewett et al., 2005).

Clinical imaging and arthroscopic studies also indicate that frontal plane mechanisms play a role in ACL injury. Bone bruises of the lateral femoral condyle or posterolateral portions of the tibial plateau occur in 80% of MRI studies after acute ACL injury (Quatman et al., 2010). These bruise locations suggest that ACL injury resulted from and abduction mechanism, because bone bruising on the lateral part of the knee joint indicates that compression occurs laterally while the medial aspect of the joint opens up (Quatman et al., 2010).

The MCL, not the ACL, is considered the primary restraint against abduction stress in the knee joint. If ACL injury were to occur due to abduction motion and torque at the knee joint, then the MCL would be expected to be injured also, yet ACL/MCL injuries only make up 4-27% of all ACL injuries (Hewett et al., 2006). Additionally, cadaver studies and mathematical simulation studies show that pure valgus motion could not tear the ACL without tearing the medial collateral ligament first (Quatman et al., 2010). This supports the multiplanar theory suggesting that other motions and forces would have to combine with valgus motion to load the ACL high enough to result in a rupture (Quatman et al., 2010).

iii. Transverse plane

Many studies neglected to assess transverse rotations, thus transverse plane contributions to ACL injury may be significantly underestimated (Quatman et al., 2010).

A majority of studies that have found significant differences in transverse plane biomechanics have been during cutting tasks. One jump-landing study by Chappell et al. (2007) demonstrated that female soccer, basketball, and volleyball players prepared for landing during a stop jump task with decreased hip external rotation and increased knee internal rotation compared with male athletes (Chappell et al., 2007). Zazulak et al. (2005) reported significantly lower gluteal EMG activity in female athletes compared with male athletes during landing. Numerous studies have reported that the ACL experiences higher strains during internal tibial rotation, while only minimal increases in strains during external rotation have been noted (Quatman et al., 2010). However, more research is needed to establish the role of transverse plane biomechanics on ACL loading.

2. Neuromuscular Activation

Neuromuscular control is the unconscious activation of dynamic restraints (muscle) surrounding a joint in response to a stimuli (Alentorn-Geli et al., 2009a). Unconscious muscle activation is crucial during many actions in sports, and differences in neuromuscular control may explain, in part, the increased ACL injury risk in female athletes (Olsen et al., 2004). Dynamic stabilization via the neuromuscular control system helps to protect the knee joint during dynamic sport-related tasks (Alentorn-Geli et al., 2009a). Muscle actions must be coordinated and co activated in order to protect the knee joint, hence antagonist-agonist relationships are crucial for joint stability (Withrow, Huston, Wojtys, & Ashton-Miller, 2008). Coactivation of the hamstrings and quadriceps muscles are believed to be critical in preventing or reducing knee motion and loads that increase the risk of ACL injury (Huston et al., 2008). Absence of neuromuscular control may be responsible for the increase rate of knee injury rates in females. This has led to numerous studies examining the effect of neuromuscular control on ACL strain, and gender differences in neuromuscular activation strategies during various sports-related tasks.

i. Neuromuscular Deficiencies

Neuromuscular mechanisms may play the largest role in gender differences in ACL injury (Hewett et al., 2007). Previous authors have identified three neuromuscular deficits related to biomechanical or neuromuscular coordination postulated to affect ACL loading (Ford et al., 2003). These neuromuscular deficits include ligament dominance, quadriceps dominance, and leg dominance (Ford et al., 2003). Ligament dominance occurs when the lower extremity musculature does not adequately absorb the forces during a sports maneuver resulting in excessive loading of the knee ligaments, especially the ACL (Hewett et al., 2006). Ligament dominance often results in high ground reaction forces, valgus knee moments, and excessive knee valgus motion (Ford et al., 2003). Quadriceps dominance is an imbalance between the recruitment patterns of the knee flexors (hamstrings) and extensors (quadriceps) (Ford et al., 2003). Females tend to rely on their quadriceps over their hamstrings to produce dynamic knee stability during jumping and landing activities (Hewett, Stroupe, Nance, & Noyes, 1996). Leg dominance is an imbalance between muscular strength and recruitment patterns on opposite limbs, with one side often demonstrating greater dynamic control (Hewett et al., 1996). Over-reliance on one limb can put greater stress on that knee, whereas the weaker side might not be able to effectively absorb the high forces associated with sporting activities (Ford et al., 2003).

ii. Ligament Dominance

The body has both passive and active means of shock attenuation. Passive mechanisms include elasticity of bone, cartilage, and soft tissue while joint position and muscle activity make up the active mechanisms. Landing involves certain lower extremity joint muscle actions that serve to dissipate kinetic energy converted from potential energy of the athlete at a particular landing height (Yeow, Lee, & Goh, 2009). This kinetic energy dissipation reduces the extent of impact stresses experienced by passive restraints or supporting tissues such as cartilage, ligaments and bones (Devita & Skelly, 1992). The lack of necessary magnitude of energy dissipation during impact landing may be implicated in the elevated risk of sustaining common landing injuries such as cartilage lesions, ligament tears, and bone bruises/ fractures at the lower extremities (Devita & Skelly, 1992). Devita and Skelly (1992) evaluated ground reaction forces in soft and stiff landings (less than and greater than 90° of knee flexion). During a soft landing, lower extremity muscles were found to absorb 19% more of the body's kinetic energy, with the hip extensor eccentric contraction responsible for 22% of the total kinetic energy (Devita & Skelly, 1992). McNitt-Gray et al. (2001) indicated that subjects appeared to increase shock attenuation via hip and knee flexion and that angular displacement must increase during landing, while the landing impact increases as the drop height increases in order to reduce risk of injury (Wang, Gu, Chen, & Chang, 2010). Decker, Torry, Wyland, Sterett, and Steadman (2003) reported that female athletes experience high ground reaction forces at the lower extremity during landing because of decreased use of the hip musculature to absorb these forces. In contrast to male athletes who effectively use their hip musculature to absorb energy, female athletes may adopt landing strategies in which more energy is absorbed at the knee and ankle (Decker et al., 2003). Decreased neuromuscular control of the knee joint reduces knee joint stiffness and thus increases risk of injury to the ligaments, specifically the ACL (Hewett et al., 2006).

iii. Hamstring to Quadriceps Ratio

The quadriceps and hamstrings muscles exhibit an agonist-antagonist relationship that plays an important role in stabilizing the knee. Deficiencies can result when the hamstrings are under recruited during landing maneuvers. If the hamstrings are under recruited or weak, quadriceps activation would have to be reduced to provide a net flexor moment required to perform the movement (Hewett et al., 2005). Deficits in strength and activation of the hamstrings directly limit the potential for muscular co-contraction to protect the ligaments about the knee (Hewett et al., 2005). If hamstring recruitment is high, the quadriceps can be highly activated and a net internal knee flexor moment predominates (Hewett et al., 2005). Disproportional recruitment of the quadriceps musculature may lead to anterior tibial shear force in female athletes. Female athletes with decreased ability to adequately balance muscular recruitment through positions of high joint loading, significantly increase their risk of subsequent ACL failure (Hewett et al., 2005).

During flexion exercises, female athletes demonstrate increased activation of their quadriceps relative to their hamstrings and increased anterior tibial loads during dynamic exercises (Markolf et al., 1995) Colby, Francisco, Yu, Kirkendall, Finch, and Garrett (2000) found high-level quadriceps muscle activation beginning just before foot strike and peaking in mid-eccentric motion during landing. Hamstring muscle activation was submaximal at and after initial contact. The combination of shallow knee flexion angle and low level of hamstring muscle activity could produce significant anterior displacement of the tibia resulting in ACL tear (Colby et al., 2000). Cadaveric studies have found that quadriceps and hamstring forces are the major contributors to anterior shear force at the proximal end of the tibia (Markolf et al., 1995; Withrow et al., 2008).

Neuromuscular recruitment patterns and recruitment velocity of the quadriceps and hamstring muscles play a crucial role in providing stiffness and dynamic stability at the knee (Medina, McLeod, Howell, & Kingma, 2008). There is a preparatory and reflexive co-contraction of the quadriceps and hamstrings to stiffen the area around the joint to prevent injury (Medina et al., 2008). The preparatory action is the neuromuscular activity before foot contact, while reflexive action is the activity after foot contact (Medina et al., 2008). Therefore there is a need for efficient neuromuscular control of the thigh muscles to create this dynamic joint stiffness and protective stability (Medina et al., 2008). Numerous studies evaluating the neuromuscular differences between males and females found females demonstrated muscular recruitment characteristics that may be predispositions to ACL injury, including preferential recruitment of the quadriceps over the hamstrings (Chappell et al., 2007; Cowley et al., 2006; Hewett et al., 2005; Huston & Wojtys, 1996), shorter latency periods of the quadriceps (Shultz & Perrin, 1999), less muscular stiffness of the thigh muscles (Horita, Komi, Nicol, & Kyrolainen, 2002), and unbalanced quadriceps-to hamstrings strength ratios (Hewett et al., 1996).

Chappell et al (2007) found that female soccer, basketball, and volleyball players prepared for landing with increased quadriceps activity and decreased hamstrings activity which may result in increased ACL loading during landing of jump stop task. Padua, Arnold, Carcla, and Granata (2005) found increased quadriceps and soleus activation during hopping as well as decreased hamstrings activity. Yu et al. (2006) found females exhibited increased hamstring activation before landing but a trend of decreased hamstring activation after landing.

3. Multi-planar ACL Loading

Landing, jumping, and cutting maneuvers can require movements of the ankle, knee, and hip joints in multiple planes, making it unlikely that an ACL injury occurs in a single isolated plane (Quatman et al., 2010). Authors of ACL studies have come to the conclusion that the mechanism underlying gender disparity in ACL injury risk is likely multifactorial and multiplanar in nature (Alentorn-Geli, 2009a). As a result 82% of ACL injury mechanism studies have supported a multi-planar knee loading mechanism (Quatman et al., 2010). In retrospective interview studies, individuals often report that their knee moved in multiple planes (Shimokochi & Schulz, 2008). Specifically a valgus displacement combined with either and internal or external tibial rotation at low knee flexion angles (Quatman et al., 2010). Similarly video studies indicate that ACL injuries occur with minimal knee flexion and are often combined with knee valgus or transverse rotation movements (Boden et al., 2000; Krosshaug et al., 2007; Olsen et al., 2004). This is supported by the bone bruise patterns associated with ACL injuries located on the lateral femoral condyles and posteriolateral tibial platueaus of patients with acute ACL injured knees (Quatman et al., 2010). This bone bruise pattern indicates that internal tibial rotation, femoral external rotation, abduction and/or anterior tibial translation would lead to these specific bone bruise locations (Quatman et al., 2010).

Cadaveric investigations show that valgus moments combined with a quadriceps force contraction or anterior shear force increases ACL strain (Quatman et al., 2010). Markolf et al. (1995) and Berns et al. (1992) demonstrated that coupled loading of an abduction moment to an anterior tibial force (at a knee flexion greater than 10°) or coupled loading of an anterior tibial force with an internal tibial torque (at knee flexion less than 20°) leads to additive generation of ACL force and strain compared with isolated anterior tibial force (Quatman et al., 2010). In contrast, coupled external tibial torque and anterior tibal force appears to lower the ACL tensile force after 20° of knee flexion. As such, the ACL may be less vulnerable to injury, since the MCL could be shielding the ACL from stress in this knee position (Markolf et al., 1995; Quatman et al., 2010).

The most common ACL injury positions occur when the lower extremity is in a position that involves knee valgus, internal rotation and/or external rotation, and anterior translation force (Boden et al., 2000; Markolf et al., 1995; Olsen et al., 2004; Yu & Garrett, 2007). The anterior translation force, specifically at flexion angles around 20–30°, may be the most detrimental isolated force associated with ACL injury, and is often identified as a contributing factor to ACL injury mechanisms (Berns et al., 1992; Boden et al., 2000; Markolf et al., 1995; Yu & Garrett, 2007). Cadaveric studies indicate that a combination of forces produces a higher strain on the ACL than isolated motions and torques.

Pollard et al. (2009) found that females who utilized a low hip and knee flexion landing pattern during a drop vertical landing task exhibited increased knee valgus angles, increased knee adductor moment, decreased energy absorption at the knee and hip musculature, increased knee extensor moments, increased vastus lateralis muscle activation, and decreased hip extensor moments (Pollard et al., 2009) Pollard et al. (2009) suggest that these results support the theory that females who limit motion in sagittal plane employ a strategy of reliance on passive restraints in the frontal plane to control deceleration of the body. This strategy emphasizes use of knee extensors over hip extensors to attenuate impact forces. Females who utilized high flexion landing pattern demonstrated the opposite biomechanical pattern (i.e. increased energy absorbed at the knee and hip, decreased knee extensor moments, decreased vastus lateralis muscle activation, and increased hip extensor moments) (Pollard et al., 2009). This landing strategy attenuates impact forces through a more equal utilization of the knee and hip extensors. The reason for these different strategies is not fully understood however, Pollard et al. (2009) postulate that in eccentric hip extensor weakness may contribute to a low flexion landing strategy. For example, if the hip extensors are unable to share the control of the body center of mass during landing, individuals may compensate by adopting an over-reliance on their quadriceps (Pollard et al., 2009). Although the exact mechanism of the ACL tear continues to be debated, Pollard et al. (2009) suggest that a low flexion landing strategy results in potentially abnormal loading in both planes.

D. Upper Limb Effect on Lower Limb Synchrony

While the ACL injury is the direct result of what occurs at the knee joint, it is important to consider the contribution of the entire kinetic chain to knee joint loading (Quatman et al., 2010). Motion and forces at any segment of the kinetic chain (foot, ankle, hip, trunk, and upper extremities) may influence knee joint mechanics (Quatman et al., 2010). Although characteristics of the knee and the rest of the lower limb are likely to have the most influence on the loading of the knee and the risk of injury to the ACL, the position and motion of the trunk and arms may also affect the loading environment of the knee (Chaudhari et al., 2005). In sports such as basketball, volleyball, and handball, the upper extremity is constantly called into play to handle or attend to a ball. Steele and Brown (1999) postulated that the upper-limb motion required to catch a ball may interfere with muscle coordination during dynamic tasks, such as an abrupt landing, thereby compromising the preprogrammed synchrony of the lower-limb muscles required to ensure that the integrity of the ACL is maintained (Cowling & Steele, 2001). Simulation and kinetic studies have shown that arm position does affect lower limb dynamics during a standing broad jump and during a running-forward somersault (Chaudhari et al., 2005). Despite this, only three studies have examined the influence of upper-limb motion on the function of the lower limb muscles during dynamic tasks (Chaudhari et al.. 2005; Cowling & Steele, 2001; Miyatusu et al., 1988). If upper limb motion substantially alters the synchrony of the lower limb muscles during a landing task, there are immediate applications for this knowledge with regard to developing strategies to prevent ACL injury and developing rehabilitation programs (Cowling & Steele, 2001). One Study by Miyatusu et al. (1988) compared the dynamic properties of the muscles in the knee joint as subjects jumped own from a 40 centimeter (cm) high box while throwing a ball versus not throwing a ball. Although this maneuver is vastly different than a basketball rebound task, it was the first study to analyze effect of upper limb motion on lower limb mechanics. Miyatusu et al. (1988) found that forearm extension involved in throwing a ball compared with that involved in not throwing a ball resulted in greater knee extension and suppressed hamstring activity upon landing, thereby imposing greater tibio-femoral shear forces and increasing the potential for injury of the ACL (Cowling & Steele, 2001). Miyatsu et al. (1988) suggested that the forearm extension involved in the release of the ball was responsible for the observed increase in knee extension and the suppressed hamstring-muscle activity at the time of landing. (Cowling & Steele, 2001)

A second study by Cowling and Steele (2001) compared two test conditions of (1) catching a leather netball at chest height during landing (catch), and (2) refraining from use of any pronounced upper-limb motion upon landing (no catch). The authors found when catching a pass, the subjects demonstrated earlier rectus femoris onset relative to the timing of initial ground contact and the peak of tibiofemoral shear, and they showed delayed biceps femoris onset relative to the timing of the peak tibiofemoral shear force compared with the findings in trials without catching (Cowling & Steele, 2001). Earlier activation of Rectus Femoris in catch condition (to initial contact and to peak tibial anterior shear force) suggests that upper-limb motion caused earlier activation of the anterior thigh muscles (Cowling & Steele, 2001). These results were similar to Miyatsu et al. (1988) who found increased vastus medialis, and decreased semi-membranosus activities.

Increased quadriceps contraction may promote anterior tibial translation, particularity if the hamstring muscles are not activated sufficiently to generate an antagonistic posterior-tibial drawer force. Miyatsu et al. (1988) and Cowling and Steele (2001), both suggested that motion of upper limbs delayed or suppressed the activation of the hamstring muscles which act as synergistic to the ACL. Upper limb motion was responsible for altering the preprogrammed activity of the lower-limb muscles, however the reason for this mechanism is currently unknown (Cowling & Steele, 2001).

A third study by Chaudhari et al. (2005) investigated the influence of sport-dependent variations in arm position on the valgus loading of the knee during single-limb stance of cutting maneuvers. They found that constraining the plant-side arm while holding a lacrosse stick or football resulted in significantly higher peak valgus moments (Chaudhari et al., 2005). Any condition that causes higher valgus moments during deceleration and landing may put athletes at greater risk of ACL injury. Results from these three studies suggest that adapting training methods to consider arm position as a risk factor could help to reduce the probability of non-contact ACL injury.

E. Drop Vertical Jump Studies

The drop vertical jump (DVJ) (Hewett et al., 2005) and stop jump (Chappell et al., 2002) are two land-and-jump maneuvers believed to be associated with risk factors for noncontact ACL injury. The DVJ consisted of the subject starting on top of a box (31 cm in height) with feet positioned 35 cm apart (distance measured between toe markers). Participants were instructed to drop directly down off the box and immediately perform a maximum vertical jump, raising both arms as if they were jumping for a basketball rebound. The DVJ has been shown to demonstrate high within-session reliability with intra-class correlation coefficients of greater than 0.93 (Ford, et al., 2003). Hewett et al. (2005) found that knee motion and knee loading during a drop landing task are predictors of anterior cruciate ligament injury risk in female athletes. The amount of knee abduction and external knee abduction moment during landing from a drop vertical jump

(DVJ) was predictive of women who went on to tear their ACL (sensitivity=0.78, specificity=0.73).

DVJ studies have found gender differences in that females tended to land with greater total valgus knee motion and a greater maximum valgus knee angle (Ford et al., 2003), demonstrated side-to-side imbalances with greater maximum valgus angle on their dominant leg (Ford et al., 2003), lower normalized thigh strength and greater quadriceps activation (Schultz & Perrin, 1999). In a prospective study of 205 healthy female athletes, Hewett et al. (2005) reported those who went onto injure their ACL landed with 2.5 times greater knee abduction moment, 20% greater ground reaction forces, and 16% shorter stance time.

F. Stop Jump Studies

One maneuver commonly researched, the stop-jump (SJ), is of particular interest because it is believed to mimic maneuvers commonly associated with ACL injury seen in volleyball, soccer, and basketball (Boden et al., 2000; Chappell et al., 2002).

