ANTICIPATORY EFFECTS ON LOWER EXTREMITY KINETICS AND KINEMATICS DURING A LAND AND CROSS STEP MANEUVER IN FEMALE VOLLEYBALL PLAYERS

A THESIS

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF SCIENCE

BY

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BALL STATE UNIVERSITY

MUNCIE, INDIANA

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DECEMBER 2014

Declaration

The work presented in this thesis document, is to the best of my knowledge to be true and original, unless cited otherwise, and this document has not been submitted to another institution for requirements of another degree.

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Bart Richwalski, Primary Investigator

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Abstract

Thesis: Anticipatory Effects on Lower Extremity Kinetics and Kinematics during a Land Cross Step Maneuver in Female Volleyball Players

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Anticipation has been previously shown to affect lower extremity mechanics during both landing and cutting maneuvers. However, little research has been conducted looking at the effects of anticipation on the lower body kinetics and kinematics during a land and cross step maneuver, which due to similar kinematics, may elicit injury. Twelve female, college-level volleyball players performed right and left cross step maneuvers following a landing under anticipated and unanticipated conditions. Kinetics and kinematics were measured for the ankle, knee and hip of the dominant limb during the landing phase of the various movement conditions. Both anticipatory and directional effects were seen for many of the variables including VGRF, ankle, knee and hip power absorption, peak ankle dorsiflexion, inversion and eversion angles, knee angles in all three planes, peak hip flexion and initial contact external rotation angles as well as all joint moments except for knee and hip abduction. However, higher order interactions were seen for knee flexion, abduction and internal rotation (all $P < .001$) at initial contact as well as maximum knee flexion and internal rotation (both $P < .001$). These interactions for the knee are important factors to consider when looking at knee injury. Other contributors to high risk landings including maximum ankle inversion ($P < .001$) and hip external rotation ($P = .026$) had significant interactions at initial contact. However, effects were not limited to unanticipated trials as high risk positions were recorded during the landing of anticipated trials as well. The findings from the current study suggest that both anticipation and direction played an important role in landing mechanics. Drills familiarizing players with unanticipated changes of direction along with strength training of the muscles required to effectively decelerate the body may help prevent injury.

Keywords: Biomechanics; Jump; Anterior Cruciate Ligament

<u>Chapter 1</u>: Introduction

Volleyball has become one of the world's most popular sports and has been growing ever since being introduced in 1895 by William Morgan. The International Volleyball Federation (FIVB) claims over 800 million participants [1] in both indoor and beach volleyball with more than 200 member countries[2,3] as of 1997. Both male and female volleyball have been part of the Olympics since 1964 [3] and with the inclusion of beach volleyball in 1996, the popularity of the sport has increased so significantly that the number of volleyball athletes worldwide rival those of soccer athletes.[4] The participation of females in NCAA volleyball has grown substantially over the past 30 years from 752 schools participating in the sport with 8,418 athletes to 1,096 schools and 15,890 athletes total between Divisions I, II and III.[5]

Along with the growing popularity of the sport and number of participants, increases in the number of sports-related injuries have been reported. The incidence of volleyball-related injuries for a single player has been estimated to be between 2.5 and 4.3 injuries per 1000 hours of play, which includes game play and training in both indoor and beach volleyball.[3,6,7] These findings are comparable to injury incidences in other high performance sports such as soccer (4.1) and ice hockey (4.7).[6] An increase in number of injuries is to be expected with an increase in participation, however, a disproportionate number of injuries have occurred in women relative to men,[8,9] and a majority of these injuries affect the lower extremities, primarily the knees and ankles.[1-3,6,10,11] Females participating in the same sport as males, have been reported to be at a higher risk (2-8 times) of injury when high risk cutting or jumping are involved.[8,12,13] These sports injuries can be classified into two categories: overload injuries and traumatic injuries. Knee injuries sustained during volleyball play can fall into an overload or "overuse" category and are referred to as patellar tendinopathy or "jumper's knee" or can fall into an acute traumatic injury category and typically entail internal knee derangement.[1-3,6,7,14-17]

An estimated 63% of volleyball injuries are observed during jumping and landing movements that are fundamental parts of blocking and spiking [1,3,14,17] and the most frequent mechanism of injury is landing from a jump in the attack zone.[1,15,17] Ankle injuries account for up to 60% of recorded injuries in volleyball and typically occur when landing while coming in contact with another player's foot underneath the net.[2,10,14] It has been found that higher plantar flexor strength and decreased ROM in dorsiflexion are significant risk factor for not only ankle sprains [18-22], but also injuries in the knee such as patellar tendinopathy.[23,24] Although the most common acute traumatic injury in volleyball occurs at the level of the ankle, traumatic knee injuries do occur, commonly in the form of damage to the anterior cruciate ligament (ACL), and are often times more devastating to the athlete and their future performance. It was found that knee internal derangement made up 14% of game injuries in NCAA female volleyball athletes from 1988-2004 and of those, 26% were ACL injuries.[25] Roughly 70% of ACL injuries are labeled as noncontact [15,26-30] and are classified as those reported to be caused by no apparent contact with a stationary object, contact with a ball or contact with another player.[31] It has been reported that injuries also commonly occur during step-stop actions or a sudden change of direction as in a cutting maneuver.[15,26,32] Multiple studies have built off of these findings and found that the greatest loads presented to the knee occur during deceleration combined with a cutting or pivoting movement.[33-35] During this maneuver, injuries occur when the foot is planted creating a closed chain position while the knee is near full extension and in valgus combined with the tibia being either internally or externally rotated.[36,37] This position while cutting or pivoting applies excessive torsional force at the knee and can cause disturbance to the ACL.[38] Lower extremity kinematic changes due to these external loads have been seen which has led to various theories on the exact mechanism of ACL injuries. The etiology of ACL injuries can be divided into intrinsic and extrinsic factors.[9,26,28] Intrinsic factors include a narrow intercondylar notch, weak ACL, generalized physiologic laxity, hormonal effects and malalignment of the lower extremity. Extrinsic factors include abnormal quadriceps to hamstring interactions, altered neuromuscular control, the shoe-surface interface, the playing surface and the athlete's playing style.

Several studies have examined the cutting maneuver through kinematic analysis of the lower extremities and estimated the amount of stress placed on the knee during the maneuver. From the point of foot strike prior to a cutting maneuver, the knee is typically in a valgus position with an internal or external rotation while the knee is near full extension preparing to decelerate and change directions.[26,39,40] While performing the cutting task, it has been reported that females tend to have greater knee valgus as well as less knee flexion compared to males.[35,41] The greatest potential for tension development in the ACL is during sidestepping through weight acceptance and peak push off, where the knee experiences combined loads of anterior tibial force, internal rotation and valgus moments while in 30° to 40° of flexion.[42,43] Joint loads experienced during the cutting maneuver have been shown to be at their highest when the knee is in valgus with a slight knee flexion and internal or external rotation.[29,39,42,44-46] However, volleyball is a sport which involves executing lateral steps or cutting maneuvers after landing from a jump rather than during running.

Landing studies have revealed sex differences in kinematics of the lower extremities. Females, when compared to males, displayed a significantly greater knee valgus angle and moment upon landing from a jump or dropping from a box.[47-51] It was also demonstrated that females tended to land with a more erect posture having less knee flexion and greater hip extension when compared to their male counterparts.[13,52,53] Landing with a more erect posture has been shown to produce a higher peak GRF [13,54,55], which, if paired with the differences in lower extremity kinematics between males and females may help to explain the higher number of knee injuries in females.