The landing phase of the maneuver exhibits biomechanical characteristics associated with risk factors for noncontact ACL injury, and female subjects display kinematic and kinetic parameters that may predispose female subjects to a greater risk for noncontact ACL injury than male subjects (Chappell et al., 2002; Malinzak et al., 2001; Yu et al., 2006). Powel and Barber-Foss (1999) found that the rebound task accounts for 70% of all ACL tears during a basketball game. The stop jump task consists of an approach typically ranging from 2 to 5 steps, a two-footed landing with countermovement arm swing (landing phase), followed by a two-footed takeoff for maximum height (takeoff phase) (Chappell et al., 2002). The performance of the landing phase in a stop jump task is important for overall jumping performance and for the prevention of lower extremity injuries (Wang et al., 2010)

Previous stop jump studies have found gender differences in landing mechanics during these maneuvers. Chappell et al. (2002) found that female athletes exhibited greater proximal tibia anterior shear forces, knee extension moments and knee valgus moments compared with men during 3 stop jump tasks. Chappell et al. (2007) found significant gender differences in knee and hip motion patterns and quadriceps and hamstring activation patterns during a stop jump task. These authors concluded that lower extremity motion patterns during landing of a stop-jump task are preprogrammed before landing. Female subjects prepared for landing with decreased hip and knee flexion at landing, increased quadriceps activation and decreased hamstring activation, which may result in increased ACL loading during the landing of a stop jump task (Chappell et al., 2007).

Several studies found females exhibited decreased knee flexion angles at initial contact and came to the conclusion that increasing knee flexion angle at initial contact may decrease impact forces and knee loading in landing tasks (Chappell et al., 2002; Decker et al., 2003; Malinzak et al., 2001). Yu et al. (2006) however, suggest that increased hip and knee flexion angles at initial contact do not necessarily reduce the impact force during landing, but rather active hip and knee flexion motions do. Faster hip and knee flexion angular velocities at initial contact reduced impact forces during landing.

G. Neuromuscular Training Programs

Alentorn-Geli et al. (2009b) performed a systematic review of ACL injury prevention programs that were developed to modify risk factors associated with non-contact ACL injuries, and to reduce the rate of non-contact ACL injuries in soccer players. To date there is no standardized intervention program established to prevent non-contact ACL injuries (Alentorn-Geli et al., 2009b). Prevention programs have focused on neuromuscular training methods to change modifiable neuromuscular and biomechanical risk factors. Neuromuscular and biomechanical risk factors justify the need for specific sports technique modification (in such cases where skills place the athletes to a higher risk of injury, proprioception and neuromuscular training, stretching, plyometric training, adequate hamstring/quadriceps ratios, and trunk/core control training) (Alentorn-Geli et al., 2009a).

Multi-component programs show better results than single-component preventive programs to reduce the risk and incidence of non-contact ACL injuries and include: lower extremity plyometrics, dynamic balance and strength, stretching, body awareness and decision-making, and targeted core and trunk control appear to be successful training components to reduce non-contact ACL injury risk factors (decrease landing forces, decrease varus/valgus moments, and increase effective muscle activation) and prevent non-contact ACL injuries in female athletes (Alentorn-Geli et al., 2009b). Recent data, however, suggest that in spite of the increased number and quality of neuromuscular training programs, and reported early success, ACL injury rates and the associated sex-disparity have remained (McLean, Borotikar & Lucey, 2010). Improved insight into the ACL injury mechanism and the subsequent formulation of more effective injury screening and prevention methods is thus critical (Alentorn-Geli et al., 2009b).

Prevention programs were created to decrease the rate of injuries and address the faulty biomechanical risk factors of different general sport tasks. However, more biomechanical studies of sport-specific actions in basketball are needed (Alentorn-Geli et al., 2009b). Of all the prevention programs reviewed none of these programs incorporate the use of a sport-specific ball such as a basketball. Few incorporated catching a medicine ball during balance exercises (Chappell et al., 2004; Myer et al. 2005; Soderman et al., 2000) and only one incorporated catching a ball during the plyometric exercises (Myer et al., 2005). A sport-specific neuromuscular training program geared for basketball should add the complex skill of catching a ball during plyometric and balance based exercises.

Literature on non-contact ACL injuries has been extensive and has provided us with many advances in our knowledge of the mechanisms that lead to injury. Despite this ACL injuries in female athletes are still occurring at a frequent rate. Two jump-landing protocols, the SJ and DVJ, have been established to compare gender differences in landing strategies. These protocols have failed to analyze a key component of landing tasks that occur frequently in women’s sports such as basketball, soccer, and volleyball. With better understanding of the landing mechanics during the second landing of the SJ and the DVJ, enhanced neuromuscular training programs can be established.

Chapter Three: Methods

The purpose of this research study was to compare the lower extremity biomechanics and neuromuscular firing patterns in healthy female collegiate basketball, soccer and volleyball players during the second landing of two jump-landing tasks associated with ACL injury. Kinetic, kinematic, and electromyography measures were compared during the second landing of both the stop jump and drop vertical jump.

A. Participants

Nineteen female collegiate athletes (10 soccer, 6 basketball, and three volleyball players) participated (age, 20.2$\pm$ .34; height, 171 cm $\pm$ 2.23; body mass, 70.43 kg $\pm$ 2.3) in the study. All participants were clear of any health problems that may compromise their jumping or landing mechanics. All participants were required to sign a consent form indicating their willingness to participate in the study.

B. Data Collection

Kinetic, kinematic and electromyography measures were analyzed in the laboratory using synchronized biomechanical instrumentation. A Delsys electromyography (EMG) system will be used to measure muscular activation created by the quadriceps (vastus lateralis, vastus medialis, and rectus femoris), and the hamstrings (medial aspect, and lateral aspect) of the dominant leg. Electrode placement was in accordance with Fauth et al (2010), who found EMG measurement is a reliable method for assessing the reproducibility of both the quadriceps and hamstrings muscle activation during either isometric or ballistic exercises. Electrodes were placed on the longitudinal axis of the muscles with the rectus femoris electrode placed halfway between the greater trochanter and medial epicondyle of the femur. The vastus lateralis electrode was placed one quarter of the distance from the midpoint of the lateral line of the knee joint to the anterior superior iliac spine. The vastus medialis electrode was located 20% of the distance from the anterior superior iliac spine to the midpoint of the medial joint line. A point was made for the midline of the hamstring belly located halfway between the gluteal fold and the popliteal fossa. The lateral hamstring electrode was placed 3 cm lateral of the midline point, and the medial hamstring was placed 3cm medial of the midline point. A ground electrode was placed on the patella of the non-dominant leg. The sensors were attached to the skin with a double-sided adhesive sensor interface and oriented so that the two silver bar contracts were perpendicular to the muscle fibers. Skin preparation included cleansing with alcohol wipes, and light abrasion. All electrodes were secured properly with tape. EMG wires were secured with twist ties and taped to the amplifier. The EMG signals were detected with DE-2.1 sensors (Delsys Inc.) and amplified by a Bagnoli™ 8-channel system (Delsys Inc.) The amplifier gain was set to 1000 and the EMG signal filtered to a bandwidth between 20 Hz and 450 Hz. The EMG signal was sampled at 1000 Hz.

Kinematic data was collected using a 7 camera high speed motion capture system (Vicon Nexus 1.4.116). A rigid body segmental skeleton was created using the Vicon static gait model. The video data were collected at a rate of 240 Hz. Kinematic data was filtered using a Woltring method. The data was analyzed using Polygon Version 3.1. and Microsoft Excel.

Kinetic data was collected using two AMTI force plates (Advanced Medical Technologies, Inc., Watertown, Mass) sampled at 960 Hz. A Vicon Analog to Digital Interface Unit converted input analog voltage (or current) to a digital number proportional to the magnitude of the voltage. Sixteen reflective markers were placed along the lower extremity at the posterior superior iliac spine, anterior superior iliac spine, left and right shafts of the femurs, both lateral aspects of the knee at the joint line, bilateral lower shanks, lateral malleoli, heels, and distal head of the second metatarsals. Each subject's height, weight, knee widths, and ankle widths were recorded.

C. **Procedures**

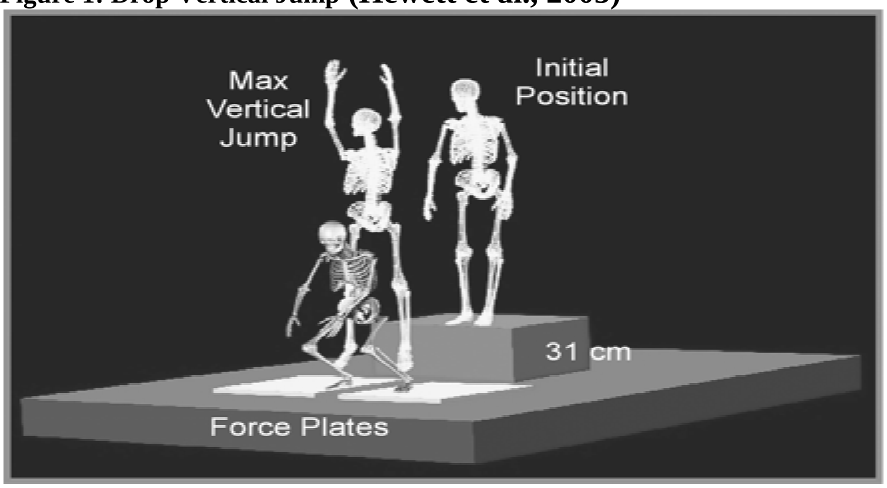
Data collection occurred on one test day and took approximately one hour per participant. Prior to the testing procedures each participant warmed up on an ergometer bike, and performed a light dynamic stretching routine. The participant then performed a vertical jump test (VJ). A Vertec Jump Measurement & Jump Training System was used to record the participant's maximum vertical jump height. The participants performed three maximal vertical jumps, and the highest reach height of these three jumps was recorded. This test was performed in proper athletic footwear and comfortable clothing. The participants then had a five-minute rest before performing the next two jumping tasks.

To perform the drop vertical jump and stop jump task the participants were asked to wear tight fitted shorts and a sports bra or tank top. Participants wore the same athletic footwear as in the previous test. Retroreflective markers and electromyography electrodes described above were attached to the participant during these tests.

In both the drop vertical jump and stop jump tests, a basketball was suspended from the ceiling at 80% of the participant's maximal vertical jump height. The basketball was connected to a small wood block hanging from a rope with Velcro straps allowing for easy release. The participant was required to grab the ball and successfully land on the force plates with the basketball in hand. A successful trial was defined as one in which the subject performs the tasks as required and all data was successfully collected. The order in which each athlete completes the following two tasks was randomized.

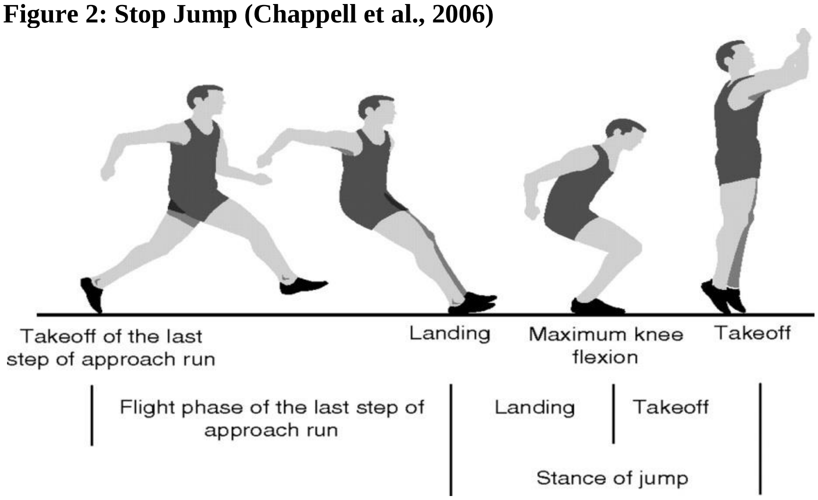
For the drop vertical jump, the participant was given as many practice trials as needed to become familiar with the movement. Each participant performed three successful trials of the drop jump task with a minimum one-minute time interval between trials to prevent fatigue. The DVJ consisted of the participant starting on top of a box (31 cm in height) with feet positioned 35 cm apart (distance measured between toe markers). Participants dropped directly down off the box and immediately perform a maximum vertical jump, raising both arms and grabbing the basketball overhead, and then landing successfully with the basketball on two feet onto two force plates.

Figure 1: Drop Vertical Jump (Hewett et al., 2005)



For the stop jump, the participant was given as many practice trials as needed to become familiar with the movement. Each participant performed three successful trials of the stop jump task with a minimum one-minute time interval between trials to prevent fatigue. The stop jump task consisted of the participant taking a two-step approach run, two foot landing, an immediate maximum vertical jump to grab a basketball suspended overhead, and then successfully landing with the basketball in hand on two feet onto two force plates.

Figure 2: Stop Jump (Chappell et al., 2006)



Kinematic, kinetic and electromyography variables were collected during the second landing after the participant successfully landed with the basketball in their hands on the force plate. All variables were collected for the dominant leg only.

D. **Data Analysis**

Three separate MANOVAs were conducted on the kinematic, kinetic, and electromyography dependent variables for both the drop vertical jump and stop jump. Statistical analysis was conducted using SPSS 17.0 software (SPSS Inc. Chicago, IL). Within each task nine dependent variables were analyzed at initial contact and peak knee flexion. These dependent variables included knee flexion angle at initial contact, hip flexion angle at initial contact, peak knee valgus angle, peak knee extension moment, peak knee valgus moment, peak vertical ground reaction forces, hamstrings to quadriceps activation ratio (Q:H) at initial contact and peak vertical reaction forces, and peak proximal tibial anterior shear force. Initial contact was defined as the point at >10 N of vertical ground reaction force. The vastus lateralis electrode values were dropped from the study due to the erratic results. Ground reaction and joint forces were normalized for body weight. Joint moments were normalized for body weight and height. Statistical means and standard deviations for each dependent variable were calculated. The data was inspected and outliers were transformed to ensure normality and sphericity of the MANOVA were not violated.

Chapter Four: Results

Three separate MANOVAs were run to compare the dependent variables (kinematics, kinetics, EMG) between the two tasks (stop jump, drop vertical jump). The MANOVA comparing kinematics between the two tasks found no significant results as indicated by the Wilks' Lambda (3, 78) = .106 p >.05). The MANOVA comparing kinematics between the two tasks found no significant results as indicated by the Wilks' Lambda (4, 87) = .257 p >.05). The MANOVA comparing electromyography variables between the two tasks found no significant results as indicated by the Wilks' Lambda (2, 84) = .164 p >.05). No significant effects were found for any of the kinematic, kinetic, and electromyography variables compared between the two tasks. The means and standard deviations for all the dependent variables are presented below.

Table 1: Kinematic means and standard deviations

Kinematics			
		Mean	SD
Drop Jump	Knee Flexion	8.74	4.8
	Hip Flexion	16.49	8.7
	Knee Valgus	13.1	8.2
Stop Jump	Knee Flexion	11.3	6.4
	Hip Flexion	20.2	8.8
	Knee Valgus	15.18	7.7

Table 2: Kinetic means and standard deviations

Kinetics			
		Mean	SD
Drop Jump	Knee Extension Moment (N*m/mass*height)	0.04	0.022
	Knee Valgus Moment (N*m/mass*height)	0.02	0.022
	Peak Anterior Tibial Shear Force (N/mass)	0.137	0.045
	Vertical Ground Reaction force (N/ Body Weight)	1.94	0.029
Stop Jump	Knee Extension Moment (N*m/mass*height)	0.038	0.025
	Knee Valgus Moment (N*m/mass*height)	0.01	0.016
	Peak Anterior Tibial Shear Force (N/mass)	0.127	0.041
	Vertical Ground Reaction force (N/ Body Weight)	1.98	0.395

Table 3: Electromyography means and standard deviations

EMG			
		Mean	SD
Drop Jump	Q:H at IC	1.44	0.912
	Q:H at peak VGRF	2.73	2.576
Stop Jump	Q:H at IC	1.43	0.891
	Q:H at peak VGRF	2.01	2.176

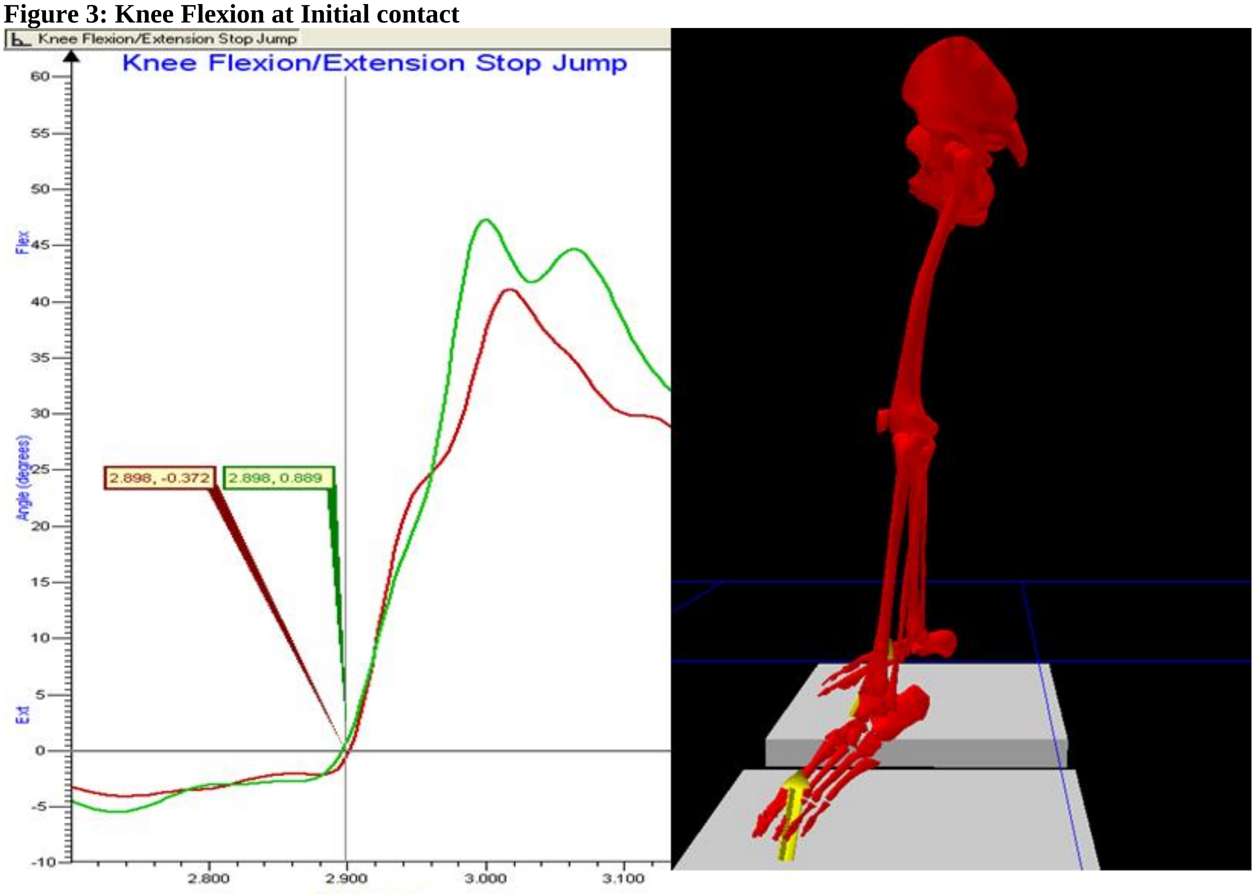
Chapter Five: Discussion

The drop vertical jump and stop jump are 2 land-and-jump maneuvers believed to be associated with risk factors for noncontact ACL injury and these jump-landing protocols (drop jump and stop jump) have been proscribed to represent a variety of movement tasks seen in a several different sports including volleyball, soccer, and basketball (Chappell et al., 2002; Hewett et al., 2005). Identification of these ACL injury risk factors has lead to neuromuscular training programs designed to prevent ACL injury and modify ACL injury risk factors (Alentorn-Geli et al., 2009b). While many studies on these programs have reported success in improving potential ACL injury risk factors, ACL injury numbers continue to be high (Agel, Arendt, & Bershadsky, 2005). A potential reason for the continuing high rates of ACL injuries could be due to the fact that drop vertical jump and stop jump studies have only measured ACL injury risk factors during the first landing (initial deceleration) of the task. To the author's knowledge, this is the first study to compare the kinematic, kinetic, and electromyography variables during the second landing (descending after maximal jump) of these tasks. Identification of ACL injury risk factors exhibited during the second landing could explain the lack of decline in ACL injury rates despite the improvement and insight into neuromuscular training programs.

The purpose of this study was to compare the kinematics, kinetics and muscular activation patterns during the second landing between the stop jump and drop jump. As indicated above, no significant differences were found among kinematic, kinetic, and electromyography variables between the tasks.

The kinematic variables analyzed in this study were knee flexion angles, hip flexion angles, and valgus angles. Previous studies have found low knee flexion angles at initial contact have been associated with ACL injuries (Boden et al., 2000; Krosshaug et al., 2007). An example of low knee flexion angle at initial contact can be seen in figure 3. In the present study, knee flexion angles were lower during the drop vertical jump (8.74° $\pm$ 4.8) than the stop jump (11.3° $\pm$ 6.3). This would indicate that the drop vertical jump exhibited higher ACL injury factor than the stop jump in terms of knee flexion upon landing. Interestingly, Chappell and Limpisvasti (2008) also found lower knee flexion angles at initial contact during the first landing in the drop vertical jump (29.9° ± 9.0) compared to the stop jump (36.4° ± 9.4). Chappell and Limpisvasti (2008) hypothesized this differences was most likely because the stop jump task is a more dynamic jumping task and introduces shear with the horizontal approach.

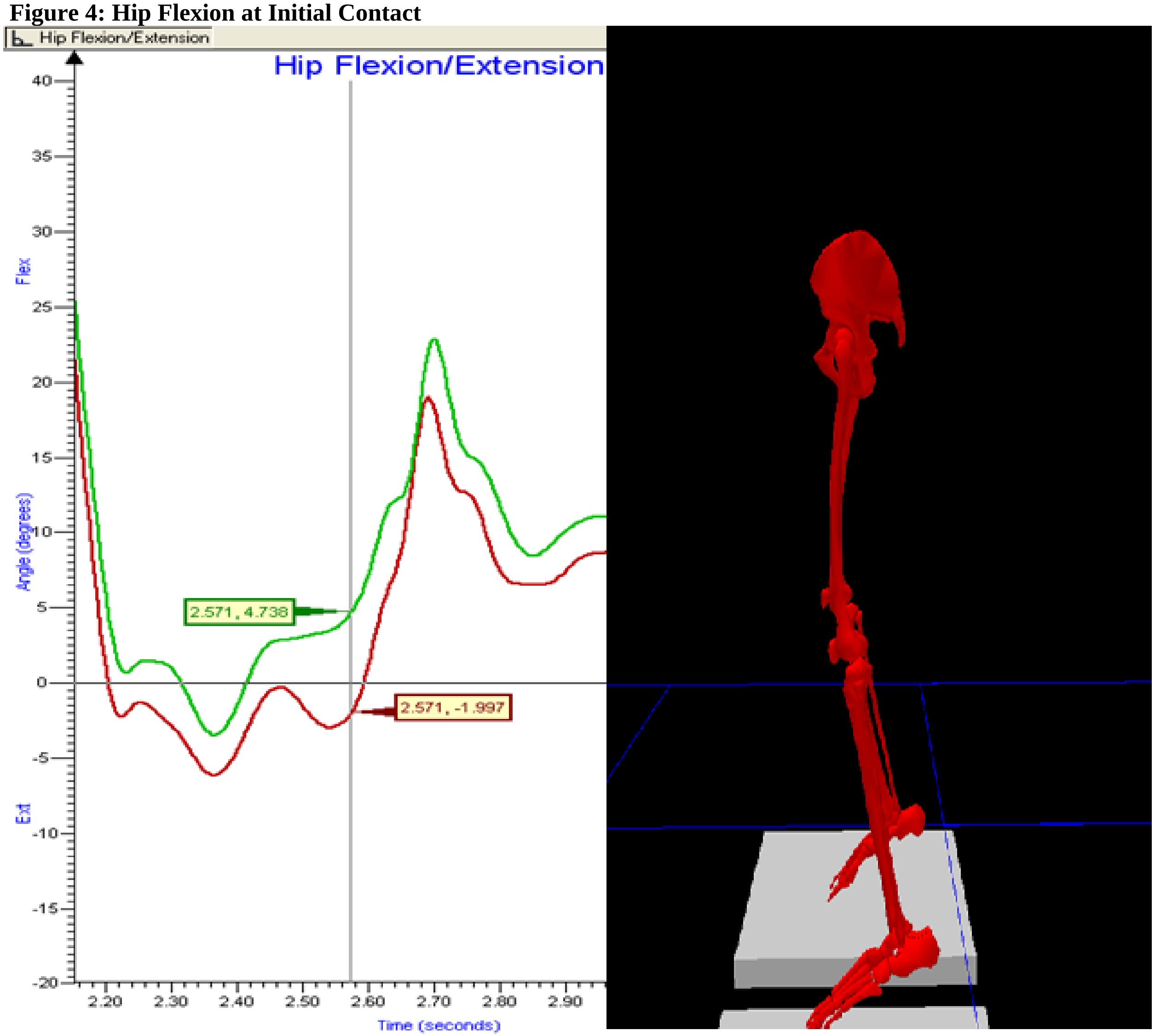
Figure 3: Knee Flexion at Initial contact



Decreased hip flexion angles at initial contact of landing has been postulated to place the ACL at a greater risk of injury, because a greater peak landing force is transmitted to the knee

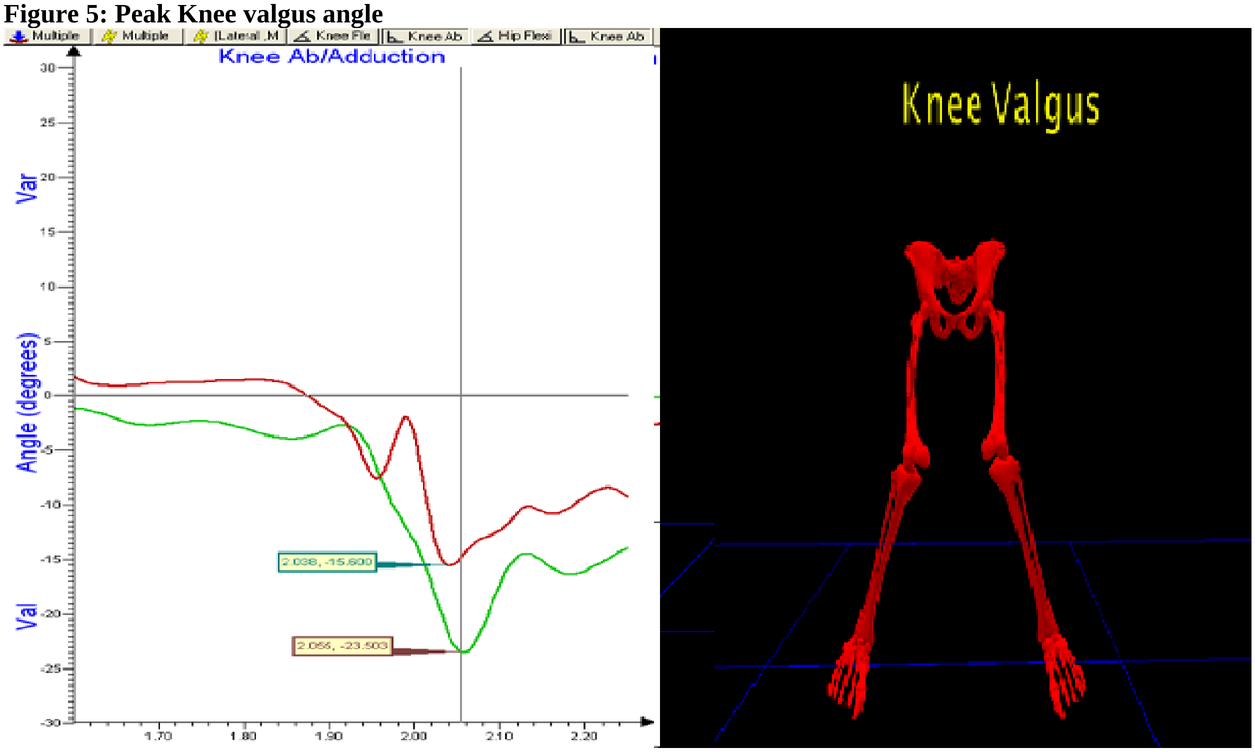
(Alentorn-Geli et al., 2009a). An example of low hip flexion at initial contact can be seen in figure 4. In the present study, hip flexion angles were lower during the drop vertical jump (16.49° + 8.7) than the stop jump (20.17° + 8.8). This would indicate that the drop vertical jump exhibited a higher ACL injury risk factor than the stop jump in terms of the decreased hip flexion upon landing. Yu et al. (2006) found that female athletes who exhibited smaller hip and knee flexion angles at the initial foot contact with the ground landed with greater impact forces. Chappell and Limpisvasti (2008) found greater hip flexion angles at initial contact during the first landing during the drop vertical jump (54.8° ± 11.4) compared to stop jump (72.2° ± 11.0).

Figure 4: Hip Flexion at Initial Contact



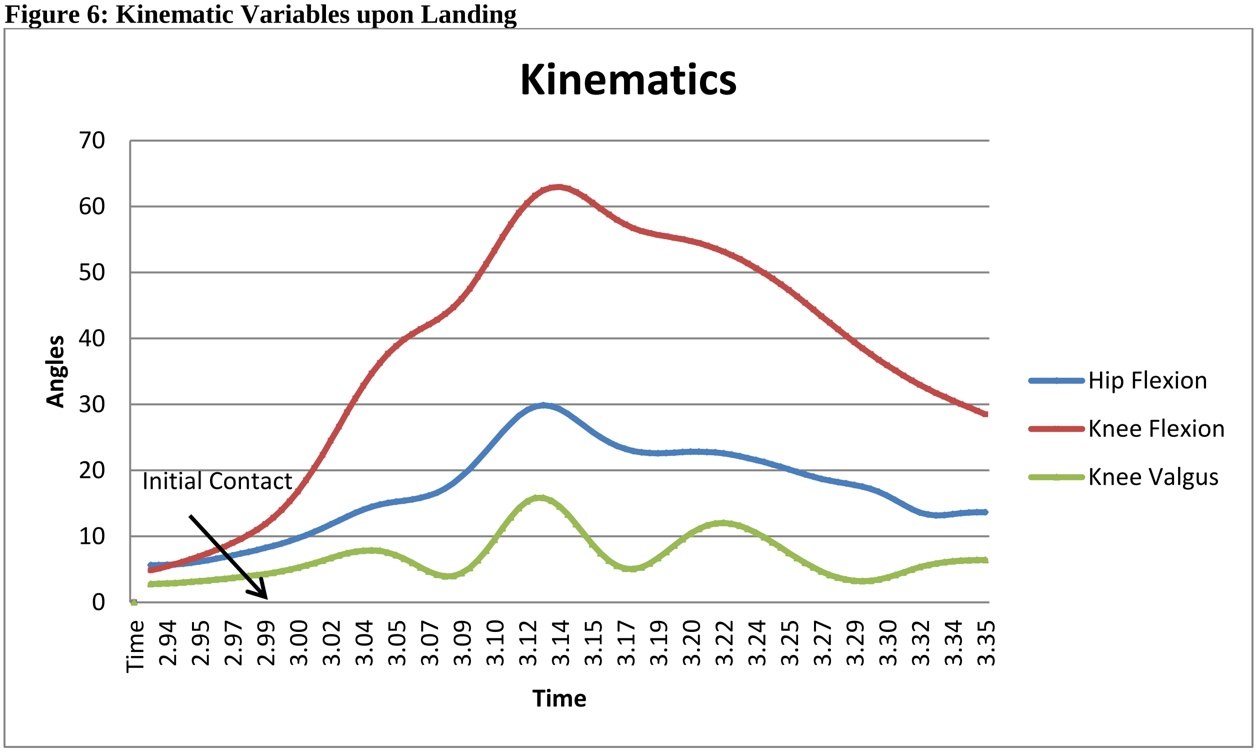
Valgus collapse, a commonly reported scenario for ACL injury, is a situation where the knee collapses medially from excessive valgus motion at the knee (Krosshaug et al., 2007). High valgus angles suggest an inability of an athlete's musculature to control ground reaction forces, and as a result ligaments such as the ACL may absorb these additional forces (Cowley et al., 2006). An example of a high knee valgus angle can be seen in figure 5. Peak knee valgus angles in the present study were greater in the stop jump (15.18° ± 7.7) than the drop vertical jump (13.11° ± 8.2). This would indicate that the stop jump exhibits a higher ACL injury risk factor in terms of frontal plane kinematics at the knee. However, these values were very similar with a large standard of error. Chappell and Limpisvasti, (2008) found peak knee valgus angles to be higher during the first landing in the stop jump (28.4° ± 10.8) than the drop vertical jump (25.7° ± 14.7). These kinematic results showed that female athletes exhibit more sagittal plane ACL injury risk factors during the drop vertical jump, and more frontal plane ACL injury risk factors during the stop jump.

Figure 5: Peak Knee valgus angle



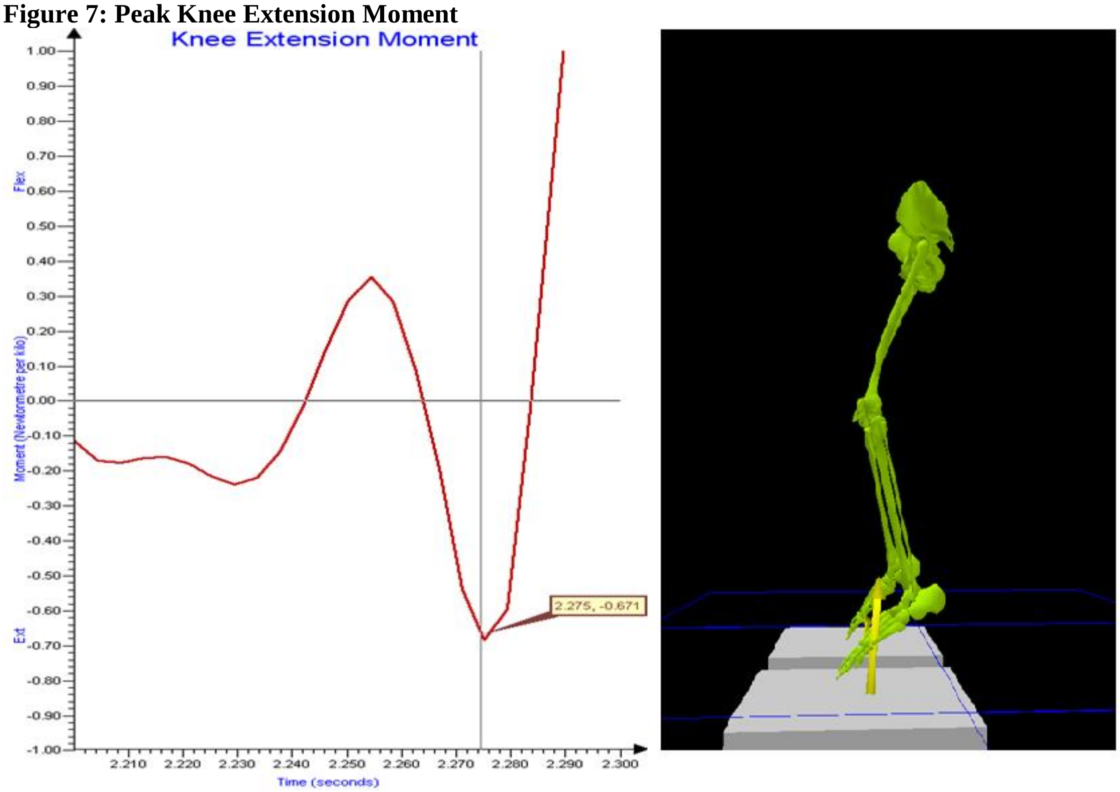
The interaction of the kinematic variables during the second landing of a stop jump can be seen in figure 6. The drop jump exhibited lower hip and knee flexion angles, while the stop jump exhibited slightly higher knee valgus angles. Devita and Skelly (1992) found during the 1st landing of a drop jump that female athletes who limited their sagittal plane loading at the hip and knee via low flexion angles, relied on frontal plane loading to decelerate the body center of gravity by increasing knee valgus angles. In this study however, no such interaction was able to be found upon the second landing of these tasks.

Figure 6: Kinematic Variables upon Landing



The kinetic variables in this study analyzed were peak knee extension moment, peak valgus moment, peak anterior tibial shear force, and peak vertical ground reaction force. Previous studies have indicated that the quadriceps muscle is the major contributor to the ACL loading (Shelburne et al., 2004; Yu et al., 2006) Knee extension moment is also an indicator of ACL loading because patella tendon force is the result of quadriceps muscle contraction and quadriceps are the major knee extension muscles (Shelburne et al., 2004; Yu et al., 2006). An example of peak knee extension moment can be seen in figure 7. The peak knee extension moments in this study were slightly higher in the drop vertical jump (.004 N·m ±.022) than in the stop jump (.0038 N·m ± .0025). These values were much lower than results found by Yu et al (2006) who found peak knee extension moment values of .18 N·m ± .05 during the first landing of a stop jump for recreational female athletes. The use of collegiate female athletes in this study instead of recreational athletes could account for the large discrepancies. Most likely, this indicates that the knee extension moment does not play much of a role during the second landing of a drop vertical jump or a stop jump.