When looking at EMG of both cutting and landing maneuvers, females demonstrated different neuromuscular control patterns than did males. Females tend to have relatively weaker activation of hamstrings musculature[13] which contributes to a greater hamstrings to quadriceps imbalance.[41,46,56-59] Since the hamstrings stabilize the knee joint, lower hamstrings activation may provide an inadequate counter to the eccentric contraction of the quadriceps decelerating the body during landing or cutting. In volleyball, two landings commonly utilized are a 'land and stop' or a 'land and go' and are dependent upon whether a player needs to land and avoid contact with the net or another player, or needs to land and move into another position to prepare for the following play.[60] There are also two types of lateral movement involved when playing against the net, 'slide step' and a 'cross step'.[61] Players are often required to perform one of the two lateral movements directly after landing from a block or spike creating similar movements to those found in sports involving rapid deceleration of the body followed by a quick change in direction. In a game situation, conditions are constantly changing requiring players to make quick, split second decisions for their next move. In order to make laboratory experiments as close to game-like situations as possible, an anticipatory factor has been added which can alter reflex responses and postural modifications in order to decrease the approaching perturbation.[62] Studies have found that unanticipated conditions increased external valgus/varus and internal/external rotation moments applied to the knee as well as decreased hip abduction angles in both males and females [63-65] and even greater ROM in the sagittal plane in females.[66] The use of an unanticipated task has also been shown to increase GRF and joint loads in both females and males during sidestep cutting.[34,67] These altered biomechanical factors and neuromuscular control patterns are the leading areas of interest when considering possible mechanisms of ACL injuries. Studies have looked at the combination of running and cutting as well as forward jumping and cutting, however no studies to date have looked at a drop landing and then performing a lateral or cutting maneuver such as a cross step similar to that seen in volleyball. It is crucial to understand the mechanisms of ACL injury to develop preventative training programs.

Purpose

The purpose of this study was to investigate university club-level female volleyball players and the effect of anticipation on lower extremity mechanics during a landing and subsequent cross stepping maneuver. Since the dynamic tasks during a game are typically unplanned, this study sought to explore unanticipated tasks to more closely simulate game-like situations.

Hypothesis

We hypothesized that unanticipated conditions would alter hip, knee and ankle joint kinetics and kinematics such that: the knee would experience greater external loads (e.g., varus/valgus and internal/external rotation loads), shallower knee flexion angles; the hip would experience decreased flexion and abduction and larger internal rotation; and the ankle would display greater inversion and plantar flexion.

Limitations

The limitations of this study included: the sample population and that the sample was non-random and identified a very specific group of individuals which could affect external validity.

Delimitations

The delimitations of this study included: using only college-aged female volleyball players and the study was conducted in a laboratory setting. Additionally, the visual cues used to signal the direction of the movement were images of arrows and not actual player or ball movements. This was done in order to exert more experimental control over the signals.

Assumptions

The researchers assume that the participants answered the health assessment questionnaire honestly and that full effort was given during testing.

Chapter 2: Review of the Literature

1. Intro

The knees and ankles are the most frequent sites of injury in volleyball players [15,17,25,68] with knee internal derangement accounting for roughly 14% of game injuries in NCAA female volleyball athletes and of those, 26% were ACL injuries.[25] Female athletes have a 2- to 8-times higher incidence of sustaining a noncontact knee injuries, most common being anterior cruciate ligament (ACL) injury, compared to male athletes participating in the same sport or activity.[12,13] The most frequent mechanism of injury is landing from a jump in the attack zone.[15] The jumping and landing task is a crucial aspect of volleyball and in many cases, following a landing task a player must quickly move to another location on the court by using a cutting-like maneuver. Both landing and the cutting maneuver are important to understand mechanically due to their potential to cause injury. In an attempt to simulate a realistic game situation and understand the mechanism of injury, unanticipated directional changes were added to the landing tasks for this study.

2. Anterior Cruciate Ligament

The anterior cruciate ligament's (ACL) origin is on the posterior side of the intercondylar notch of the femur and it inserts on the anterior side of the intercondylar eminence of the tibia. It acts in preventing hyperextension and anterior tibial translation, as well as guides tibial rotation as the knee extends.[69] It has been shown that isometric hamstring activity decreases strain on the ACL, whereas isometric quadriceps activity at flexion angles of 0° and 45° significantly increases strain in the ACL relative to passive strain.[59] Most knee ligament injuries occur during game play rather than during training with a possible explanation being that more often maximum effort is expended during game situation than during training, thus the risk for injury is higher.[15] In order to identify the athletes that are at a higher risk for this type of injury, it is important to understand the biomechanics of the human body while performing tasks that are associated with ACL injuries.

Landing and changing direction in volleyball can place a player at risk of a knee injury. An ACL rupture is often the most distressing of knee derangements and can potentially remove an athlete from activity for months and many athletes may never return to their original level of play.[70] The etiology of ACL injury has been of major concern to researchers over the past three decades in order to understand the anatomy and biomechanics of the ACL. It has been described that sudden deceleration, an abrupt change in direction and a fixed foot as being key elements of an ACL injury.[32] Research suggests that the greatest potential for tension development in the ACL is during a sidestepping or cutting maneuver, through weight acceptance and peak push off.[42,43] Here, the knee experiences combined loads of anterior tibial force, internal rotation and typically experiences the highest valgus moments while in 30° and 40° of flexion. Multiple studies have confirmed this by simulating a run and cut maneuver, commonly experienced during game play, in a laboratory setting.[15,26,32] The majority of ACL injuries (70%) occur without the player coming into contact with an object or another player and are labeled as noncontact.[15,26-30] When comparing males and females, females participating in the same sport as males, have been revealed to be at a higher risk (2-8 times) of injury when cutting or jumping tasks are involved.[8,12,13]

3. Landing

3.1 Techniques in Volleyball

A volleyball landing task can be categorized as one of two different types: a ‘land and go’ task or a ‘land and stop’ task.[60] For example, a blocker would be expected to ‘land and stop’ in order to avoid collision with a teammate, where as a player performing a jump serve would be expected to 'land and go' to play defense following the serve. A player jumping to set would 'land and go' in order to cover an attack and an attacker in the front row would 'land and stop' to avoid contact with the net.[71] For blocking specifically, there are two types of footwork used to move laterally during play, the "slide step or 2 step" and the "cross step or 3 step".[61] The slide step starts with a player sliding the lead foot in the direction they wish to travel followed by the lagging foot moving close to begin the push off for the jump. The cross step begins with a short slide of the lead foot, followed by the lag foot crossing over the lead foot closer to the net finishing with the lead foot crossing behind and moving close to the other foot to prepare for the push off. Tillman et al. (2004) quantified the number of jumps performed during a typical volleyball game and categorized each jump by type (offensive spike or defensive block) and phase (jump or landing). The phase was further divided into foot use patterns (right, left or both). After analyzing 1087 jumps and subsequent landings from four elite female volleyball teams it was found during the jump phase 84% of offensive jumps and 99% of defensive jumps were performed bilaterally, however during the landing phase, the use of a unilateral landing was relatively more prominent than in the jump phase. Bilateral offensive landings occurred only 55% of the time and bilateral defensive landings were performed only 57%.[72] Lobietti et al. also found that players land either bilaterally or unilaterally based on the task being performed, the task prior to the jump as well as the position from which the task was performed. For example, female volleyball players had a significant difference in landing styles between a jump spike serve, landing bilaterally 93.9% of the time, and a jump float serve landing unilaterally 83.3% of the time.[71] The kinematics of the lower extremities while decelerating the body during landing are affected by the landing style.

3.2 Kinetics and Kinematics

The mechanical goal of a landing task is to effectively convert the total body momentum at touchdown to achieve a subsequent task.[60] A successful landing from a jump depends on the posture at initial contact, ROM and adequate muscle activity. Measuring a successful landing requires quantifying biomechanical factors such as lower extremity joint configurations, vertical ground reaction forces (VGRF), joint moments and work.