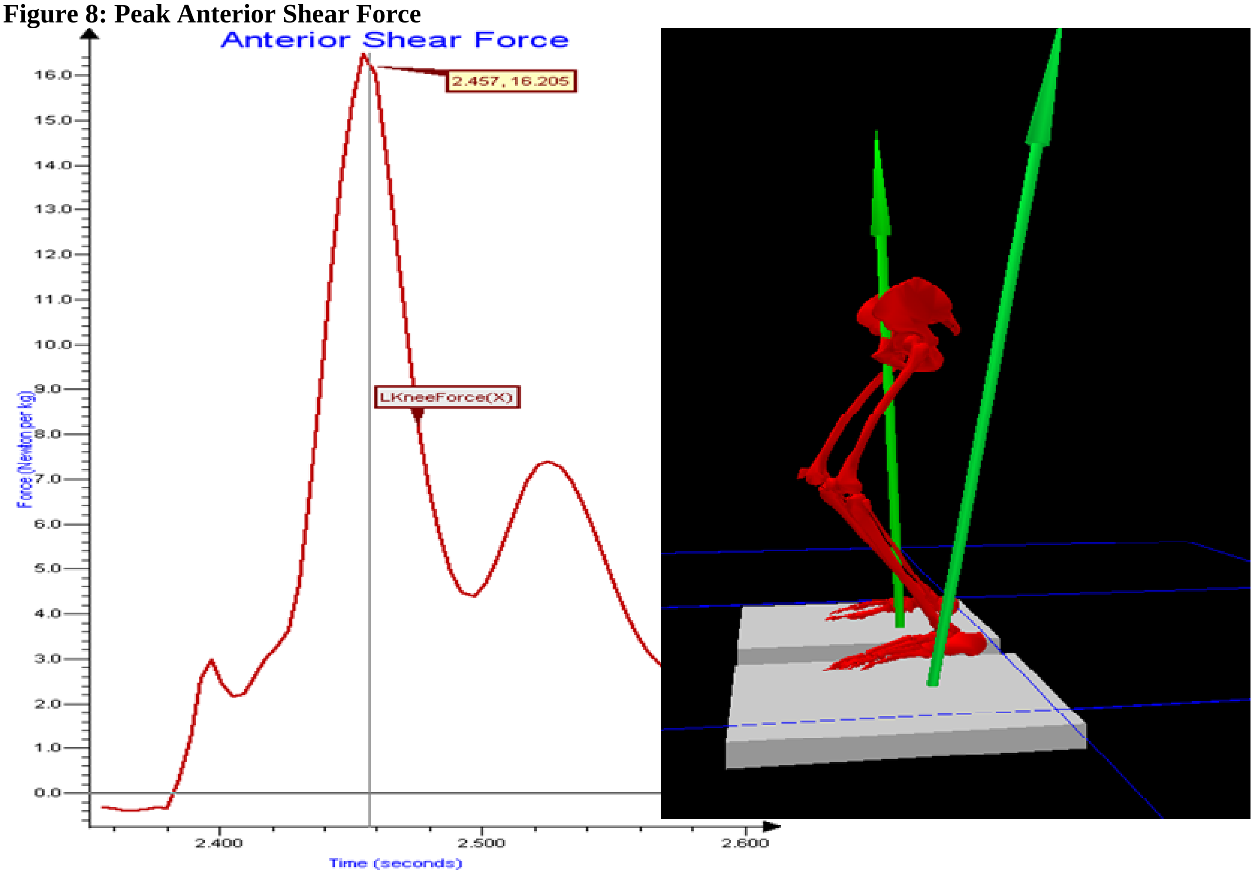
Figure 7: Peak Knee Extension Moment



Anterior shear forces in the knee cause the tibia to translate anteriority relative to the femur and to load the ACL (Kulas, Hortobagyi, & Devita, 2010). Markolf, Burchfield, and

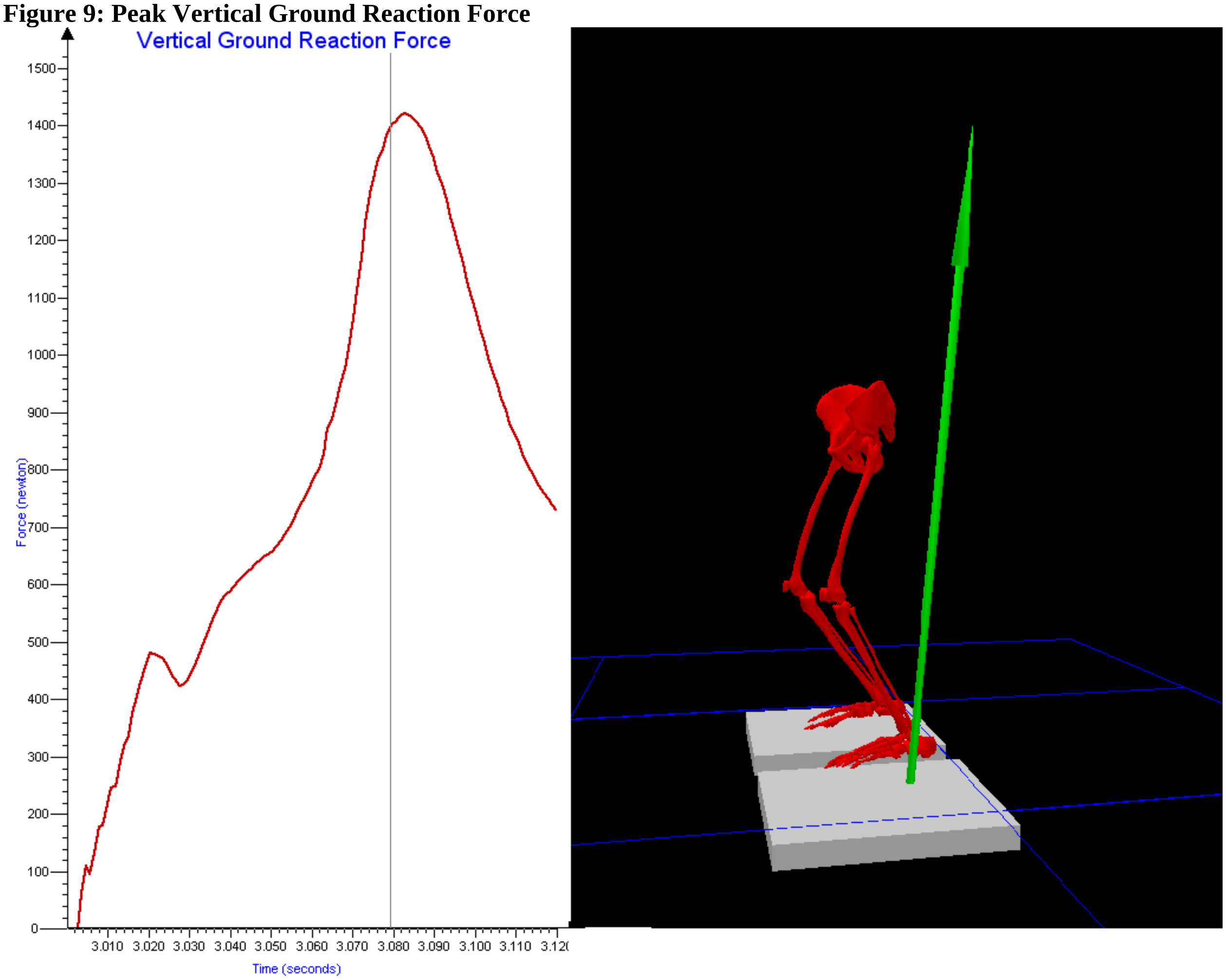
Shapiro (1995) found that anterior shear force at the proximal tibia is the major ACL loading mechanism. ACL loading is also reduced as the knee flexion angle is increased (Alentorn-Geli et al., 2009a). An example of peak anterior shear force can be seen in figure 8. In this study, peak anterior shear forces were higher during the drop vertical jump (.137 N + .45) than the stop jump (.127 N ± .04). These values were much lower than results found by Yu et al (2006) who found peak anterior shear force values of .79 N ± .34 during the first landing of a stop jump. This may indicate that the knee extension moment does not play much of a role during the second landing of a drop vertical jump or a stop jump.

Figure 8: Peak Anterior Shear Force



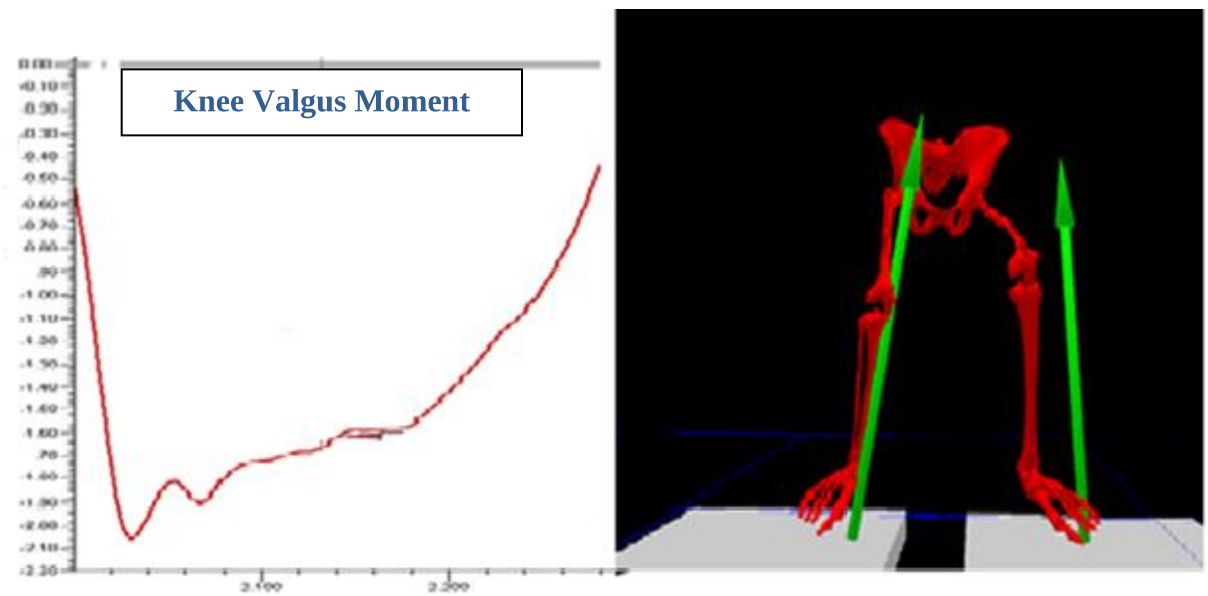
Previous studies have demonstrated a significant relationship between peak ground reaction forces and knee injury (Devita & Skelly, 1992) particularly to ACL loading (Shelburne, Pandy, Anderson, & Torry, 2004). The impact on the lower extremity passive restraints, such as the ACL, increases as the peak vertical ground reaction forces increase (McNitt-Gray, 1991). Peak vertical ground reaction forces may elaborate internal loads that may cause injury if not sufficiently distributed or attenuated by the musculoskeletal system (Devita & Skelly, 1992). In this study, peak vertical ground reaction forces were lower during the drop vertical jump (1.94 N ± .029) than the stop jump (1.98 N ±.395). Interestingly, these values were much lower than the peak vertical ground reaction forces during the first landing in Yu et al. (2006) 2.67 N ± .95, but identical to Milner et al. (2011) 1.98 N ± .59.

Figure 9: Peak Vertical Ground Reaction Force



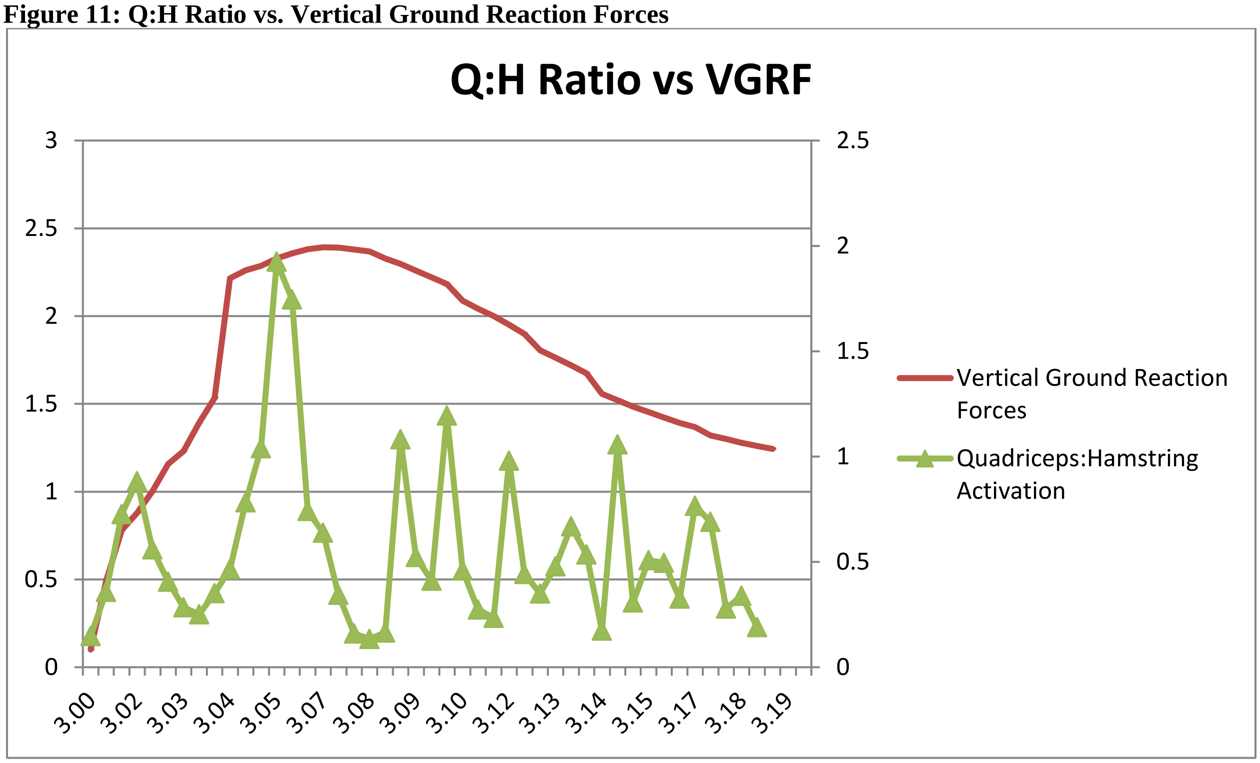
Dynamic valgus torques on the knee can significantly increase anterior tibial translation and load on the ACL several-fold (Hewett et al., 2006). The knee valgus moments in this study were lower in the stop jump (.01 N·m ± .016) than the drop vertical jump (.02 N·m ± .022). These were significantly lower than Milner et al. (2011) who found knee valgus moments of .45 ± .14 during the first landing of a stop jump. These values could suggest that valgus moments are not significant during the second landing.

Figure 10: Peak Knee Valgus Moment



The quadriceps and hamstrings muscles exhibit an agonist-antagonist relationship that plays in important role in stabilizing the knee. Deficits in strength and activation of the hamstrings directly limit the potential for muscular co-contraction to protect the ligaments about the knee (Hewett et al., 2005). The electromyography variables measured during this study were the ratio of Quadriceps to Hamstring (Q:H) at initial contact with the ground, and at peak vertical ground reaction. At initial contact the Q:H ratio was almost identical between the drop vertical jump (1.44 mV ± .912) and the stop jump (1.43 mV ± .891). These results were in accordance with previous studies who also found female athletes to demonstrate a preferred quadriceps activation strategy upon landing (Chappell et al., 2007; Cowley et al., 2006; Hewett et al., 2005; Huston & Wojtys, 1996; Padua et al., 2005). The Quadriceps to Hamstring ratio at peak vertical ground reaction force was greater during the drop vertical jump (2.73 mV $\pm$ 2.576) than the stop jump (2.01 mV $\pm$ 2.176). This would indicate that the drop vertical jump may exhibit a higher ACL injury risk factor than stop jump. To the author's knowledge, no study has compared differences in neuromuscular firing patterns between the stop jump and the drop vertical jump during the first or second landings.

Figure 11: Q:H Ratio vs. Vertical Ground Reaction Forces



There were several limitations to the current study. Only female athletes from Barry University participated in the study limiting the demographic range that the results can be applied to. Traditional studies stop jump and drop vertical jump studies have investigated for effects between genders. The purpose of this study was not to investigate for gender differences in jump-landing mechanics because this has already been well established in literature. The use of a basketball may have increased variance between the two jumps and within the three trials. However, the use of the basketball was intended to incorporate a more sport specific nature.

An interesting trend noticed in this study that should be analyzed in future studies is the timing relationship between kinematic, kinetic, and electromyography variables during the two jump landing tasks. An example of these trends can be seen in Figures 11, 12 & 13.

Figure 12: Electromyography vs. Kinetic Variables

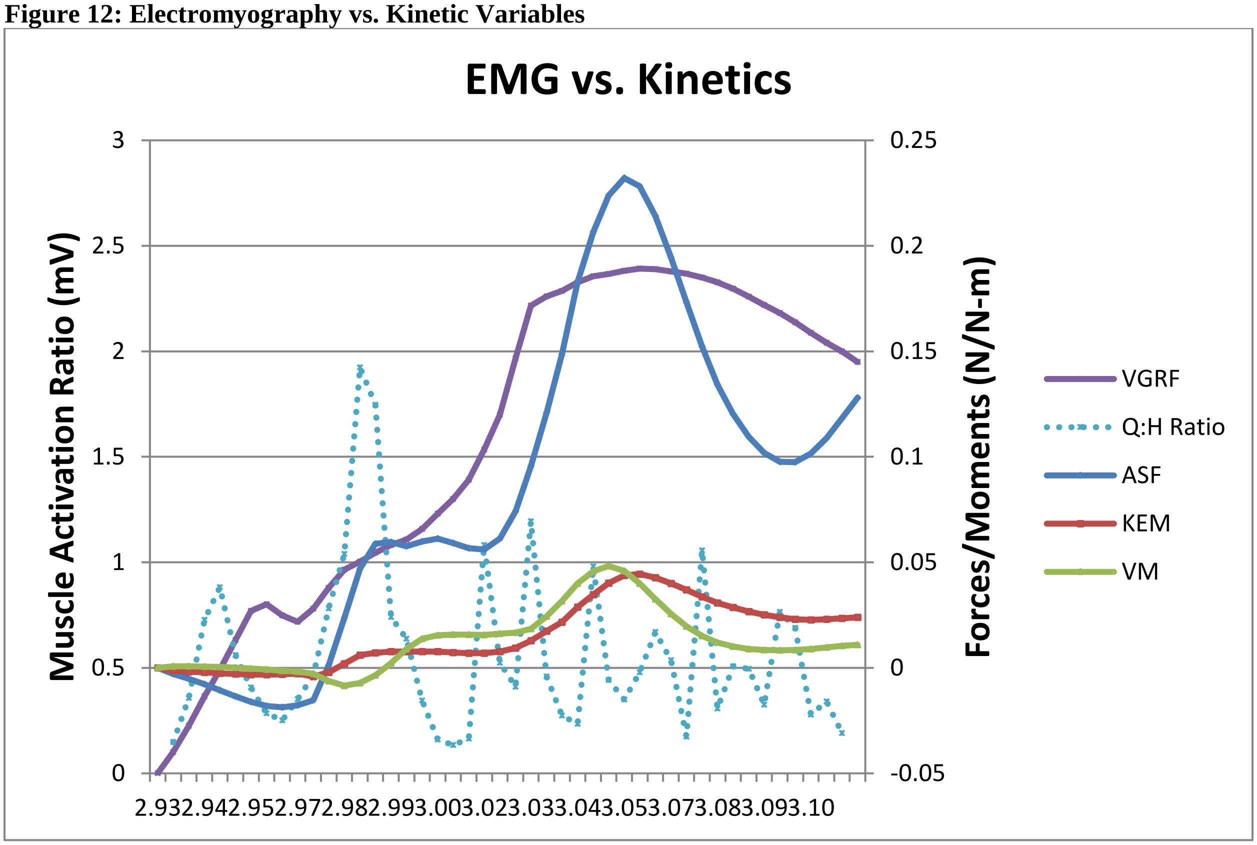


Figure 13: Electromyography vs. Kinematic Variables

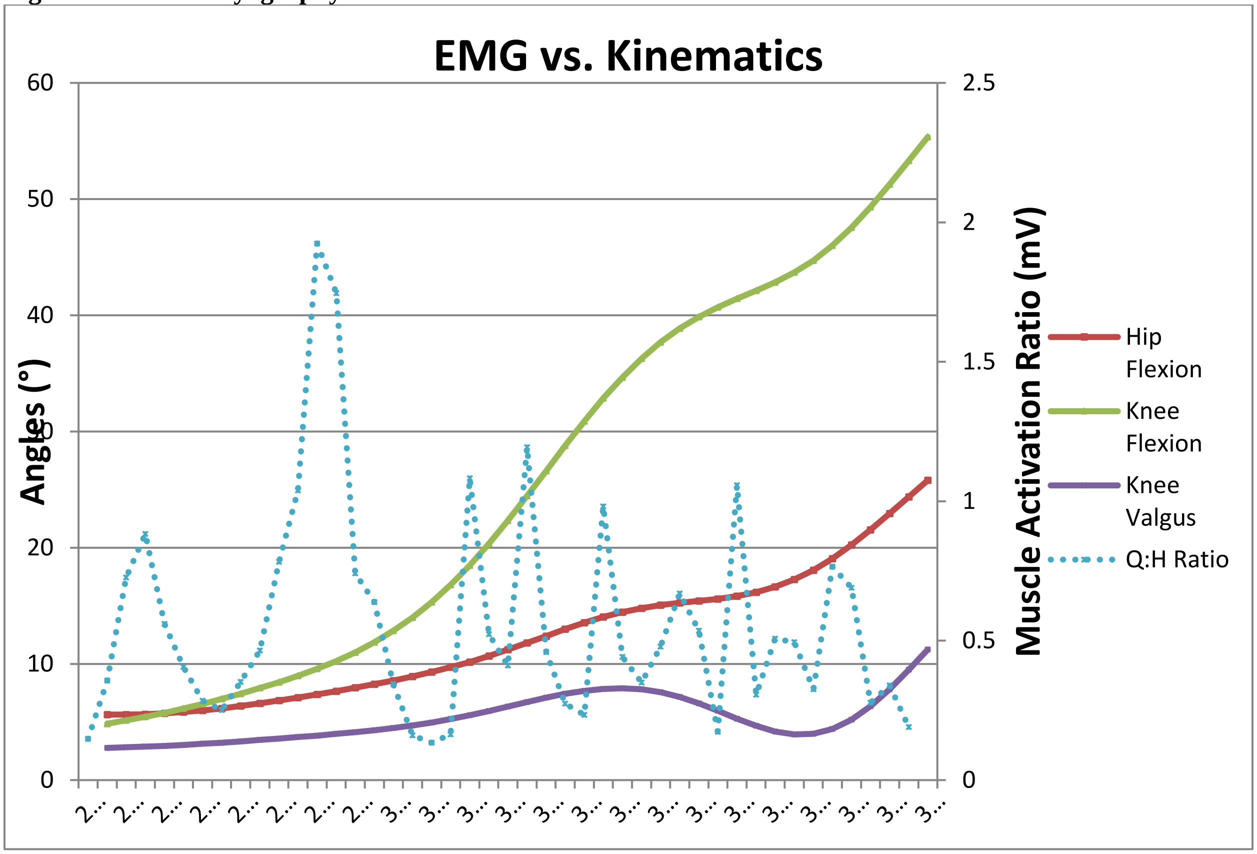
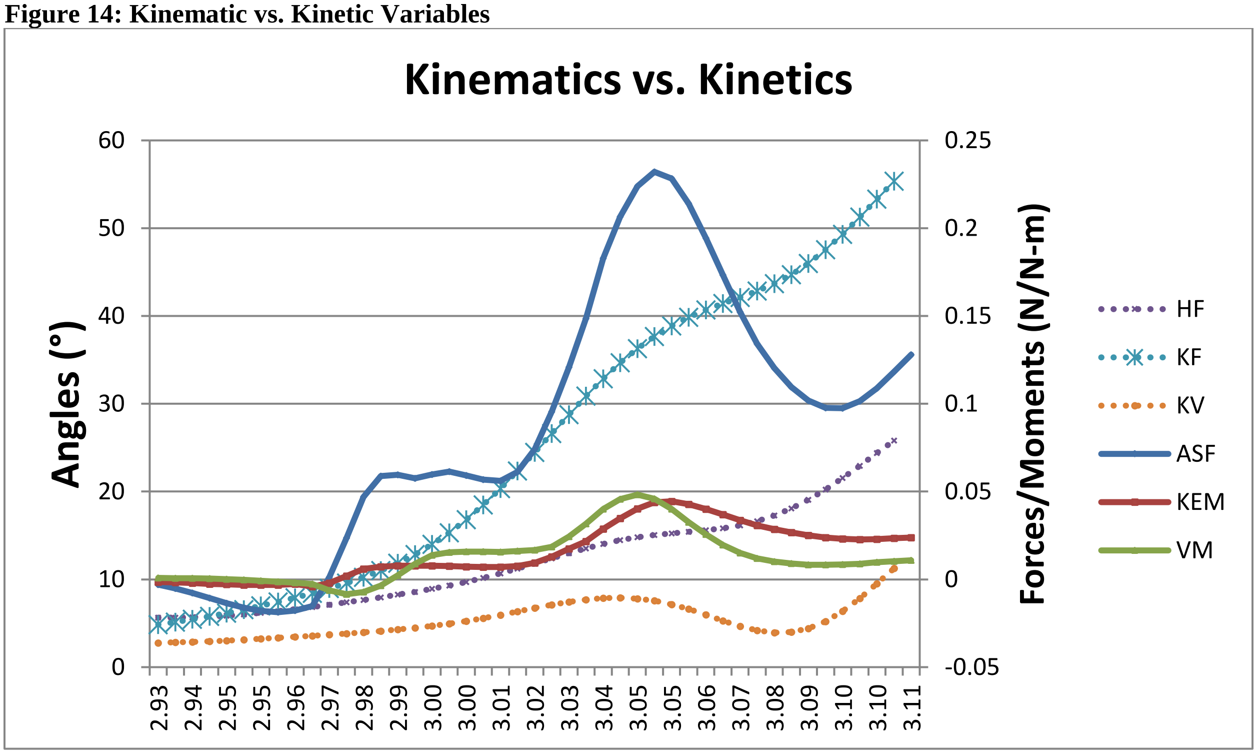


Figure 14: Kinematic vs. Kinetic Variables



Conclusion

In summary, it appears that the drop vertical jump produced higher ACL injury risk factors than the stop jump with a lower knee flexion upon landing, lower hip flexion upon landing, higher peak knee extension moments, higher peak anterior shear forces, higher knee valgus moments, and a higher quadriceps to hamstring activation ratio during the second half of landing. The stop jump exhibited higher ACL injury risk factors compared to the drop vertical jump with higher peak knee valgus angles, and peak vertical ground reaction forces. The two tasks were almost identical in quadriceps to hamstring ratio upon initial contact of landing. The kinematic variables, electromyography variables, and vertical ground reaction forces produced results that are seen to increase ACL injury risk previously measured during the first landing of these tasks. However, the lack of significant joint reaction forces and moments indicated that the low knee flexion, low hip flexion, high knee valgus, and high quadriceps to hamstring activation ratio may not have been significant enough. This study was the first to establish biomechanical and neuromuscular values of the stop jump and drop vertical jump during the second landing. Future studies should compare the first and second landings of these jump-landing tasks.

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APPENDIX A: INFORMED CONSENT FORM

Barry University
Informed Consent Form

Your participation in a research project is requested. The title of the study is "Comparison of the Second Landing During a Stop Jump and Drop Vertical Jump Task: Implications for ACL Injury." The research is being conducted by Steven E. Capehart, Graduate Student of Biomechanics in Movement Science in the Department of Sport and Exercise Science at Barry University. Four additional graduate students in biomechanics will be assisting with data collection and analyses. The aim of the research is to gather information analyzing the female landing strategies during two jump-landing maneuvers commonly associated with a high risk of ACL injury. You will be asked to first perform a vertical jump test. You will then be asked to perform 3 trials of each jump-landing task with adequate rest in between each task. The tasks will be performed in one day and should take no longer one hour. These tasks are described below.

Vertical Jump (VJ) A Vertec Jump Measurement & Jump Training System will be used to record the your maximum vertical jump. You will perform three maximal vertical jumps, and the highest reach height of these three jumps will be recorded. This test will be performed in proper athletic footwear and comfortable clothing.

A basketball will be suspended from the ceiling at approximately 80% of your maximal vertical jump height. You will be required to grab the ball and successfully land on the force plates with the basketball in hand during each of the next two jump-landing tasks.

For these tasks, reflective markers and surface electrodes will be attached to your skin using adhesive tape. The electrodes will be placed on the anterior and posterior thigh. Markers will be placed on the hip, two in front and two in the back. On each leg/foot a marker will be placed on the mid thigh, knee, mid lower leg, ankle, back of heel and top of foot.

Drop Vertical Jump (DVJ)
The DVJ will start with you standing on top of a box (31 cm in height) with feet positioned 35 cm apart (distance measured between toe markers). You will then be instructed to drop directly down off the box and immediately perform a maximum vertical jump, raising both arms to grab the basketball overhead and successfully land with it.

Stop Jump
The stop jump task will consist of you with taking an approach run typically ranging of 2 steps, a two-footed landing, an immediate maximum vertical jump raising both arms to grab the basketball overhead and successfully land with it.

There are no foreseeable risks or discomforts to you resulting from participation in this research program, other than those associated with physical performance testing. This means you may experience mild shortness of breath while performing these tests. You may also experience a feeling of fatigue, characterized by a slight burning sensation in the muscles or a feeling of "heaviness" in your lower-extremities following this test, nothing out of the ordinary for athletes or what is commonly experienced by athletes on a regular basis during training and competition. Ample rest periods between trials will be given to minimize the risk of this effect, and any feeling of fatigue should last no more than 3-5 minutes following test completion. The action performed in these tests is similar to ones found the in plyometric portion of a collegiate strength and conditioning program and testing. Though unlikely, there is a chance of lower-extremity muscular or joint injury during this movement. The risk of this occurring is no more than would be experienced during athletic competition or a typical strength and conditioning testing. This risk will be minimized through the use of ample rest periods to limit fatigue, warm up prior to testing and practice trials of the different vertical jumps and the two different starting positions.

Participation in this study will have no direct benefits to the participant. The knowledge gained as a result of this investigation could benefit society by contributing to the current knowledge of ACL research regarding female landing strategies during 2 movements that simulate high ACL risk of injury mechanisms. A better understanding of female landing strategies can further improve ACL injury prevention programs that exist today

As a research participant, any information provided will be held in confidence to the extent permitted by law. Only the Principle Investigator and the Faculty Advisor (Dr. Claire Egret) will have access any personal information provided. All other research assistants will know that the athletes are participating in the study, but will not know anything (e.g., injury history, health history, or age) that goes beyond their presence as assistants during data collection at pre- and post-test. Since many students have access to the program used to collect biomechanical data, participants will be assigned a code, which will be used to reference them in all tests. All data collected via the infrared cameras and force plates will be stored in this manner, and none of this data can be used to physically identify any participant. This will eliminate the participant's name from being on any documents, excepting the Informed Consent, which will be stored under lock and key in the Faculty Advisor's office. Should any published results occur from this investigation, the data will refer to group averages and will not refer to any participant by name. No photos of participants will be taken or used at any time. Data will not be destroyed for a minimum of 7 years, but may remain in the possession of the Principle Investigator indefinitely. Due to the use of coding, this data will in no way be able to be traced back to the participants. Despite all efforts to conceal the identity of the participants, anonymity cannot be guaranteed since they will be undergoing testing and training in public locations.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Steven E. Capehart, Dr. Claire Egret at (305) 899-3064 or the Institutional Review Board point of contact, Barbara Cook, at (305) 899-3020. If you are satisfied with the information provided and are willing to participate in this research, please signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Steven E. Capehart and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment and understand that I may discontinue my participation at any time.

_____________________ __________

Signature of Participant *Date*

_____________________ __________

Appendix B:

TITLE

Comparison of the Second Landing During a Stop Jump and Drop Vertical Jump

Authors

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KEY WORDS

ACL injury, Drop vertical jump, Stop jump

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Article Format

Abstract

ACL injuries are the most frequently and debilitating knee injuries in sport. There exists a large gender disparity with female athletes tearing their ACLs at an alarmingly much higher rate (4-6) times that of their male counterpart. Two jump-landing protocols the drop vertical jump and stop jump have been studied because they represent ACL injury inciting maneuvers. These tasks have been proscribed to represent movements commonly seen in basketball, volleyball, and soccer. However, previous research has only focused on the first landing (initial deceleration) of these jump-landing protocols. The purpose of this study was to compare the differences between the drop vertical jump and stop jump during the second landing of these tasks. Nineteen female collegiate athletes were recruited to participate in this study. Three separate MANOVAs were conducted on the kinematic, kinetic, and electromyography dependent variables for both the drop vertical jump and stop jump. Within each task nine dependent variables were analyzed at initial contact and peak knee flexion. These dependent variables included knee flexion angle at initial contact, hip flexion angle at initial contact, peak knee valgus angle, peak knee extension moment, peak knee valgus moment, peak vertical ground reaction forces, hamstrings to quadriceps activation ratio (Q:H) at initial contact and peak vertical reaction forces, and peak proximal tibial anterior shear force. No significant differences were found for the kinematic, kinetic, and electromyography variables between the two jump-landing tasks. Future studies involving more participants and potentially different variables are needed to see if there are differences between during the second landing of these two jump-landing protocols

Introduction

The most frequently occurring and debilitating knee injury in sports is rupture of the anterior cruciate ligament (ACL) (Cowling & Steele, 2001). Rupture of the ACL is costly both financially, with conservative estimates of surgery and rehabilitation at $17,000-25,000 per injury, and personally with potential loss of entire seasons of sports participation, loss of scholarship funding, lowered academic performance, long term disability, and significantly greater risk of developing osteoarthritis (OA) in that knee (Hewett, Myer, & Ford, 2006). Adding to the detriment is the fact that ACL injury is often concomitant with a meniscus tear, and this type of meniscus injury is an indicated risk factor for tibiofemoral OA (Alentorn-Geli et al., 2009a). A particularly perplexing issue associated with ACL ruptures is the existence of a large gender disparity between these ACL injuries with a 4-6 fold greater incidence in female athletes compared with male athletes playing the same landing and cutting sports (Arendt & Dick, 1995; Ford, Myer, & Hewett, 2003). This increase in ACL injury in the female sports population has fueled intense examination of the mechanisms responsible for the gender disparity in these debilitating sports injuries (Hewett, Myer, & Ford et al., 2006). Despite the vast amount of research into ACL injury, the underlying mechanisms responsible for this gender disparity still remains poorly understood and very little is known about the effect of sports-specific factors on ACL injury (Renstrom et al., 2008).

Video analyses and retrospective interviews have found that the majority of ACL ruptures are noncontact in nature and range anywhere from 70-84% of all ACL injuries in both male and female athletes (Boden, Dean, Fagin, & Garret, 2000; Krosshaug et al., 2007). There is a general consensus among researchers that a majority of these non-contact ACL injuries occur during cutting, pivoting, sudden deceleration, and landing from a jump (Chappell, Kirkendall, & Garrett 2002; Ford et al., 2003; Hewett & Bahr, 2007; Yu, Lin, & Garret, 2006). Focusing on these playing scenarios, Alentorn-Geli et al. (2009a) identified numerous risk factors for non-contact ACL injury and categorized them into 2 groups: non-modifiable and modifiable. Non-modifiable risk factors include anatomical risk factors and hormonal risk factors. Anatomical risk factors that have been proposed include increased Q-angle, narrower femoral notch, and increased hypermobility or laxity in female athletes. Few, if any, anatomical variables, however, has been directly correlated with an increased risk of noncontact ACL injury (Alentorn-Geli et al., 2009a). There has been significant research focus on the effects of sex hormone relationships to ACL injury. The increase in estrogen seen during the pre-ovulatory phase of the menstrual cycle has been purported to increase anterior knee laxity (Zazulak et al., 2006), decrease ACL tensile stiffness (Woodhouse et al., 2007), and decrease neuromuscular function (Sarwar, Niclos, Rutheford, 1996). However, literature provides conflicting evidence, which has prevented a strong consensus to be reached on whether ACL injury risk is associated with specific sex hormone fluctuation (Alentorn-Geli et al., 2009a). There is no conclusive evidence that anatomical or hormonal risk factors are directly correlated with an elevated risk of ACL injury in female athletes. Furthermore, most of these factors are congenital factors and are not easily controlled so they will not be analyzed in this study.