Devita and Skelly (1992) differentiated landings by the relative joint contribution and divided them into either a stiff landing or a soft landing.[54] A landing was labeled as stiff when maximum knee flexion was less than 90° from full extension and a landing was labeled soft when maximum knee flexion was greater than 90° from full extension. In their study, Devita and Skelly found that during the soft landing, the lower extremity muscles absorbed 19% more kinetic energy than the stiff landing. The relative joint contribution of the hip, knee and ankle was 25, 37 and 37% for the soft landing and 20, 31 and 50% for the stiff landing, respectively. The majority of the landing was absorbed by the knee extensors and ankle plantar flexors and as the stiffness of the landing increased, the relative contribution of the ankle plantar flexors increased while the contribution from the knee and hip extensors decreased. Sex differences have been found when landing from a jump. It has been demonstrated that females tend to land with a more erect posture when compared to males, which means having significantly smaller knee flexion and larger hip extension angles at initial ground contact than males.[13,52,53,73] Studies looking at males and females dropping from box heights of 20, 40 and 60 cm or performing a vertical jump found that females had significantly greater knee extension and ankle plantar-flexion angles at initial ground contact, however, they subsequently exhibited greater knee and ankle ROM suggesting that the females adopted a different strategy during landing to dissipate the large external forces. This proposes that the preferred shock absorption strategy for females required the ankle and knee to be in a more extended position to fully utilize the capacity of the ankle plantar flexor muscles and that as box height increased, the posture while landing became more upright. Studies have shown that players with greater plantar flexor strength, as well as decreased dorsiflexion ROM, tend to land with shortened plantar flexors predisposing the player to an inversion injury such as an ankle sprain.[18-22] Additionally, landing with a more extended knee angle decreases the ability of the hamstring muscles to prevent anterior tibial translation, thereby increasing the risk of ACL injury. However, Fagenbaum et al. (2003) found that females rather than males had greater knee flexion angles at initial ground contact which contradicts the findings of other studies.[74] One possible explanation for the contradiction was that subjects were taken from the same institution and it is possible that they share the same training techniques. These studies have not only shown sex differences in landing mechanics but also that height of the drop landing plays a role in the change of landing strategy.

In volleyball, players do not always jump vertically but oftentimes with a forward motion and land with forward momentum, as in a serving and spiking. This adds jumping distance as a factor to consider when landing. In an attempt to replicate a landing in a game-like situation, Salci et al. (2004) changed not only box height but also the distance the box was away from the force plate replicating a spike and a block landing. When comparing male and females, not only did females land with less knee flexion, but they also applied a higher normalized ground reaction force (GRF) than males which is likely attributed to the smaller knee flexion angle of the females upon landing.[13] A similar study looked at males jumping and completing a ‘land and stop’ after a spike at two different distances and found significant postural and kinematic differences, mainly unilaterally. Subjects performed a spike jump from their usual (Normal condition) jumping distance followed by one 0.7 m further (Long condition) than their usual distance. Although, GRF increased from the normal to the long distance condition, the results were not significant. Significantly larger center of gravity velocities in both vertical and horizontal directions were found for the Long condition than the Normal condition. During the take-off phase of the normal condition, significantly larger trunk lean was observed along with larger ROM throughout the energy absorption phase for the left limb joints (ankle, knee and hip) and the right ankle. Additionally in the normal condition, the left hip and foot showed significantly smaller angles during the take-off phase. One conclusion from this study was that different landing strategies were utilized when jumping distance changed. It was suggested that when landing with higher horizontal velocities, a more erect posture and larger ranges of motion throughout the joints will provide a safer landing [75] suggesting that a stiffer landing may increase the risk and incidence of injury.[76]

Along with a stiffer landing, sex differences have been seen in valgus knee angle (VKA). Valgus angles may be a predictor of non-contact ACL injuries and can be attributed to other injuries such as those found at the patellofemoral joint. Olsen et al. (2004) analyzed video of circumstances where ACL injuries occurred in team handball games and found that in 19 out of 20 cases the knee was estimated to be in a valgus angle greater than 10°.[36] It was then concluded that valgus knee movement is a high risk factor for ACL injury. Multiple studies have looked at VKA while landing and the results show that females tend to land with a greater VKA thus contributing to the elevated risk of ACL damage in females.[48-50] Palmieri-Smith et al. (2008) also found that when exclusively including females in the regression model an increase in preparatory muscle activity from the vastus lateralis (VL) and lateral hamstring (LH) was accompanied by an increase in a higher peak VKA while increased preparatory activity from the vastus medialis (VM) was accompanied by a lower peak VKA.[50] Under certain conditions, males also displayed knee valgus angles associated with ACL injury. Male team sport athletes performed four different landing tasks while catching a ball overhead at their maximum jump height. Results showed that catching the ball while it moved toward the subject's support leg caused a greater peak valgus knee moment compared to catching the ball while it moved away from the support leg. These increased valgus moments were correlated with increased knee flexion, hip flexion, and torso lean, as well as torso rotation towards the support leg, and foot and knee external rotation.[77] This suggests that specific biomechanical factors and postures can contribute to increased knee valgus moments.

3.3 Ground Reaction Force

Stiffer landings have also been associated with greater vertical VGRF. The VGRF is the opposing force from the ground upward upon the body equal in magnitude of the force being applied from the body downward. During landing from a jump, VGRF causes the lower extremities to collapse by accelerating the hip, knee and ankle joints into (dorsi) flexion. The goal of a safe landing is to resist this collapse by reducing the body's velocity to zero without causing injury.[54] Quantifying it can reveal an athlete's ability to efficiently and effectively attenuate the impact of a landing and its forces. Depending on the height from which a person lands, VGRF can be as much as 7 to 11 times body weight (BW).[78-80] Landing with more erect posture has been associated with a greater VGRF [55]. This is demonstrated by the findings of Allyn and Stoner (1994) who found that movement about the knee dictates if a landing will be a "hard" or "soft" landing.[81] Salci et al. (2004) further demonstrated this concept with females exhibiting a greater normalized peak VGRF and shallower knee flexion in four different landing conditions when compared to males.[13] Another study compared the VGRF of traditional and slide attack techniques, to quantify and compare the kinetic and kinematic differences during the impact absorption phase of landing from the two volleyball attack techniques.[81] During the traditional technique, subjects approached the net perpendicularly to attack and during the slide technique subjects travelled parallel to the net and on the last step pivoted and rotated their body to face the net. Forces ranged from 1.1 BW to 6.4 BW with a mean of 3.4 BW for the traditional technique and a mean of 2.5 BW for the slide technique. The traditional technique produced significantly larger VGRF than the slide technique. It was also found that ROM about the knee for both the traditional (59°) and the slide (61°) techniques would classify the landings as a stiff or "hard landing" according to Devita and Skelly (1992). The differences at the knee between the two techniques may be explained by the medial-lateral movement during the stabilization phase following the slide technique. If coaches emphasize the importance of a soft landing and if players could absorb the landing more efficiently, the risk of injury may be reduced.

3.4 Maturation Level

During the different stages of maturation, the size and strength developments alter the way forces are transmitted through the body. The maturational changes paired with the increasing competitiveness of sports may further increase the risk of injury. Interestingly Sigward et al. (2012) found that maturation level of the athlete was not correlated to the change in landing biomechanics when comparing males and females.[51] Placing athletes into four maturation-related groups (pre-pubertal, pubertal, post-pubertal and young adult), it was found that even in the pre-pubertal groups, males and females were already displaying significant differences in landing mechanics. When averaged across maturation levels, females exhibited greater knee adductor moments and a 30% higher knee/hip moment ratio suggesting their landing strategy favored using knee flexors rather than hip extensors to decelerate their center of mass. Another study found that when comparing prepubescent and post pubescent females during three type of stride jumps, post pubescent females displayed a 4.4° greater knee extension, 30% greater knee and hip extension moments, and 40% greater knee power.[47] The post pubescent group also exhibited greater knee anterior/posterior and medio-lateral forces. Contrary to the Sigward et al. (2012) study, these results suggest that the anatomical and physiological changes experienced during puberty may lead to differences in strength and neuromuscular control which influenced the dynamic restraint system in these recreational athletes and may increase the risk for injury. This suggests that further research is needed to determine the effect of maturation level on landing biomechanics.

3.5 Muscle Activation

Electromyography (EMG) is a technique for collecting and analyzing electrical activity in skeletal muscle which translates into muscle activation levels and recruitment order. EMG is recorded using surface electrodes which detects the electrical potential generated by the muscle cells which are activated neurologically. According to Zebis et al. (2009), the excessive activation of the quadriceps over the hamstrings muscles is a possible risk factor for injuries of the ACL in women.[37] Studies looking at GRF and EMG in the lower extremities, found asymmetrical loading during the take-off phase of jumps when a single-leg landing was required as well as asymmetrical activation between the quadriceps and hamstrings.[57,82] The contralateral limb was loaded 0.12 BW more during the take-off phase when a single landing was required, however jumps requiring a two-legged landing showed no significant difference for peak loading between limbs. During the flight phase however, activation levels of the vastus medialis and lateral gastrocnemius were far greater in the single-leg landings than in the two-legged landings activating 90% and 39% more, respectively.[82] The muscle activation for the biceps femoris was significantly different between the two jump types but not for the jump phases (pre-contact, 100 ms prior to ground contact, post-contact, and 100 ms after ground contact). Conversely, the rectus femoris resulted in significant differences between the jump phases but not the jump types. These results suggest that the quadriceps are the primary absorbers of the landing through eccentric contractions while the hamstrings act as stabilizers. During activities of higher impact, the biceps femoris seems to help attenuate the loads at the knee, staying more active during the cycle in the single-leg landing.[57] The BF/RF activation ratio found in these studies corroborate previous findings that excessive activation of the quadriceps and insufficient activation of the hamstring muscles increases the tension in the ACL constituting a possible risk factor for injuries in this ligament.[59]

Studies comparing landing from three different box heights found asymmetrical activation patterns of the quadriceps and hamstring muscles between males and females.[56] During the preparatory phase (100 ms before landing), as the heights increased the hamstring-to-quadriceps ratio significantly decreased, though no significant difference was found during the reactive phase (100 ms after landing). The researchers reported that females relied heavily on the increased activation of the quadriceps muscles as plyometric intensity increased to decelerate the body, while activation of the hamstrings remained relatively constant agreeing with the findings of the previous research. Lower extremity mechanics play an important role in the activation of muscles used to decelerate the body. Palmieri-Smith et al. (2008, 2009) found that a larger VKA was associated with increased preparatory muscle activity from the vastus lateralis and lateral hamstring while increased preparatory activity from the vastus medialis was accompanied by a lower peak VKA. It was also revealed that the ratio of medial-to-lateral leg co-contraction and quadriceps: hamstrings co-contraction was unbalanced in women and may limit their ability to effectively counter abduction loads.[50,58] However, it was demonstrated that the reduced activation of the gluteus medius did not significantly influence the VKA suggesting that muscles acting directly on the knee joint (quadriceps and hamstrings) are the most influential in increasing/reducing the VKA. The decreased hamstrings-to-quadriceps muscles activation ratios found in the research may signify altered neuromuscular control patterns and may be a contributor to increased ACL strain.

3.6 Anticipation

Sports are inherently unpredictable and constantly challenging athletes to make split second decisions based on specific game situation. In an effort to make laboratory situations more realistic, researchers have begun to add unanticipated maneuvers and have revealed alterations in landing mechanics.[63,64,80] Males and females were asked to perform a forward jump onto one of two force plates and immediately cut to the right or left in anticipated and unanticipated conditions. Differences were found in the unanticipated initial contact hip posture as well as peak stance hip and knee internal rotation when compared to anticipated landings. Initial contact hip and knee flexion/extension, hip and knee abduction/adduction, hip internal/external rotation, and peak stance hip and knee internal rotation all showed differences between both sexes and dominant/non dominant limbs. This suggests that there may be muscle imbalances across the body and could lead to an increased risk of injury. Both males and females displayed lower limb mechanical changes placing the knee, and more specifically the ACL, at risk of injury and therefore should be considered when developing prevention programs for both sexes.

Another way research has been attempting to make studies as close to a real game situation as possible is through the addition of fatigue. Similar in design to a study done by Brown, Palmieri-Smith and McLean (2009), Borotikar et al. (2008) introduced fatigue as well as a third task of a vertical jump.[63] Comparisons of results included pre, 50% and 100% fatigue level, dominant and non-dominant legs and anticipated and unanticipated landings. Neuromuscular fatigue promoted significant decreases in initial contact hip flexion and significant increases in initial contact hip internal rotation and in peak stance phase (0-50%) knee abduction, knee internal rotation and ankle supination positions during the execution of dynamic single-leg landings. Also, the fatigue-induced modifications in lower limb kinematics observed at maximum fatigue (100%) during single-leg landings were already present at the 50% fatigue level. Likewise, the fatigue-induced changes in initial contact hip flexion and internal rotation, and peak stance phase (0-50%) knee abduction positions were significantly more pronounced during the unanticipated compared to the anticipated single-leg landing tasks. These findings suggest that there was degradation in peripheral and central processing mechanisms. Integrating fatigue and decision-making into the research was done in attempt to replicate real game situations and in doing so may represent the worst case scenario in terms of injury risk.

In a study looking at the effect of shoes on impact forces and soft-tissue vibrations, basketball players were asked to perform drop jumps and unanticipated drop landings in a basketball shoe and a control shoe from three different heights.[80] The mean ROM values increased for all three lower extremity joints as drop heights increased with the exception of ankle ROM values (45 to 60 cm) during the drop jump. No significant shoe effect was found in peak VGRF, peak loading rate or GRF frequency during the impact phase of the anticipated drop jump. Conversely, for the unanticipated drop landing, peak VGRF, peak loading rate and GRF frequency were significantly lower in the basketball shoe across all three heights. The VGRF and loading rates were higher in the unanticipated drop landings compared to the drop landings across all three heights suggesting that the preparatory muscle activation prior to landing allowed the subject to absorb the landing properly and attenuate the impact forces when able to anticipate the landing. Alternatively, these findings suggest that if the neuromuscular system fails to prepare for the impact of landing, a shoe intervention may be an effective method for minimizing impact force and reducing soft tissue resonance which in turn may help reduce the risk of overuse injury.

4. Cutting

4.1 Mechanism

Cutting is a mechanism that allows athletes to change direction quickly and is common in a number of sports including, but not limited to, soccer, rugby, handball and basketball. Cutting maneuvers are also seen in sports such as volleyball where a cut may be performed following a landing rather than during running. A cut may be a directional change of only a few degrees to over 90°, and can vary in execution from one individual to another. Within these sports, two types of cuts exist; a sidestep cut and a crossover cut. The sidestep cut consists of an athlete planting the foot opposite of the direction they wish to go and using the other leg as the first step in the new direction. For the crossover cut, the athlete plants the foot on the same side as the new direction they wish to travel and crosses over the opposite foot to begin stepping in the new direction.[33]

As the athlete performs the cutting maneuver, there is a need to reduce momentum prior to changing direction by altering the gait pattern from a normal gait cycle to a modified gait cycle.[33] The cycle to decelerate begins with the movement of the foot to be planted for the cut being modified during the decent phase, with the knee extended, before the foot strike occurs. The foot immediately plantar flexes as it contacts the ground causing a deceleration force to be generated as the body is moving forward. The torso becomes more erect and the foot begins to dorsiflex until the tibia angle is past vertical. The knee flexes to compensate for the dorsiflexion of the foot so the COM remains posterior to the planted foot. As the COM passes the planted foot the second step is a passive one, usually with no change in velocity. Beginning the plant and cut phase, the free leg swings in the new direction and provides initial acceleration