Emphasis has turned to modifiable risk factors which include both biomechanical and neuromuscular mechanisms that predispose an athlete to ACL injury because these aspects can be altered or improved with feedback and proper intervention (Alentorn-Geli et al., 2009a). Numerous studies have examined gender differences in lower extremity mechanics during athletic tasks consistently reporting that females exhibit: decreased hip and knee flexion angles, increased knee valgus angles, increased quadriceps activation, and decreased hamstring muscle activation; all factors have been suggested to increase strain on the ACL (Blackburn & Padua, 2008; Chappell et al., 2002; Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Ford et al., 2003; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Myer, Ford, & Hewett, 2005; Pollard, Sigward, & Power, 2009). Identification of these ACL injury risk factors has lead to neuromuscular training programs designed to prevent ACL injury and modify ACL injury risk factors (Alentorn-Geli et al., 2009b). While many studies on these programs have reported success in improving potential ACL injury risk factors, ACL injury numbers continue to be high (Agel, Arendt, & Bershadsky, 2005). ACL numbers may continue to be high due to a lack of sport-specific motion analysis studies and neuromuscular training programs incorporating factors intrinsic to each individual sport. ACL loading studies for jumping and landing maneuvers have analyzed landing mechanics during either drop vertical jumps or stop jumps. Focus has concentrated on these jump-landing tasks because they are purported to mimic playing situations commonly seen in a variety of sports including handball, volleyball, soccer, and basketball (Chappell et al., 2002). While the movements that occur during these sports leading to ACL injury are similar, the sports themselves are very different in nature and have factors intrinsic to their sport that could affect ACL loading characteristics. The stop jump task protocol established by Chappell et al. (2002) consists of an approach typically ranging from 2 to 5 steps, a two-footed landing with countermovement arm swing (landing phase), followed by a two-footed takeoff for maximum height (takeoff phase). The drop vertical jump protocol established by Hewett et al. (2005) consists of a subject dropping directly down off a box (31 cm) and immediately performing a maximum vertical jump, raising both arms as if they were jumping for a basketball rebound. Thus both jump landing studies consist of two separate landings: 1) an initial deceleration landing, and 2) landing after performance of a maximum vertical jump. Two drop jump studies (Ford et al., 2005; Smith et al., 2007) and one stop jump study (Onate et al., 2005), incorporated the use of a basketball overhead so that the athletes jump maximally, catch the ball, and then land. However, these studies only analyzed the initial landing (deceleration before jump), and not the second landing after the maximal jump with the basketball in the athlete's hand. Landing after grabbing a rebound in basketball, spiking a ball in volleyball, or heading a ball in soccer are examples dynamic functional activity in which the athlete has a tendency to concentrate on attending to the ball rather than concentrating on their mechanics upon landing. During basketball, female high school athletes injure their ACL more often while jumping or landing (60%) (Piasecki, Spindler, Warren, Andrish, & Parker, 2003). Specifically, Powell and Barber-Foss (2000) found that rebounding the basketball was the cause of the majority of injuries to female basketball players. Steele and Brown (1999) postulated that the upper-limb motion required to catch a ball may interfere with muscle coordination during dynamic tasks, such as an abrupt landing, thereby compromising the preprogrammed synchrony of the lower-limb muscles required to ensure that the integrity of the ACL is maintained (Cowling & Steele, 2001). The purpose of this research study was to compare the lower extremity biomechanics and neuromuscular firing patterns in healthy female collegiate basketball, soccer and volleyball players during the second landing of two jump-landing tasks associated with ACL injury.

Methods

Kinetic, kinematic, and electromyography measures were compared during the second landing of both the stop jump and drop vertical jump.

Participants

Nineteen female collegiate athletes (10 soccer, 6 basketball, and three volleyball players) participated (age, 20.2± .34; height, 171 cm ± 2.23; body mass, 70.43 kg ± 2.3) in the study. All participants were clear of any health problems that may compromise their jumping or landing mechanics. All participants were required to sign a consent form indicating their willingness to participate in the study.

Data Collection

Kinetic, kinematic and electromyography measures were analyzed in the laboratory using synchronized biomechanical instrumentation. A Delsys electromyography (EMG) system will be used to measure muscular activation created by the quadriceps (vastus lateralis, vastus medialis, and rectus femoris), and the hamstrings (medial aspect, and lateral aspect) of the dominant leg. Electrode placement was in accordance with Fauth et al (2010), who found EMG measurement is a reliable method for assessing the reproducibility of both the quadriceps and hamstrings muscle activation during either isometric or ballistic exercises. Electrodes were placed on the longitudinal axis of the muscles with the rectus femoris electrode placed halfway between the greater trochanter and medial epicondyle of the femur. The vastus lateralis electrode was placed one quarter of the distance from the midpoint of the lateral line of the knee joint to the anterior superior iliac spine. The vastus medialis electrode was located 20% of the distance from the anterior superior iliac spine to the midpoint of the medial joint line. A point was made for the midline of the hamstring belly located halfway between the gluteal fold and the popliteal fossa. The lateral hamstring electrode was placed 3 cm lateral of the midline point, and the medial hamstring was placed 3cm medial of the midline point. A ground electrode was placed on the patella of the non-dominant leg. The sensors were attached to the skin with a double-sided adhesive sensor interface and oriented so that the two silver bar contracts were perpendicular to the muscle fibers. Skin preparation included cleansing with alcohol wipes, and light abrasion. All electrodes were secured properly with tape. EMG wires were secured with twist ties and taped to the amplifier. The EMG signals were detected with DE-2.1 sensors (Delsys Inc.) and amplified by a Bagnoli™ 8-channel system (Delsys Inc.) The amplifier gain was set to 1000 and the EMG signal filtered to a bandwidth between 20 Hz and 450 Hz. The EMG signal was sampled at 1000 Hz.

Kinematic data was collected using a 7 camera high speed motion capture system (Vicon Nexus 1.4.116). A rigid body segmental skeleton was created using the Vicon static gait model. The video data were collected at a rate of 240 Hz. Kinematic data was filtered using a Woltring method. The data was analyzed using Polygon Version 3.1. and Microsoft Excel.

Kinetic data was collected using two AMTI force plates (Advanced Medical Technologies, Inc., Watertown, Mass) sampled at 960 Hz. A Vicon Analog to Digital Interface Unit converted input analog voltage (or current) to a digital number proportional to the magnitude of the voltage. Sixteen reflective markers were placed along the lower extremity at the posterior superior iliac spine, anterior superior iliac spine, left and right shafts of the femurs, both lateral aspects of the knee at the joint line, bilateral lower shanks, lateral malleoli, heels, and distal head of the second metatarsals. Each subject's height, weight, knee widths, and ankle widths were recorded.

Procedures

Data collection occurred on one test day and took approximately one hour per participant. Prior to the testing procedures each participant warmed up on an ergometer bike, and performed a light dynamic stretching routine. The participant then performed a vertical jump test (VJ). A Vertec Jump Measurement & Jump Training System was used to record the participant's maximum vertical jump height. The participants performed three maximal vertical jumps, and the highest reach height of these three jumps was recorded. This test was performed in proper athletic footwear and comfortable clothing. The participants then had a five-minute rest before performing the next two jumping tasks.

To perform the drop vertical jump and stop jump task the participants were asked to wear tight fitted shorts and a sports bra or tank top. Participants wore the same athletic footwear as in the previous test. Retroreflective markers and electromyography electrodes described above were attached to the participant during these tests.

In both the drop vertical jump and stop jump tests, a basketball was suspended from the ceiling at 80% of the participant's maximal vertical jump height**.** The basketball was connected to a small wood block hanging from a rope with Velcro straps allowing for easy release**.** The participant was required to grab the ball and successfully land on the force plates with the basketball in hand. A successful trial was defined as one in which the subject performs the tasks as required and all data was successfully collected**.** The order in which each athlete completes the following two tasks was randomized.

For the drop vertical jump, the participant was given as many practice trials as needed to become familiar with the movement. Each participant performed three successful trials of the drop jump task with a minimum one-minute time interval between trials to prevent fatigue. The DVJ consisted of the participant starting on top of a box (31 cm in height) with feet positioned 35 cm apart (distance measured between toe markers). Participants dropped directly down off the box and immediately perform a maximum vertical jump, raising both arms and grabbing the basketball overhead, and then landing successfully with the basketball on two feet onto two force plates.

For the stop jump, the participant was given as many practice trials as needed to become familiar with the movement. Each participant performed three successful trials of the stop jump task with a minimum one-minute time interval between trials to prevent fatigue. The stop jump task consisted of the participant taking a two-step approach run, two foot landing, an immediate maximum vertical jump to grab a basketball suspended overhead, and then successfully landing with the basketball in hand on two feet onto two force plates.

Kinematic, kinetic and electromyography variables were collected during the second landing after the participant successfully landed with the basketball in their hands on the force plate. All variables were collected for the dominant leg only.

Data Analysis

Three separate MANOVAs were conducted on the kinematic, kinetic, and electromyography dependent variables for both the drop vertical jump and stop jump. Statistical analysis was conducted using SPSS 17.0 software (SPSS Inc. Chicago, IL). Within each task nine dependent variables were analyzed at initial contact and peak knee flexion. These dependent variables included knee flexion angle at initial contact, hip flexion angle at initial contact, peak knee valgus angle, peak knee extension moment, peak knee valgus moment, peak vertical ground reaction forces, hamstrings to quadriceps activation ratio (Q:H) at initial contact and peak vertical reaction forces, and peak proximal tibial anterior shear force. Initial contact was defined as the point at >10 N of vertical ground reaction force. The vastus lateralis electrode values were dropped from the study due to the erratic results. Ground reaction and joint forces were normalized for body weight. Joint moments were normalized for body weight and height. Statistical means and standard deviations for each dependent variable were calculated. The data was inspected and outliers were transformed to ensure normality and sphericity of the MANOVA were not violated.

Results

Three separate MANOVAs were run to compare the dependent variables (kinematics, kinetics, EMG) between the two tasks (stop jump, drop vertical jump). The MANOVA comparing kinematics between the two tasks found no significant results as indicated by the Wilks' Lambda $(3, 78) = .106$ $p > .05$). The MANOVA comparing kinematics between the two tasks found no significant results as indicated by the Wilks' Lambda $(4, 87) = .257$ $p > .05$). The MANOVA comparing electromyography variables between the two tasks found no significant results as indicated by the Wilks' Lambda $(2, 84) = .164$ $p > .05$). No significant effects were found for any of the kinematic, kinetic, and electromyography variables compared between the two tasks. The means and standard deviations for all the dependent variables are presented below.

Discussion

The drop vertical jump and stop jump are 2 land-and-jump maneuvers believed to be associated with risk factors for noncontact ACL injury and these jump-landing protocols (drop jump and stop jump) have been proscribed to represent a variety of movement tasks seen in a several different sports including volleyball, soccer, and basketball (Chappell et al., 2002; Hewett et al., 2005). Identification of these ACL injury risk factors has lead to neuromuscular training programs designed to prevent ACL injury and modify ACL injury risk factors (Alentorn-Geli et al., 2009b). While many studies on these programs have reported success in improving potential ACL injury risk factors, ACL injury numbers continue to be high (Agel, Arendt, & Bershadsky, 2005). A potential reason for the continuing high rates of ACL injuries could be due to the fact that drop vertical jump and stop jump studies have only measured ACL injury risk factors during the first landing (initial deceleration) of the task. To the author's knowledge, this is the first study to compare the kinematic, kinetic, and electromyographic variables during the second landing (descending after maximal jump) of these tasks.

Identification of ACL injury risk factors exhibited during the second landing could explain the lack of decline in ACL injury rates despite the improvement and insight into neuromuscular training programs.

The purpose of this study was to compare the kinematics, kinetics and muscular activation patterns during the second landing between the stop jump and drop jump. As indicated above, no significant differences were found among kinematic, kinetic, and electromyographic variables between the tasks.

The kinematic variables analyzed in this study were knee flexion angles, hip flexion angles, and valgus angles. Previous studies have found low knee flexion angles at initial contact have been associated with ACL injuries (Boden et al., 2000; Krosshaug et al., 2007). An example of low knee flexion angle at initial contact can be seen in figure 3. In the present study, knee flexion angles were lower during the drop vertical jump (8.74° ± 4.8) than the stop jump (11.3° ± 6.3). This would indicate that the drop vertical jump exhibited higher ACL injury factor than the stop jump in terms of knee flexion upon landing. Interestingly, Chappell and Limpisvasti (2008) also found lower knee flexion angles at initial contact during the first landing in the drop vertical jump (29.9° ± 9.0) compared to the stop jump (36.4° ± 9.4). Chappell and Limpisvasti (2008) hypothesized this differences was most likely because the stop jump task is a more dynamic jumping task and introduces shear with the horizontal approach.

Decreased hip flexion angles at initial contact of landing has been postulated to place the ACL at a greater risk of injury, because a greater peak landing force is transmitted to the knee (Alentorn-Geli et al., 2009a). An example of low hip flexion at initial contact can be seen in figure 4. In the present study, hip flexion angles were lower during the drop vertical jump (16.49° ± 8.7) than the stop jump (20.17° ± 8.8). This would indicate that the drop vertical jump exhibited a higher ACL injury risk factor than the stop jump in terms of the decreased hip flexion upon landing. Yu et al. (2006) found that female athletes who exhibited smaller hip and knee flexion angles at the initial foot contact with the ground landed with greater impact forces. Chappell and Limpisvasti (2008) found greater hip flexion angles at initial contact during the first landing during the drop vertical jump (54.8° ± 11.4) compared to stop jump (72.2° ± 11.0).

Valgus collapse, a commonly reported scenario for ACL injury, is a situation where the knee collapses medially from excessive valgus motion at the knee (Krosshaug et al., 2007). High valgus angles suggest an inability of an athlete’s musculature to control ground reaction forces, and as a result ligaments such as the ACL may absorb these additional forces (Cowley et al., 2006). An example of a high knee valgus angle can be seen in figure 5. Peak knee valgus angles in the present study were greater in the stop jump (15.18° ± 7.7) than the drop vertical jump (13.11° ± 8.2). This would indicate that the stop jump exhibits a higher ACL injury risk factor in terms of frontal plane kinematics at the knee. However, these values were very similar with a large standard of error. Chappell and Limpisvasti, (2008) found peak knee valgus angles to be higher during the first landing in the stop jump (28.4° ± 10.8) than the drop vertical jump (25.7° ± 14.7). These kinematic results showed that female athletes exhibit more sagittal plane ACL injury risk factors during the drop vertical jump, and more frontal plane ACL injury risk factors during the stop jump.

The interaction of the kinematic variables during the second landing of a stop jump can be seen in figure 6. The drop jump exhibited lower hip and knee flexion angles, while the stop jump exhibited slightly higher knee valgus angles. Devita and Skelly (1992) found during the 1st landing of a drop jump that female athletes who limited their sagittal plane loading at the hip and knee via low flexion angles, relied on frontal plane loading to decelerate the body center of gravity by increasing knee valgus angles. In this study however, no such interaction was able to be found upon the second landing of these tasks.

The kinetic variables in this study analyzed were peak knee extension moment, peak valgus moment, peak anterior tibial shear force, and peak vertical ground reaction force. Previous studies have indicated that the quadriceps muscle is the major contributor to the ACL loading (Shelburne et al., 2004; Yu et al., 2006) Knee extension moment is also an indicator of ACL loading because patella tendon force is the result of quadriceps muscle contraction and quadriceps are the major knee extension muscles (Shelburne et al., 2004; Yu et al., 2006). An example of peak knee extension moment can be seen in figure 7. The peak knee extension moments in this study were slightly higher in the drop vertical jump (.004 N·m ±.022) than in the stop jump (.0038 N·m ± .0025). These values were much lower than results found by Yu et al (2006) who found peak knee extension moment values of .18 N·m ± .05 during the first landing of a stop jump for recreational female athletes. The use of collegiate female athletes in this study instead of recreational athletes could account for the large discrepancies. Most likely, this indicates that the knee extension moment does not play much of a role during the second landing of a drop vertical jump or a stop jump.

Anterior shear forces in the knee cause the tibia to translate anteriority relative to the femur and to load the ACL (Kulas, Hortobagyi, & Devita, 2010). Markolf, Burchfield, and Shapiro (1995) found that anterior shear force at the proximal tibia is the major ACL loading mechanism. ACL loading is also reduced as the knee flexion angle is increased (Alentorn-Geli et al., 2009a). An example of peak anterior shear force can be seen in figure 8. In this study, peak anterior shear forces were higher during the drop vertical jump (.137 N + .45) than the stop jump (.127 N ± .04). These values were much lower than results found by Yu et al (2006) who found peak anterior shear force values of .79 N ± .34 during the first landing of a stop jump. This may indicate that the knee extension moment does not play much of a role during the second landing of a drop vertical jump or a stop jump.

Previous studies have demonstrated a significant relationship between peak ground reaction forces and knee injury (Devita & Skelly, 1992) particularly to ACL loading (Shelburne, Pandy, Anderson, & Torry, 2004). The impact on the lower extremity passive restraints, such as the ACL, increases as the peak vertical ground reaction forces increase (McNitt-Gray, 1991). Peak vertical ground reaction forces may elaborate internal loads that may cause injury if not sufficiently distributed or attenuated by the musculoskeletal system (Devita & Skelly, 1992). In this study, peak vertical ground reaction forces were lower during the drop vertical jump (1.94 N ± .029) than the stop jump (1.98 N ±.395). Interestingly, these values were much lower than the peak vertical ground reaction forces during the first landing in Yu et al. (2006) 2.67 N ± .95, but identical to Milner et al. (2011) 1.98 N ± .59.

Dynamic valgus torques on the knee can significantly increase anterior tibial translation and load on the ACL several-fold (Hewett et al., 2006). The knee valgus moments in this study were lower in the stop jump (.01 N·m ± .016) than the drop vertical jump (.02 N·m ± .022). These were significantly lower than Milner et al. (2011) who found knee valgus moments of .45 ± .14 during the first landing of a stop jump. These values could suggest that valgus moments are not significant during the second landing.

The quadriceps and hamstrings muscles exhibit an agonist-antagonist relationship that plays in important role in stabilizing the knee. Deficits in strength and activation of the hamstrings directly limit the potential for muscular co-contraction to protect the ligaments about the knee (Hewett et al., 2005). The electromyography variables measured during this study were the ratio of Quadriceps to Hamstring (Q:H) at initial contact with the ground, and at peak vertical ground reaction. At initial contact the Q:H ratio was almost identical between the drop vertical jump (1.44 mV ± .912) and the stop jump (1.43 mV ± .891). These results were in accordance with previous studies who also found female athletes to demonstrate a preferred quadriceps activation strategy upon landing (Chappell et al., 2007; Cowley et al., 2006; Hewett et al., 2005; Huston & Wojtys, 1996; Padua et al., 2005). The Quadriceps to Hamstring ratio at peak vertical ground reaction force was greater during the drop vertical jump (2.73 mV ± 2.576) than the stop jump (2.01 mV ± 2.176). This would indicate that the drop vertical jump may exhibit a higher ACL injury risk factor than stop jump. To the author's knowledge, no study has compared differences in neuromuscular firing patterns between the stop jump and the drop vertical jump during the first or second landings.

There were several limitations to the current study. Only female athletes from Barry University participated in the study limiting the demographic range that the results can be applied to. Traditional studies stop jump and drop vertical jump studies have investigated for effects between genders. The purpose of this study was not to investigate for gender differences in jump-landing mechanics because this has already been well established in literature. The use of a basketball may have increased variance between the two jumps and within the three trials. However, the use of the basketball was intended to incorporate a more sport specific nature.

An interesting trend noticed in this study that should be analyzed in future studies is the timing relationship between kinematic, kinetic, and electromyography variables during the two jump landing tasks. An example of these trends can be seen in Figures 11, 12 & 13.

Conclusion

In summary, it appears that the drop vertical jump produced higher ACL injury risk factors than the stop jump with a lower knee flexion upon landing, lower hip flexion upon landing, higher peak knee extension moments, higher peak anterior shear forces, higher knee valgus moments, and a higher quadriceps to hamstring activation ratio during the second half of landing. The stop jump exhibited higher ACL injury risk factors compared to the drop vertical jump with higher peak knee valgus angles, and peak vertical ground reaction forces. The two tasks were almost identical in quadriceps to hamstring ratio upon initial contact of landing. The kinematic variables, electromyography variables, and vertical ground reaction forces produced results that are seen to increase ACL injury risk previously measured during the first landing of these tasks. However, the lack of significant joint reaction forces and moments indicated that the low knee flexion, low hip flexion, high knee valgus, and high quadriceps to hamstring activation ratio may not have been significant enough. This study was the first to establish biomechanical and neuromuscular values of the stop jump and drop vertical jump during the second landing. Future studies should compare the first and second landings of these jump-landing tasks.

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Table 1: Kinematic means and standard deviations

Kinematics		Mean	SD
Drop Jump	Knee Flexion	8.74	4.8
	Hip Flexion	16.49	8.7
	Knee Valgus	13.1	8.2
Stop Jump	Knee Flexion	11.3	6.4
	Hip Flexion	20.2	8.8
	Knee Valgus	15.18	7.7

Table 2: Kinetic means and standard deviations

Kinetics		Mean	SD
Drop Jump	Knee Extension Moment (N*m/mass*height)	0.04	0.022
	Knee Valgus Moment (N*m/mass*height)	0.02	0.022
	Peak Anterior Tibial Shear Force (N/mass)	0.137	0.045
	Vertical Ground Reaction force (N/ Body Weight)	1.94	0.029
Stop Jump	Knee Extension Moment (N*m/mass*height)	0.038	0.025
	Knee Valgus Moment (N*m/mass*height)	0.01	0.016
	Peak Anterior Tibial Shear Force (N/mass)	0.127	0.041
	Vertical Ground Reaction force (N/ Body Weight)	1.98	0.395

Table 3: Electromyography means and standard deviations

EMG		Mean	SD
Drop Jump	Q:H at IC	1.44	0.912
	Q:H at peak VGRF	2.73	2.576
Stop Jump	Q:H at IC	1.43	0.891
	Q:H at peak VGRF	2.01	2.176

Figure 1: Drop Vertical Jump (Hewett et al., 2005)

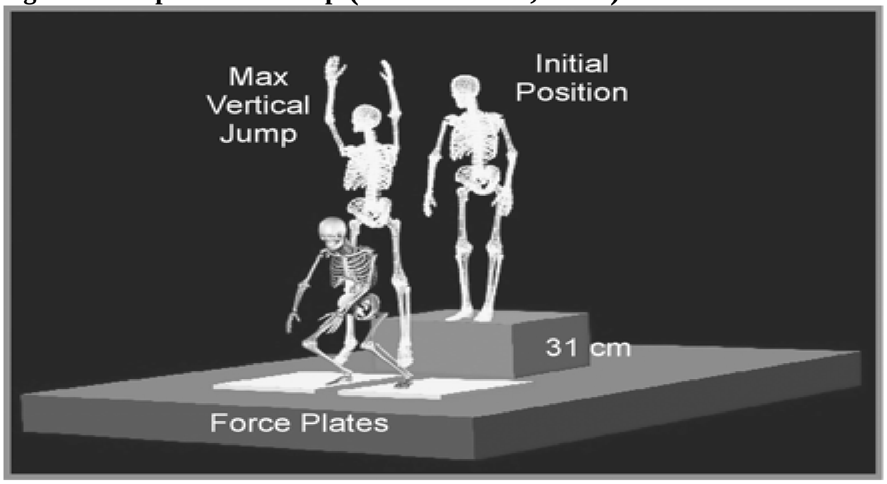

Figure 2: Stop Jump (Chappell et al., 2006)