4.2 Kinematics and Kinetics

The cutting maneuver has been shown to place large amounts of stress on the ligaments of the knee joint and so the knee has been of major concern to researchers trying to determine factors contributing to ACL injuries. While investigating the biomechanics of the knee and hip joints, elite female handball players performed side-cutting maneuvers on both their dominant and non-dominant legs.[39] Hip and knee flexion, adduction and internal rotation angles at initial ground contact were found to show no significant asymmetries between the dominant and non-dominant legs. Hip flexion, extension, adduction and internal rotation moments and knee flexion, adduction and internal rotation moments also showed no significant asymmetries between the two legs. The findings showed coinciding external moments loading the knee into valgus and outward rotation and simultaneously loading the hip into internal rotation and abduction. These loading patterns emphasize the dependency on the medial hamstrings to counteract the external knee valgus moments and knee outward rotation moments, and the importance of hip outward rotators to counteract the external inward rotation moment. Results suggest that no one leg is more at risk of injury however, a possible limitation to the study design is that all trial were performed in a lab and the subjects were aware of the direction of the cut.

When looking at joint kinematics during the cutting maneuver, participants were asked to run in a straight line and perform a sidestep cutting maneuver (between 35° and 90° from original direction) after making contact with a force plate.[35,41] It was seen that females tended to have less knee flexion angles and greater VKA compared to males. McLean et al. (1999) suggests that the increased abduction angle in females could be attributed to the fact that females typically have a larger Q-angle when compared to males.[35] Another key finding was that greater mean peak knee valgus angles were revealed during the stop phase than during the side-movement phase suggesting the risk of ACL injury is greater while decelerating. Females also displayed larger coefficients of variance for knee joint internal/external rotation values during the stance phase of cutting when compared with males.[35,45] Increased variability in knee joint kinematics may increase the chance of ACL injury with the possibility of a more hazardous cut during play being more likely to occur. However, results of this study also demonstrated that the increased variability may not be solely based on sex, but rather the experience level. Lack of experience or poor conditioning has been viewed as a major contributing factor to a higher risk of ACL injury in females over males.[83] The females in the study tended to have less experience than males and therefore may be the contributing factor to increased knee joint kinematics variability.[35]

Along with experience levels, running styles vary from person to person. The two most common styles of foot strike patterns are rearfoot and forefoot striking. Cortes et al. (2012) looked at these two types of landing techniques (forefoot/rearfoot) during a sidestep cutting and pivot task. The rearfoot landing technique used during sidestep cutting exhibited increased knee valgus angles and a decreased hip flexion angle, but was not apparent in the pivot task. One key finding was that all the subjects adopted a knee valgus position regardless of the landing technique used. It was also seen that the subjects landed with a more extended knee and abducted knee position when using the rearfoot landing technique.[40]

Cutting maneuvers have also been shown to alter the loading at the lower extremity joints of the hip and knee. Besier et al. (2001) had healthy males perform four different tasks to measure external flexion/extension, varus/valgus and internal/external rotation moments at the knee during the stance phase of each task.[42] External flexion loads were found to be similar across all four tasks while external varus/valgus and internal/external loads placed on the knee joints increased dramatically while performing the cutting tasks compared to the running task. The varus/valgus load was approximately 2 and 6 times greater during the 60° cutting tasks compared to running at weight acceptance and final push off (last 15% of stance), respectively. Significant differences were found between 30° cut, 60° cut and crossover cut compared to running. The external rotation load experienced at the knee during the crossover task was more than twice the load experienced during running. Also, the internal rotation loads experienced during sidestep cutting and the external rotation loads during the crossover task were each five times greater than those experienced during running. Sex differences also exist when comparing the lower extremity joint moments during cutting tasks. When comparing male and female athletes during running and sidestep cutting, normalized peak knee valgus moments were significantly larger in females than males.[45,46] Higher knee valgus loading was associated with higher internal hip flexion, hip internal rotation and knee valgus positions. This demonstrates that the females experienced increased moments in the frontal plane and decreased moments in the sagittal plane during deceleration. The differences suggest that the females are in an "at risk" pattern in that the frontal plane support for the knee is largely provided by passive structures (i.e., ACL, MCL).

4.3 Previous Injury

Numerous studies have looked at the mechanics and forces generated by healthy subjects during athletic maneuvers, however many athletes undergo surgeries following an injury and return to playing after a recovery period. When looking at the kinematics of males and females during a jump-cut task post ACL reconstruction, females who have never had an ACL replacement demonstrated smaller knee flexion angles (greater stiffness) and larger GRF than males who have never had an ACL replacement as well as both males and females who have had the surgery.[84] A secondary finding was that females with no history of ACL replacement had a greater rate of anterior tibial translation than their male counterparts with no ACL replacement. The kinetic differences likely influenced the rate of tibial translation after ground contact, which is commonly associated with ACL injury. It was also found that the females without ACL reconstruction displayed increased anterior tibial translation at a faster rate than their male counterparts. Since the risk of ACL injury is greater in females, the understanding of ACL reconstruction status between sexes in the kinematic and kinetic factors during athletics may help point to the root of injury and re-injury as well as injury prevention and rehabilitation.

4.4 Muscle Activation

When looking at the biomechanical factors of the knee during running, side-cutting and cross cutting tasks it was demonstrated that there were significant differences between males and females in knee flexion/extension, valgus/varus, normalized integrated EMG (IEMG) of the quadriceps and IEMG of the hamstrings in all three tasks.[41] The IEMG of the quadriceps for females was consistently above that of the males at initial ground contact. The percent activation was 17% and 40% of the corresponding EMG_{MVC} for females and males, respectively. In contrast, the hamstrings IEMG was lower in females compared to their male counterparts and the difference was generally greater than 20% of the corresponding EMG_{MVC}. In a similar study, females demonstrated greater average quadriceps EMG (191% MVIC) than males (151% MVIC) during the early stage of deceleration.[46] Just like the sex differences in the landing studies, the findings suggest that the lower extremity mechanics and the altered activation patterns contribute to the greater loads on the ACL found in females than in males.

4.5 Anticipation

Multiple studies have also looked at the differences in joint moments when comparing maneuvers that require decision-making. The magnitude of the moments experienced at the joints typically increased when the maneuver was unplanned. A study comparing male subjects performing four different running and cutting tasks, that were either preplanned or unanticipated, found that although knee flexion/extension moments were similar between tasks, varus/valgus and internal/external rotation moments were up to twice the magnitude in unanticipated compared to preplanned.[34] Females displayed similar results in unanticipated conditions. While performing a sidestep cutting maneuver to measure plane of motion force contributions it was found that the peak force on the ACL increased by 13% when the cut was unplanned in females.[67] Peak force on the ACL is made up of the three planes of motion (transverse, frontal and sagittal) with each contributing a specific amount of force (12%, 26% and 62%, respectively) to the total loading on the knee. The results suggest that ACL loading resulted from a multifaceted interaction sagittal plane shear forces (i.e., quadriceps, hamstrings and tibiofemoral). It is suggested that improper postural adjustment is the cause of the increased loads to the lower extremity joints and contributes to the increased risk of injury to the ACL.