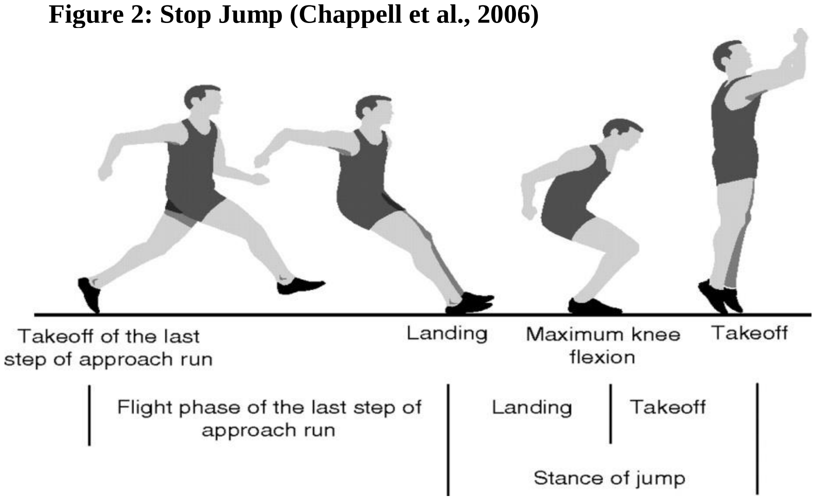

Figure 3: Knee Flexion at Initial contact

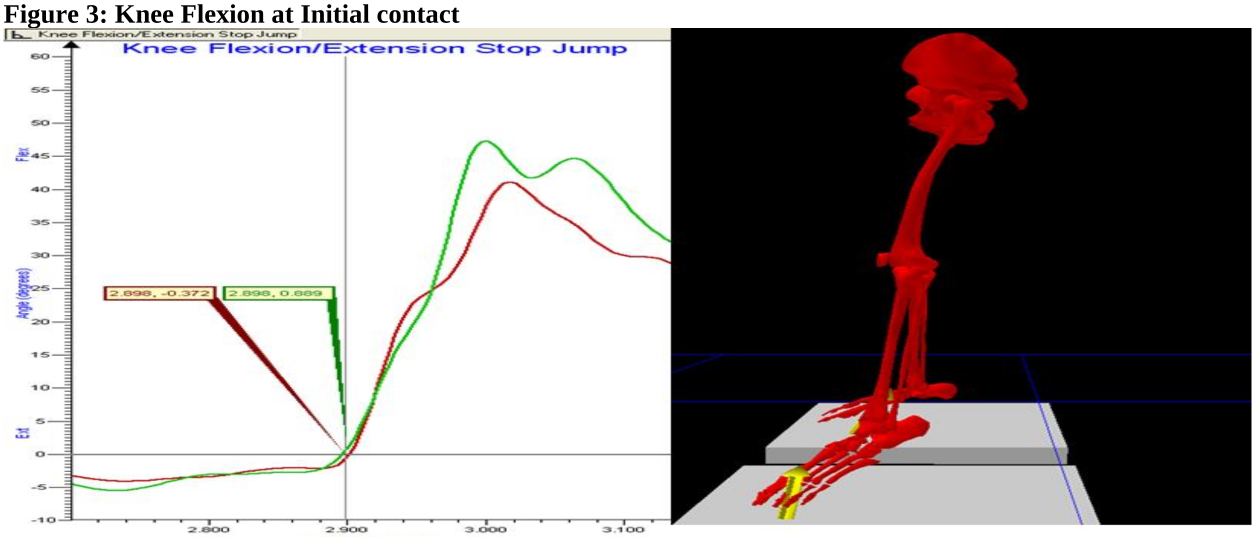

Figure 4: Hip Flexion at Initial Contact

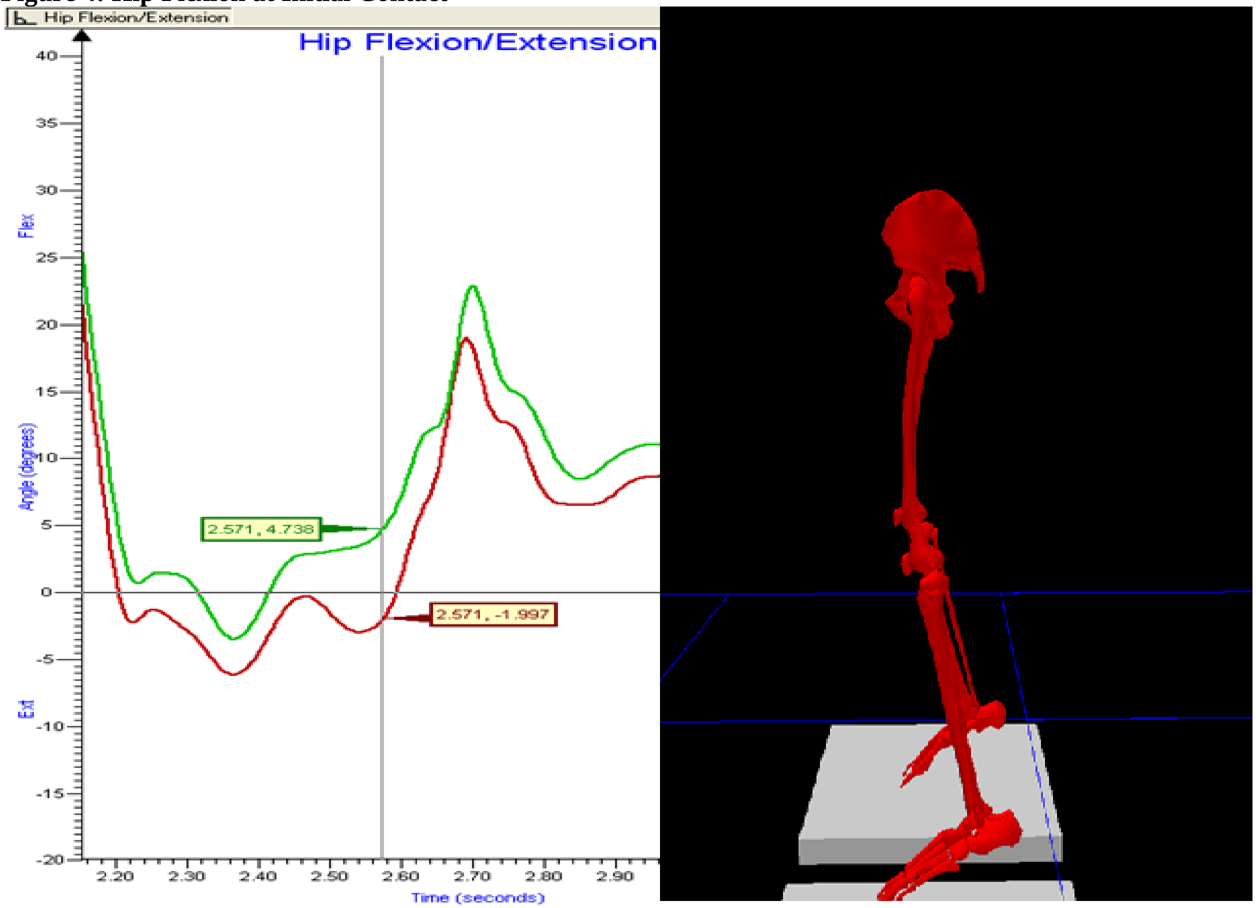

Figure 5: Peak Knee valgus angle

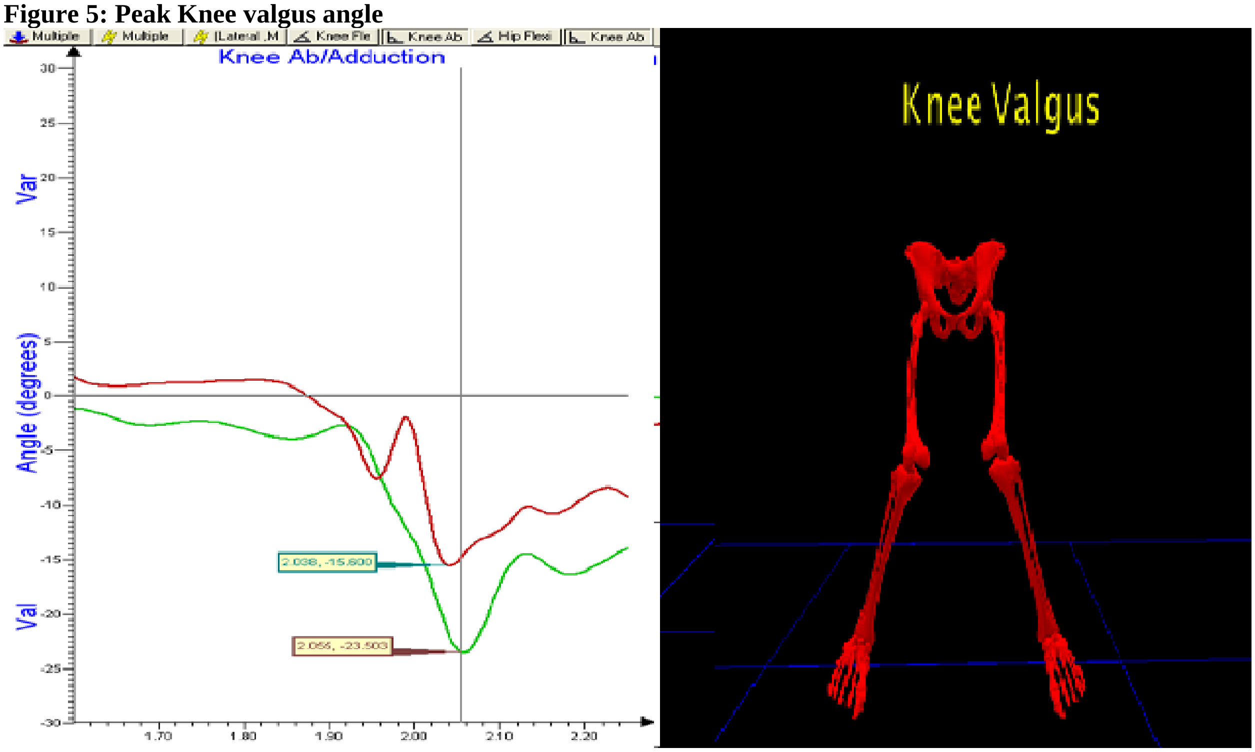

Figure 6: Kinematic Variables upon Landing

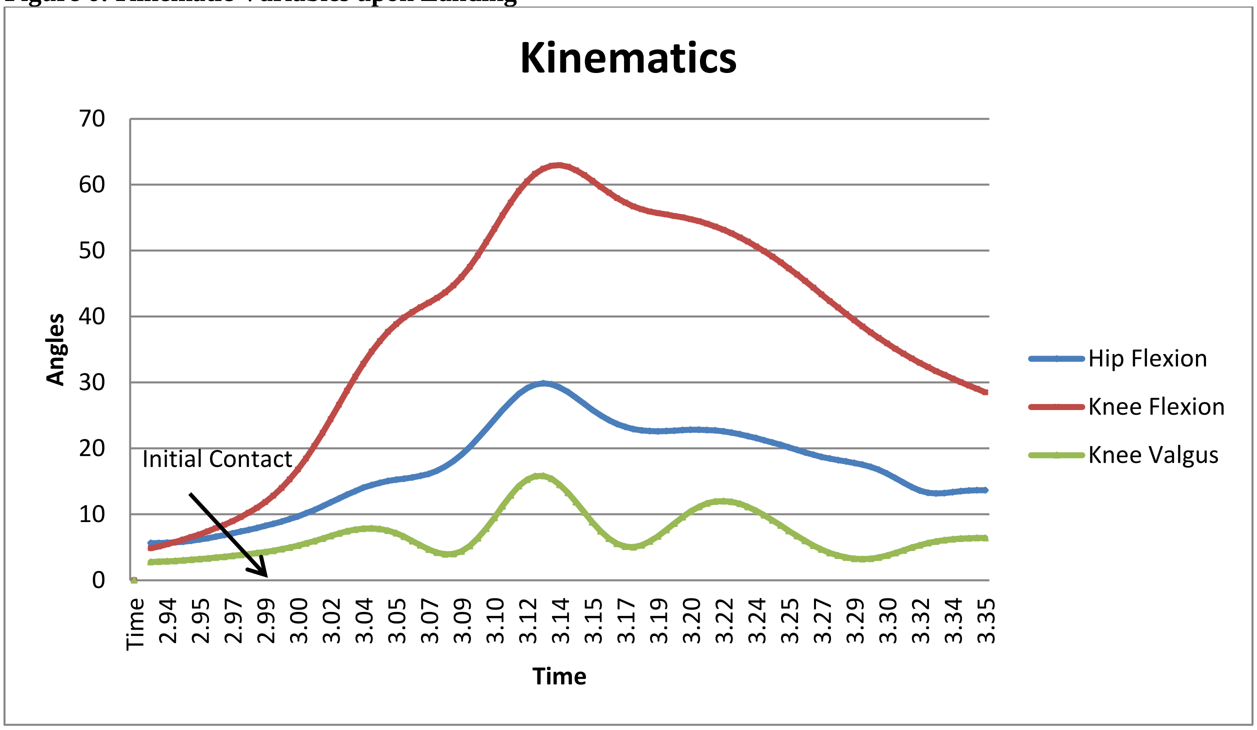

Figure 7: Peak Knee Extension Moment

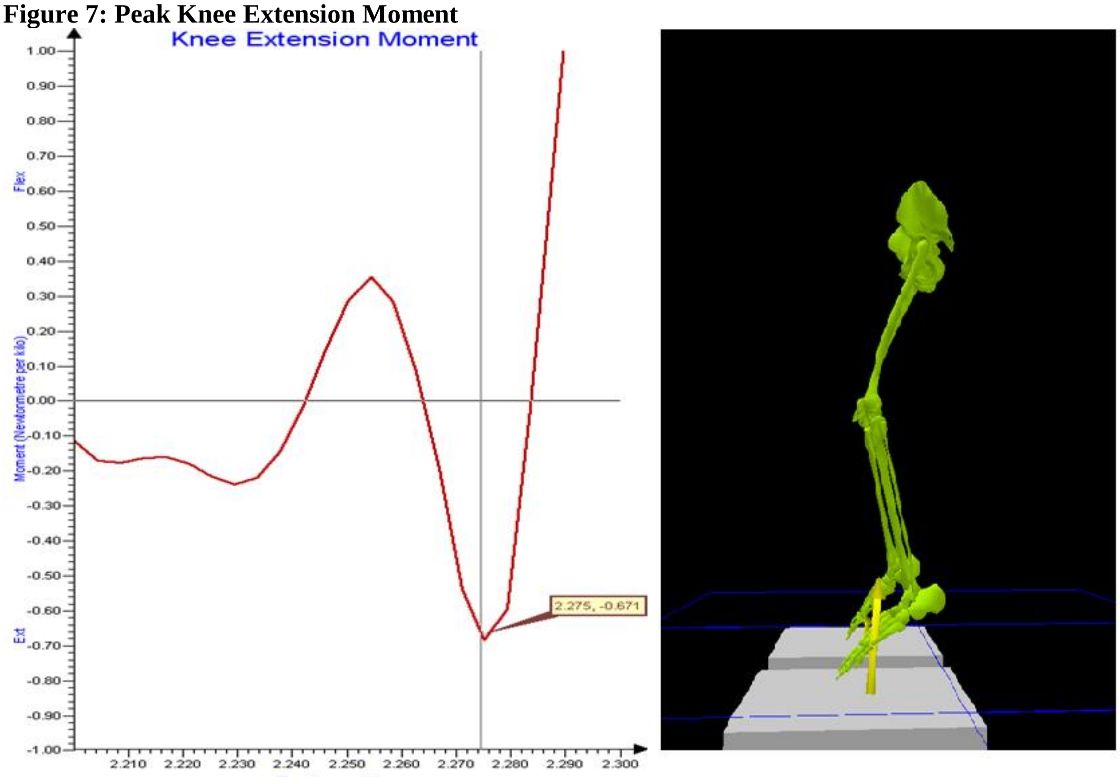

Figure 8: Peak Anterior Shear Force

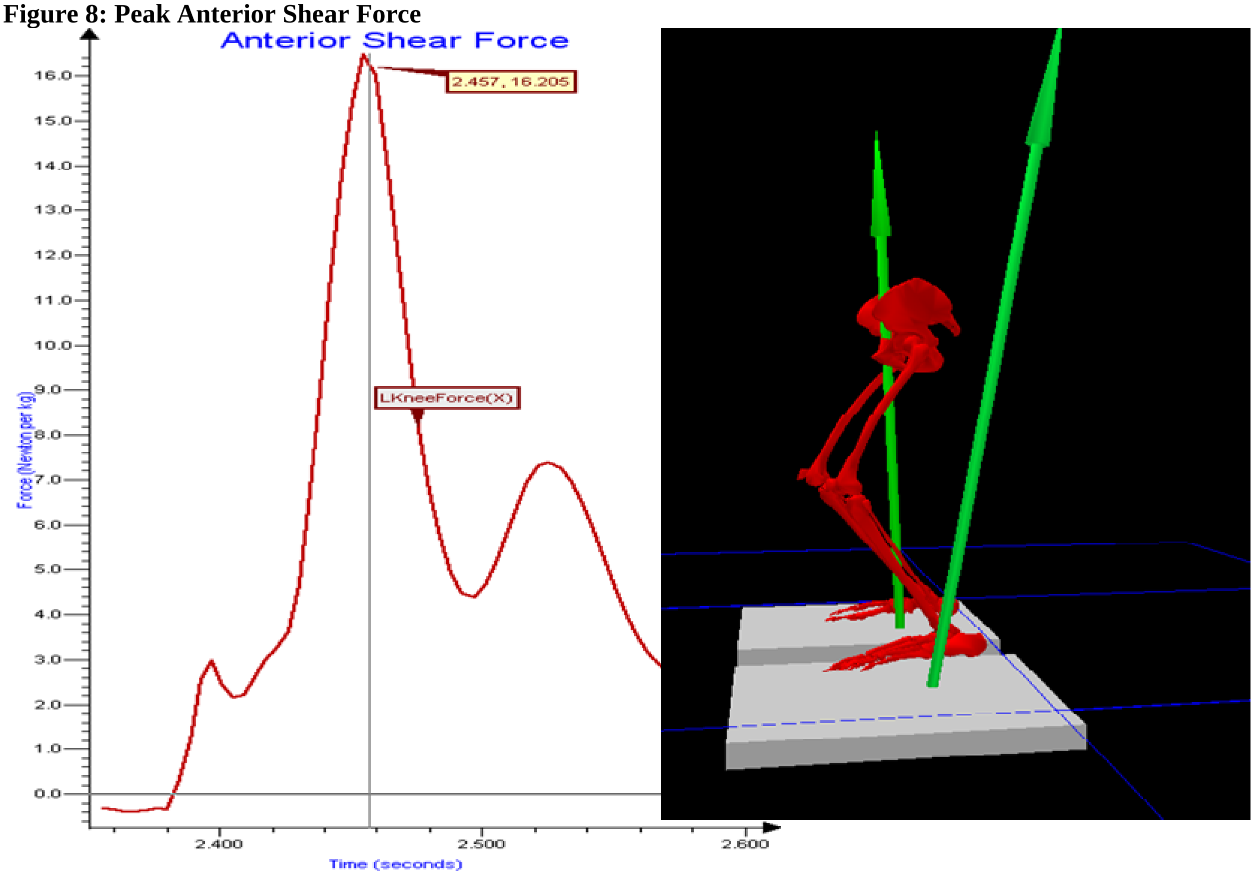

Figure 9: Peak Vertical Ground Reaction Force

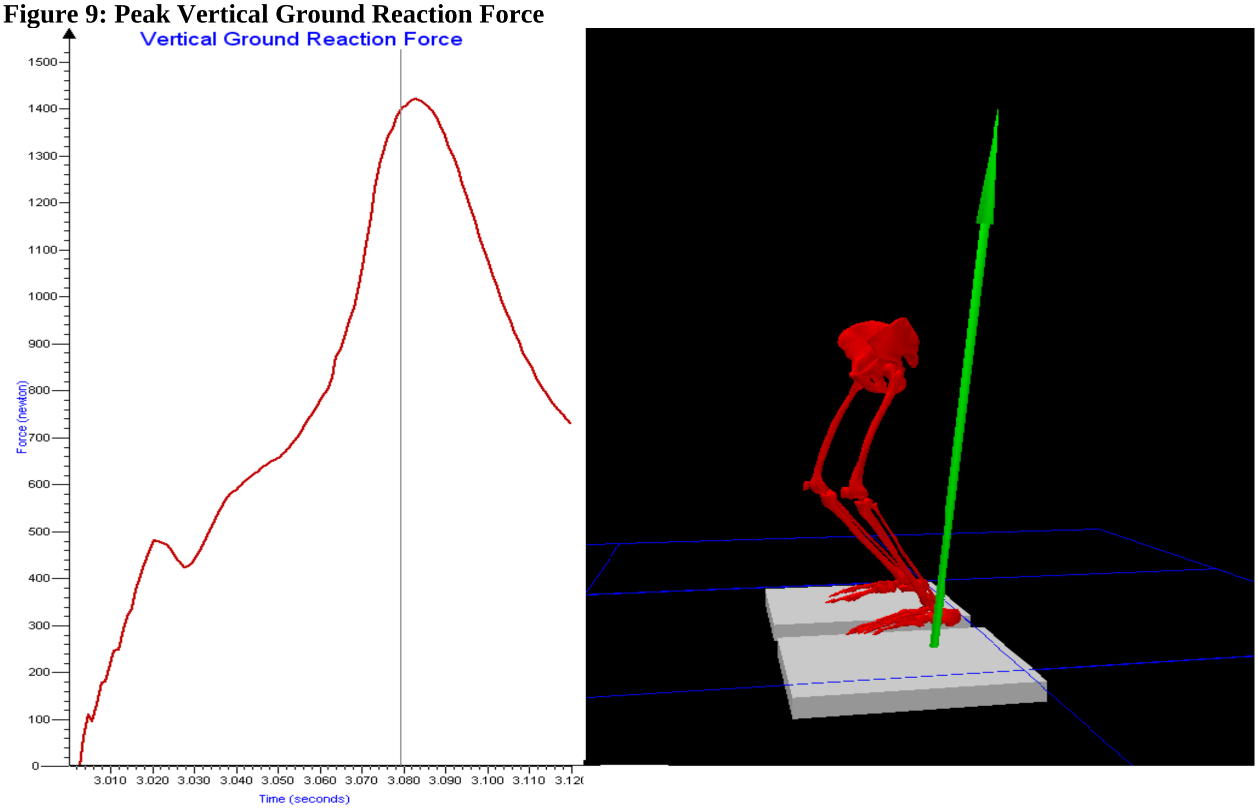

Figure 10: Peak Knee Valgus Moment

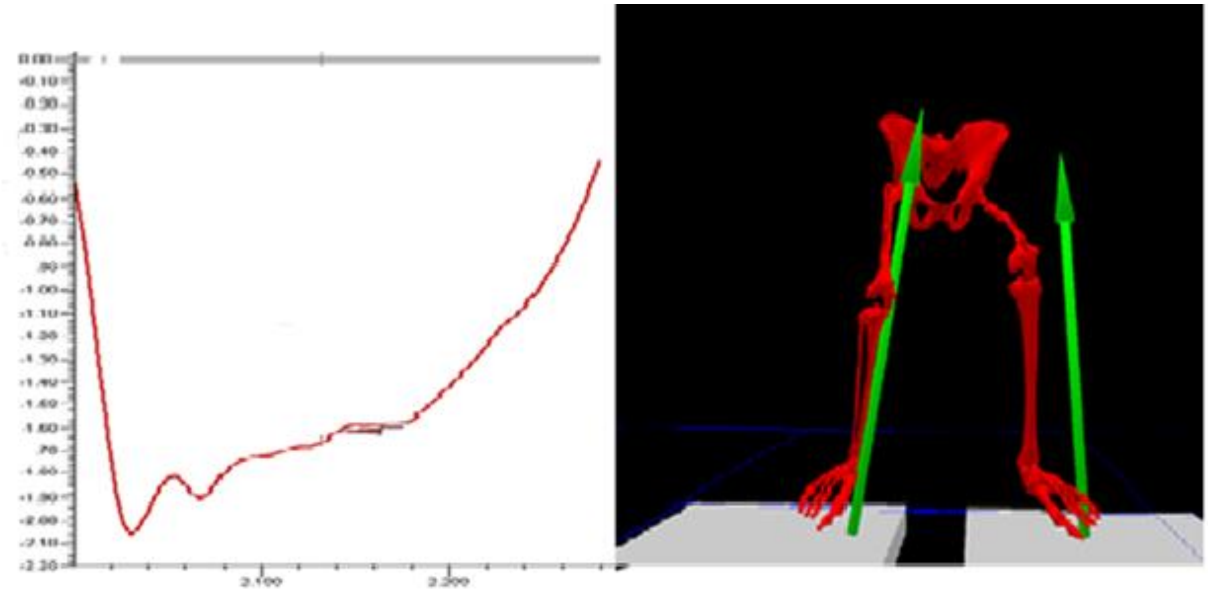

Figure 11: Q:H Ratio vs. Vertical Ground Reaction Forces

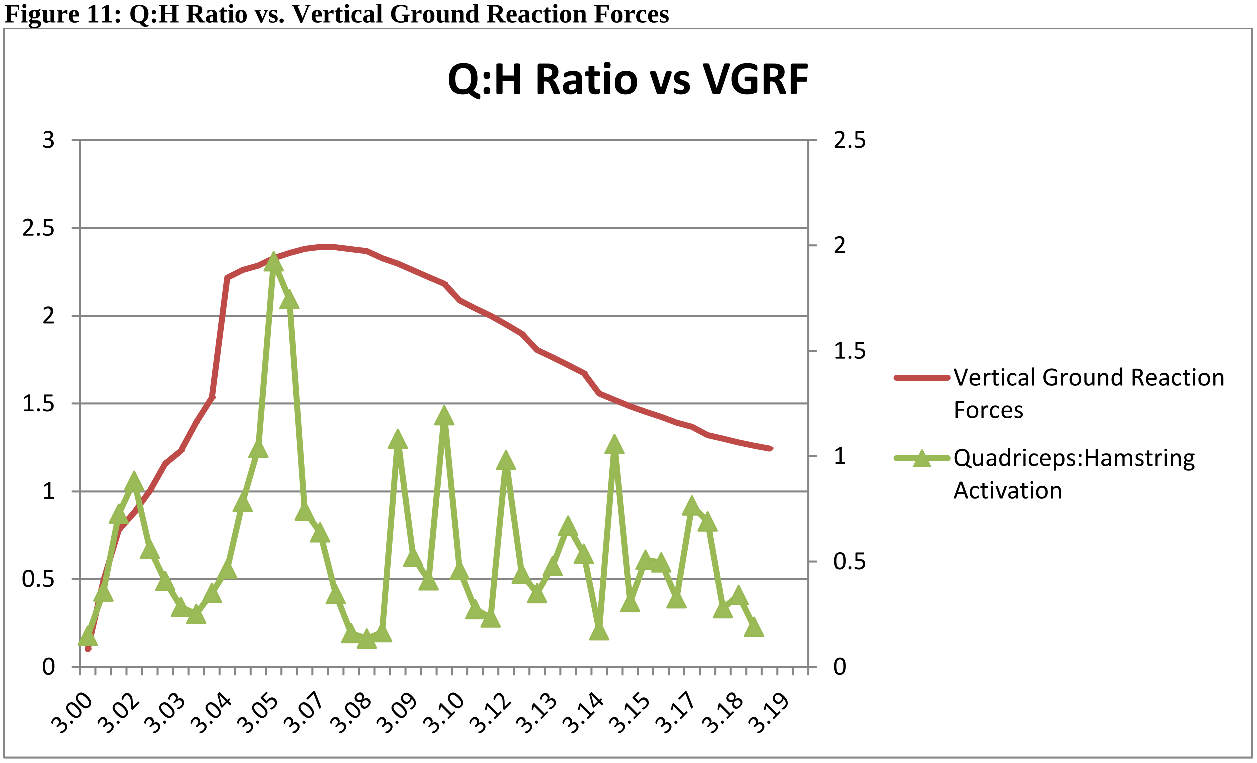

Figure 12: Electromyography vs. Kinetic Variables

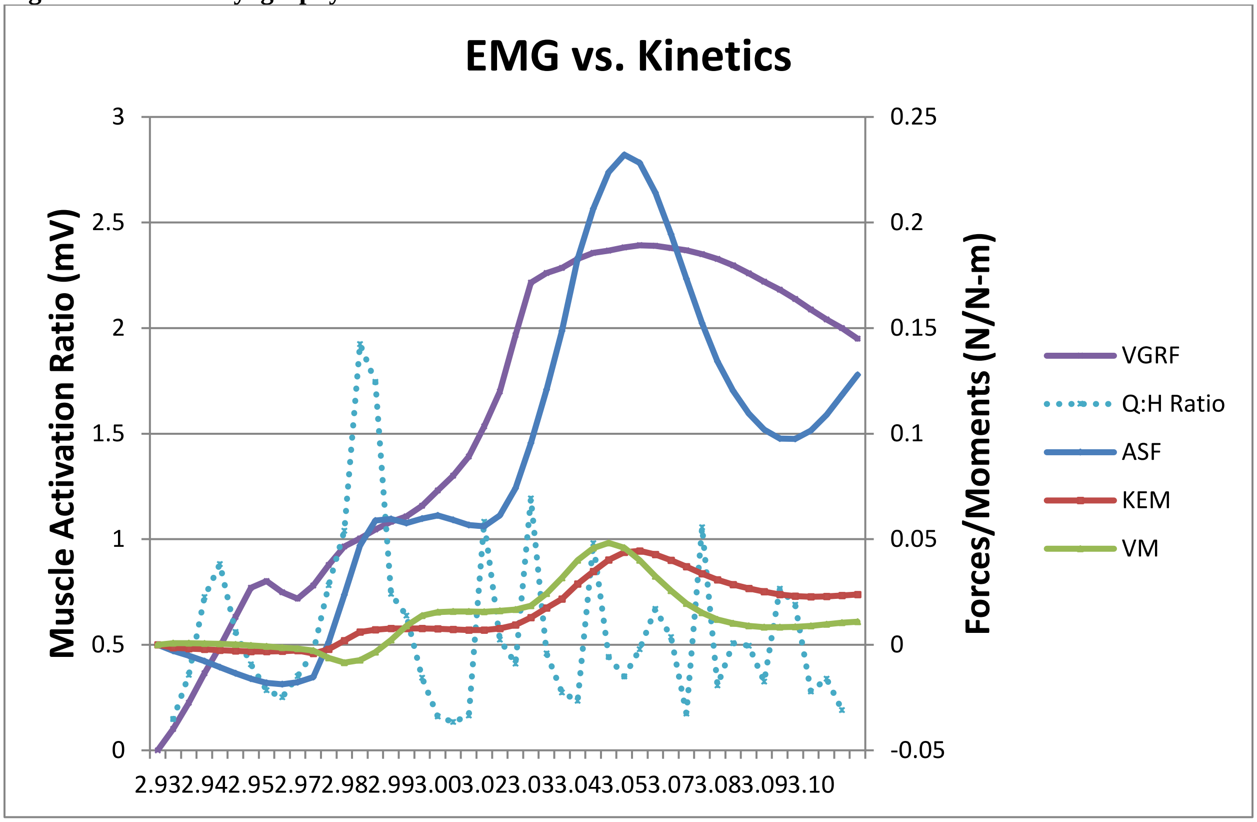

Figure 13: Electromyography vs. Kinematic Variables

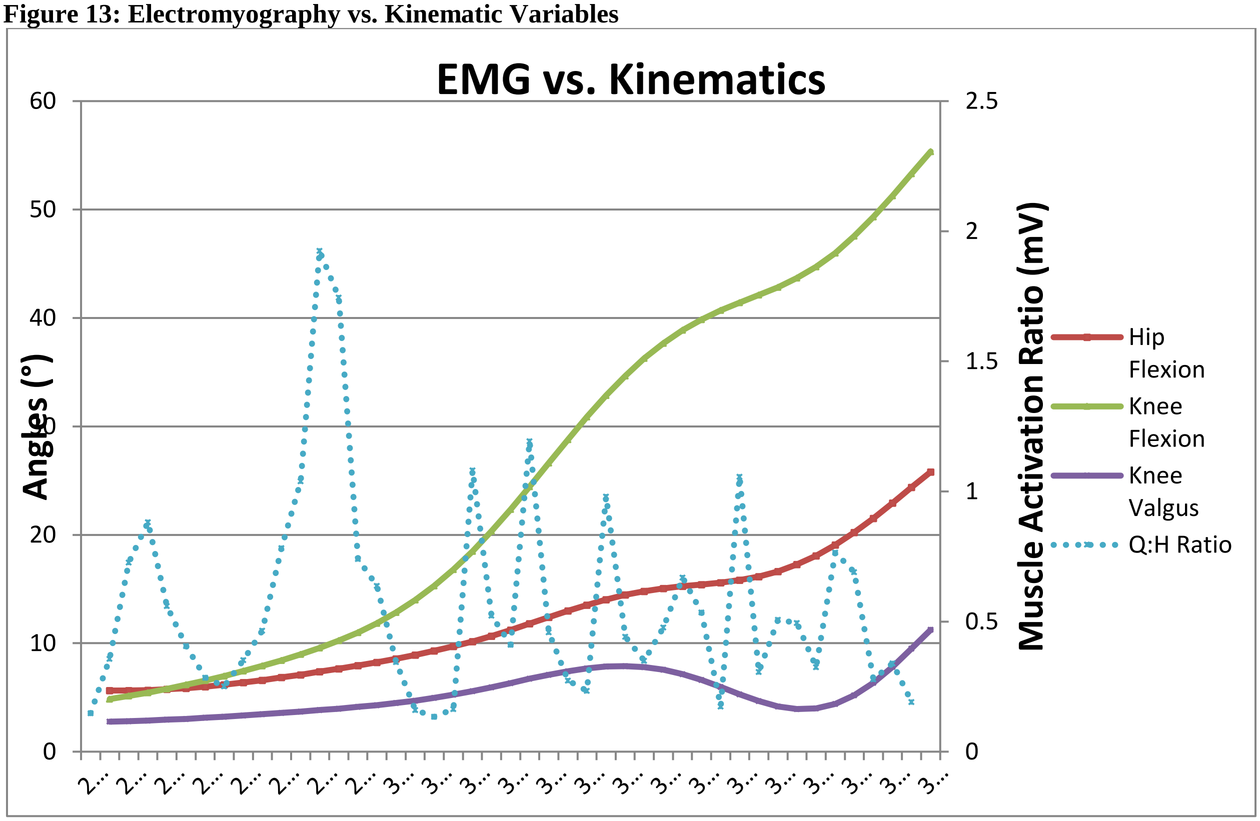

Figure 14: Kinematic vs. Kinetic Variables