Sex differences were also found when looking at lower extremity joint kinematics and muscle activation.[85-87] During an unanticipated jump, stop and cut maneuver, at initial contact, females exhibited greater knee abduction as well as increased maximum ankle eversion angles and decreased maximum ankle inversion angles compared to males. These findings are in accordance with landing studies using young male and female athletes showing that even at a young age, sex differences can be seen in joint kinematics.[47] During a run and cut maneuver, females performed the cut with a decreased hip internal rotation at initial contact and decreased peak internal hip rotation as well as with greater knee abduction angles at initial contact and greater peak knee abduction angles.[85] Even though it was not significant, females demonstrated a greater use of their vastus lateralis (154% MVIC) when compared to their vastus medialis (136% MVIC). Male athletes used the opposite strategy with greater vastus medialis (158% MVIC) activation compared to vastus lateralis (137% MVIC). A lateral/medial imbalance of the vastii can generate excessive knee abduction and adduction moments. Finally, females activated their RF more than did the males.[86] Greater quadriceps activation can cause anterior tibial-femoral shear which can disproportionately stress the ACL. These findings demonstrate the idea that males and females adopt different motor recruitment patterns when performing an unanticipated cutting maneuver. This difference in muscle activation may be a possible explanation for the difference in lower extremity kinematics, more specifically knee kinematics, when performing the unanticipated maneuver.

4.6 Task Comparisons

Being able to identify players who are at higher risk of injury is crucial in order to take proactive measures to prevent the injuries. O'Conner, Monteiro and Hoelker (2009) compared males and females in their performance of four cutting tasks in an attempt to find an experimental protocol that would correlate highly with an unanticipated task in an attempt to better screen for potential risk of injury.[66] Significant group mean differences were found between tasks and across sexes and although there were high correlations between the three constrained tasks, the variables typically associated with ACL injury risk were poorly related to the cut task making them only moderately useful in predicting cutting mechanisms. The results suggest that the constrained tasks may not be adequately representative of cutting dynamics within a realistic environment.

5. Conclusions

Studies looking at the mechanics of a landing task have shown that females tend to adopt a different landing strategy than males. Females tended to land in more erect posture with more extended knees leading to a larger ROM in hip and knee flexion in order to decelerate the body. Due to the more extended leg, females also demonstrated greater knee valgus angles and internal rotation as well as a larger GRF. Upon landing females activated their quadriceps to a greater extent than their hamstrings, which paired with the extended knee at landing allows for greater tibial translation. An unanticipated task also increased GRF and knee valgus angles during landing tasks. These lower extremity kinetics and kinematics put females at a greater risk of injury to the knee than males.

The cutting task has been shown to produce results similar to those of a landing task. Again, females displayed greater knee abduction angles and loads as well as less knee flexion than males while performing a cutting maneuver. This showed that females had increased joint moments in the frontal plane and decreased loads in the sagittal plane during deceleration putting passive support structures, such as the ACL, at a greater risk than males. Females also relied on the quadriceps more than the hamstrings to decelerate prior to performing the cutting maneuver. The lack of activation from the hamstrings, which help stabilize the knee and prevent anterior tibial translation, puts the knee at a greater risk of injury. During an unanticipated cut, females demonstrated greater knee abduction angles at initial contact and greater peak knee abduction angle when compared to an anticipated cut, again placing greater stress on the knee joint.

Both the landing task and side stepping task are equally important during the game of volleyball considering they are commonly used consecutively. Although there has been a great deal of research on the biomechanics of landing, as well as cutting, there is little research on the effect of an unplanned directional change following landing from a jump. Since athletes rarely have the ability to pre-plan a task or next move during actual game play, it is important to improve ecological validity by creating a more realistic game situation in the laboratory. Sports such as volleyball involve moving quickly to a new position following the completion of a task and a landing. Most non-contact ACL injuries occur during these unanticipated cutting maneuver during a game [26], however additional research using an unanticipated cut following landing from a jump is needed to better understand the inherent risk associated with these types of sport related movements. Understanding the kinetics and kinematics of the lower extremities of an athlete while performing these unanticipated maneuvers is important for both researchers and clinical professionals alike to develop proper training to prevent injury as well as develop rehabilitative techniques. As such it is the purpose of this study to analyze the kinematics and kinetics of the lower extremities while performing an unanticipated cross stepping maneuver following landing from a jump.

Chapter 3: Manuscript

ANTICIPATORY EFFECTS ON LOWER EXTREMITY KINETICS AND KINEMATICS DURING A LAND AND CROSS STEP MANEUVER IN FEMALE VOLLEYBALL PLAYERS

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Abstract

Anticipation has been previously shown to affect lower extremity mechanics during both landing and cutting maneuvers. However, little research has been conducted looking at the effects of anticipation on lower body kinetics and kinematics during a land and cross step maneuver, which due to similar kinematics, may elicit injury. Twelve female, college-level volleyball players performed right and left cross step maneuvers following a landing under anticipated and unanticipated conditions. Kinetics and kinematics were measured for the ankle, knee and hip of the dominant limb during the landing phase of the various movement conditions. Interactions were seen for knee flexion, abduction and internal rotation (all $P < .001$) at initial contact as well as maximum knee flexion and internal rotation (both $P < .001$). Other contributors to high risk landings, maximum ankle inversion ($P < .001$) and hip external rotation ($P = .026$) had significant interactions at initial contact. However, effects were not limited to unanticipated trials and anticipated also elicited high risk positions. Drills familiarizing players with unanticipated changes of direction along with strength training of the muscles required to effectively decelerate the body may help prevent injury.

Keywords: Biomechanics; Jump; Anterior Cruciate Ligament

Introduction

Volleyball has become one of the world's most popular sports with the International Volleyball Federation claiming over 800 million participants[1] and over 200 member countries.[2,3] As the popularity has grown, so has the number of female participants. Over the past 30 years, competing schools and female participants within NCAA volleyball has increased from 752 to 1,096 schools and over 15,890 athletes at the Division I, II and III levels.[4] Along with the increase in participants, there has been a large increase in the number of sports-related injuries. For an individual player, the incidence of volleyball-related injuries is estimated to be between 2.5 and 4.3 injuries per 1000 hours of play,[2,5,6] rivaling sports such as soccer, handball and ice hockey.

The majority of injuries affect the lower extremities, however, a disproportionate number of injuries occur in women compared to men.[7,8] It has been shown that females participating in the same sport as males are at an increased risk (2-8 times) of injury when a cutting or jumping maneuver is involved.[8-10] Knee injuries sustained during volleyball play typically occur due to (1) an overuse injury referred to as patellar tendinopathy or (2) an acute traumatic injury such as internal knee derangement.[1-3,5,6,11-13]

Within volleyball it is estimated that 63% of injuries occur during jumping or landing movements like blocking and spiking.[1,2,11] It has been shown that knee internal derangement makes up 14% of game injuries in NCAA female volleyball athletes with approximately 26% of those being ACL injuries.[14] Focusing on ACL injuries, roughly 70% are labeled as noncontact[12,15-19] in nature[20] rather than resulting from rapid deceleration and/or a sudden change of direction with at least one foot planted.[21] In volleyball, many times a player must make a quick decision after landing to cross step along the net, occasionally not knowing which direction the next play will occur. This requires split second judgment calls to be made on the player's part, sometimes while in the air, which may lead to the player making an inappropriate landing modification. Previous research has studied jump landings, without any subsequent movement, and found that unanticipated conditions increased valgus/varus and internal/external rotation moments applied to the knee as well as decreased hip abduction angles in both sexes[22-24] and even greater ROM in the sagittal plane in females.[25]

These aforementioned landing and run/cut studies have highlighted the potential injury risk associated with the movements, however few studies to date have looked at landing and cross stepping, a maneuver in volleyball, in an unanticipated condition to more closely replicate a game-like situation. Therefore, it was the purpose of this study to investigate competitive female volleyball players and the effect of anticipation on lower extremity mechanics during a landing and cross stepping maneuver. We hypothesized that unanticipated conditions would alter hip, knee and ankle joint kinetics and kinematics such that: the knee would experience greater external loads (e.g., varus/valgus and internal/external rotation loads), shallower knee flexion angles; decreased hip flexion and abduction and larger internal rotation; and greater ankle inversion and plantar flexion than during anticipated cross steps.

Methods

Subjects

Twelve female collegiate level, club volleyball players participated in this study (age: 20 ± 1.3 y, height: 1.7 ± 0.04 m, weight: 70.8 ± 10.4 kg) with sample size confirmed with 80%

statistical power with an alpha level = .05.[26,27] Participants were currently competing at the collegiate club-level and had been playing for an average of 8.6 ± 2.3 y, had not engaged in strenuous activity at least 12-hours prior to the study and were excluded if they reported: (1) lower extremity musculoskeletal injuries in the previous two months preventing game or practice participation (2) history of ACL injury requiring surgery; or (3) any physiological or neurological condition that impaired their ability to complete the required tasks. A health questionnaire assessed health status and all participants signed a university approved informed consent document.

Experimental Protocol

Subjects performed a series of bilateral drop landings, followed by one of three subsequent tasks: (1) vertical jump (2) lateral cross step towards the dominant limb with vertical jump (dominant limb was pivoting leg), or (3) lateral cross step away from dominant limb with vertical jump (dominant limb was push off leg). Subjects performed the tasks in both anticipated and unanticipated settings to simulate a continuum of landing tasks encountered in a game. All trials were fully randomized such that anticipated/ unanticipated and pivoting/push off/jump could occur on any trial. Thirty successful trials (5 trial for each task and condition) were completed and testing took approximately 60-90 minutes.

Subjects wore compression clothing and anthropomorphic measurements were recorded prior to a five minute treadmill run and 3-5 familiarization landing trials on each of the landing tasks. After familiarization, subjects performed three, three-second knee flexion and extension maximum voluntary isometric contractions (MVIC) for each leg with a 60 s rest between contractions using an isokinetic dynamometer (Norm, Cybex, Inc., Ronkonaoma, NY). MVIC tests were performed in a seated position with 90° hip flexion and knee flexion of 60° and 30° for extension and flexion, respectively.[28-31] The MVIC results were used to assess limb strength imbalances between left and right limb and between quadriceps and hamstrings prior to testing.

Following the completion of the MVIC, 40 spherical retro-reflective markers (38, 14 mm and two 25 mm to help identify and orient the pelvic crests) placed on anatomical landmarks following a modified Plug-in Gait model in preparation for the landing tasks. Cluster marker sets were used for the thigh and shank, with additional markers on the lateral malleolus, lateral knee, anterior and posterior superior iliac spine, acromion process of each shoulder, and on the manubrium and xiphoid process. Kinematic and kinetic data were collected using a 12-camera (F40) Vicon motion-analysis system (Vicon, Oxford Metric Ltd., Oxford, UK) sampling at 200 Hz and two AMTI force platforms (Model OR6-7-2000, Advanced Mechanical Technologies Inc., Watertown, MA, USA) sampling at 2000 Hz. Additional processing was completed using Visual 3D (ver. 5.1.11, C-Motion, Germantown, MD, USA).

For landing tasks, a target screen placed five meters in front of the subject displayed an arrow (roughly 30 cm x 15 cm) indicating the direction of jumping or cross stepping to be performed following the drop landing. The landing task involved dropping from a 40 cm[10,32] box located 20 cm away from the edge of the force plates. Subjects were instructed to step off the box with their dominant leg without jumping or lowering their body prior to leaving the platform and land with each foot on separate force plates (Fig. 1a). Leg dominance was determined using a procedure used by Wyon et al., (2013).[33] Immediately following landing, and in accordance with the directional arrow, subjects jumped straight up, or cross stepped laterally completing one crossover step to a target placed 1.5 m away (Fig. 1b) followed by a maximal vertical jump. A trial was repeated if not performed correctly. In anticipated conditions, the directional arrow was displayed prior to the subject leaving the platform. In unanticipated conditions, the directional arrow was displayed once an infrared timing gate (located at hip height) was triggered by the subject's forward motion while stepping off of the box. The arrow direction (dominant limb pivots, pushes off or two-leg jump) and condition (anticipated or unanticipated) were randomized over the 30 trials. Approximately 30-45 s of rest was given between each trial to reduce potential fatigue effects.

Data Reduction

During the landing phase, the variables analyzed included knee, hip and ankle kinematics at initial contact and peak flexion/extension, adduction/abduction and internal/external rotation angles and moments during the landing, VGRF and loading rate of the dominant limb. Net joint moments were calculated using inverse dynamic and normalized to body mass ($N \cdot m \cdot kg^{-1}$). Ground reaction forces were normalized to body weight (BW). The landing phase was defined as the time at which the dominant foot made initial contact with the force plate to peak knee flexion, and prior to lateral hip movement. Raw 3D coordinate data for markers were filtered using a fourth-order Butterworth filter with a cutoff frequency of 8 Hz with GRF data filtered at 50 Hz[34,35]

Statistical Analysis

Statistical analyses were performed using SPSS (Version 19.0 for Windows, SPSS Inc., Chicago, IL, USA). The independent variables were decision-making conditions (anticipated and unanticipated) and direction (pivoting or pushing off). All parameters (joint kinematics and kinetics) were analyzed using repeated measures two-way ANOVAs (condition x direction). Statistical significance was set at alpha (α) = 0.05.

Results

Ground Reaction Forces, Loading Rate and Power Absorption

Average peak VGRF, loading rate and power absorption can be found in Table 1. Direction elicited a significant difference in normalized VGRF. However, a statistically significant interaction was observed between the main effects of anticipation and direction for VGRF ($P = .001$). Specifically, a greater VGRF was observed while pivoting in unanticipated conditions than anticipated (Fig. 2). Anticipation had a significant effect on sagittal plane peak knee power absorption ($P = .033$), with greater power absorption for unanticipated trials, while separately, direction also resulted in significantly greater absorption while pushing off in sagittal plane peak knee power absorption ($P = .033$). There were interaction effects for both the ankle and hip power absorption ($P = .004$ *and* $P = .037$, respectively) with greater absorption during anticipated, push off conditions. Loading rate did not display any significant results.

Joint Kinematics

Shown in Table 2 are the means of the joint kinematics of the ankle. Anticipation and direction had significant effects on the ankle in the sagittal and frontal planes, however an interaction effect ($P = .016$) was determined for the ankle, such that at initial contact, a smaller inversion angle was elicited in anticipated, pivot conditions. An interaction ($P < .001$) also revealed greater maximum inversion angles during anticipated, push offs. Additionally, a third interaction ($P = .028$) was demonstrated with smaller maximum dorsiflexion angle during unanticipated, pivot.

The knee elicited significant effects across multiple variables for anticipation, direction, or both. Nevertheless, four significant interaction effects were also revealed and are shown in Table 3. Interaction effects were seen at initial contact for knee flexion angles ($P < .001$), adduction angles ($P < .001$) and external knee rotation angles ($P < .001$). Larger flexion and adduction angles occurred during the landing when the subject intended to cross step in the anticipated, pivot condition (Fig. 3). Greater internal rotations of the knee were seen during landing during anticipated, push off (Fig. 3). At the peak of the landing, an interaction effect was demonstrated for knee flexion ($P < .001$) and knee internal rotation ($P < .001$). Maximum flexion angles were significantly smaller while internal rotation was significantly larger when intending to travel away from the dominant limb (push off trials) in the anticipated condition (Fig. 4 and 5 respectively).

Table 4 illustrates the joint kinematic means of the hip joint. Anticipation did not elicit any significant effects at the hip, however direction elicited larger maximum flexion angles at the peak of the landing ($P < .001$), prior to moving towards the dominant limb. Additionally, there was a significant interaction effects for hip rotation ($P = .026$). The hip was more externally rotated during anticipated, pivot. The hip showed no significant interaction effects at the peak of the landing.

Joint Moments

In addition to joint kinematics, both anticipation and direction had a statistically significant effect on joint moments. Found in Table 2 are the average joint moments of the ankle within the landing phase. The results indicate that as the subject made contact with the ground, the ankle produced an internal eversion moment, however as the landing phase progressed, it transitioned to an inversion moment. Anticipation and direction demonstrated statistically significant effects on ankle moments. However, a significant interaction effect was seen between the main effects within the ankle plantar flexion ($P = .001$), inversion and eversion ($P = .002$ and $P = .001$, respectively) and internal and external rotation ($P < .001$ and $P < .001$, respectively) moments. In the anticipated condition, subjects demonstrated greater mean differences in joint moments between the two directions than seen for the unanticipated condition.

Knee moments were also affected by anticipation and direction and are found in Table 3. Significant main effects were revealed for knee flexion, adduction and internal and external rotation moments. However, significant higher order interaction effects occurred for knee flexion (P = .012) and adduction moments ($P = .001$) with larger moments in anticipated, push off. Internal rotation and external rotation moments ($P = .031$ *and* P = .001, respectively) demonstrated larger differences between unanticipated and anticipated while traveling away from the dominant limb (Fig. 6).

Hip moments shifted from extension, abduction and external rotation moments to flexion, adduction and internal rotation moments as the subject advanced through the landing phase, just prior to lateral hip translation. These moments can be found in Table 4. Anticipation had significant effects on hip flexion moments (P = .009) eliciting larger moments in the unanticipated condition. An interaction was seen for hip extension ($P = .002$), adduction ($P < .001$) and internal and external rotation moments ($P < .001$ and $P < .001$, respectively). The mean difference between directions was larger in anticipated, but was more similar across unanticipated conditions.

Discussion

The purpose of this study was to investigate the effect of anticipation on landing mechanics in collegiate-level female club volleyball players while they performed a land and cross step maneuver. Previous studies have shown that decision making, a factor synonymous with realistic sports participation, produces lower extremity neuromuscular adaptations that may contribute to the resultant cause of injury.[22-24] This study elicited similar results showing that both direction and anticipation altered some landing mechanics, such as knee extension, abduction and external rotation and hip external rotation at initial contact, as well as maximum knee abduction and ankle inversion, which resulted in the subject moving into higher risk joint positions.

Data from the current study supports the notion that both anticipated and unanticipated sport movements may elicit some potentially injurious biomechanical modifications under certain circumstances.[22-24,36,37] An anticipated maneuver affords the athlete a more preprogrammed movement strategy to be initiated without the same degree of temporal constraint as the unanticipated. Flexion angles were smaller at initial contact during push off in both anticipated and unanticipated compared to pivoting, suggesting that the knee was more extended potentially anticipating, and preparing for, the push from the dominant limb. Maximum knee flexion differences between directions were greater for anticipated movement, while more consistent during unanticipated. Differences seen are as a result of the movement itself. The anticipated cut allowed the subjects to prepare for that change of direction before hitting the ground by initiating a body turn. The role that dominant limb played as a function of cutting direction differed and was considered either a pushing or pivoting role. Based on observation during unanticipated trials in the current study, subjects were not able to preplan their movement in advance due to not knowing the direction prior to leaving the box, and consequently in an apparent more neutral stance as evidenced by the knees and toes pointed forward. The average sagittal plane knee angle, in the current study, was between 18° and 24° of flexion at initial contact for all conditions, meaning the knee was near full extension at ground contact. Based on previous research[38,39] reporting the greatest potential for knee injury at or near full extension (between 10° and 23°) at initial contact, findings from the present study demonstrate this effect regardless of the direction of travel or ability to anticipate movement direction prior to landing. This risk of injury due to an extended knee can be addressed by either fine-tuning landing mechanics or by addressing the muscles used to decelerate and control the landing within the lower extremities.

Having the knee near full extension at ground contact puts the joint at risk due positional disadvantage of the hamstring muscles. The hamstrings are responsible for pulling posteriorly on the tibia to stabilize the knee at ground contact in order to decelerate the body. If the hamstrings are unprepared for the landing, or lack sufficient strength, a more extended knee at contact could allow for increased anterior tibial translation, a risk factor for ACL injury. A normal ratio for hamstrings to quadriceps strength is between 50% to 80%,[40] while the ratio found for participants in this study was 27-70% with five of the twelve below 50%, putting them below normal range.

Increasing hamstring strength may help counteract a portion of the risk due to inappropriate landing modifications similar to those in the current study.

Another finding with implications of potential knee internal derangement was the increased maximum frontal plane knee angles. At initial contact, the knee was in abduction (with the exception of the anticipated, pivot). At the time of contact, knee angles in the frontal plane were almost directly in line with the toes for unanticipated trials resulting in small joint moments and relatively low risk landing positions.[41] As knee flexion increased during the landing, abduction angles increased creating valgus angles greater than 10° (mean values for all subjects: 12°-15°) in both conditions with larger values for anticipated cut. The abduction angles were similar to other studies[41-44] involving landing from a jump/drop or a run and cut (abduction angles were greater than 10°), however, the current results were somewhat contradictory in that the anticipated conditions elicited larger angles than unanticipated. The average maximum abduction angle was smaller in unanticipated maneuvers compared to anticipated, however, unanticipated conditions produced larger maximum knee flexion angles. This suggests that during anticipated conditions, more stress was placed on the frontal plane (abduction) motion to absorb the landing than the unanticipated trials. It is plausible that anticipation caused the subject to react to the stimulus quicker by turning their body into the new direction in flight and caused inappropriate postural adjustments for the subsequent movement.

In the transverse plane, the knee was internally rotated upon landing and continued to internally rotate until the peak of the landing, with the exception of anticipation, pivot. The current study demonstrated that anticipated, push off elicited the greatest internal rotation moments, likely due to the subject being able to begin their turn towards the direction of travel while in flight. This finding is in contrast to previous research[22,23] on cuts and jump-cuts which reported larger internal rotation angles and moments during an unanticipated task. The current outcomes are likely a result of when landing and moving away from the dominant limb the right knee is bending in a way so as to push into a new direction while preparing to swing and cross over the opposite limb, whereas when traveling towards the dominant limb, the right leg was planted and pivoted upon. Based on the findings of the knee alone, conditions at which risk was elevated most was anticipated, push off when the dominant limb was used to push and the knee was near full extension while experiencing its greatest abduction and internal rotation values. These results are not in accordance with previous research[22-24] which found that unanticipated conditions resulted in greater valgus and internal rotation moments. The differences seen in the current study may be due to movement that followed the landing requiring the subject to move laterally where as in previous studies, only a landing or cut was required. Alternatively, previous studies have included more anterior translational motion that had to be controlled prior to the landing which may also contribute to the differences.

Direction of motion rather than anticipation played a larger role when looking at VGRF. A larger peak VGRF occurred when traveling away from the dominant limb and was at its largest value (2.66 BW) when anticipated. This was likely due to the subject knowing the direction of travel was away from the dominant limb, and subsequently landing primarily on the dominant leg in anticipation of the push off. When preparing to travel towards the dominant limb, it is likely that non-dominant leg may have experienced more of the load in anticipated condition, however it is difficult to be certain since the non-dominant limb was not measured in this study.

Although not generally reported as an injury risk factor, anticipation elicited larger ankle inversion angles at initial contact during push off conditions. Additionally, at the peak of the landing, maximum ankle inversion for pushing off demonstrated an increase, regardless of anticipation. A previous study demonstrated that limiting the magnitude of ankle inversion concurrently reduces the magnitude of knee abduction in females.[45] In the current study, both anticipation and direction played a role in affecting this risk factor. Most importantly, at initial contact during unanticipated, pivoting trials resulted in larger inversion ankle angles than in anticipated suggesting that based on the previously mentioned study, there may be an elevated knee injury risk. In addition to ankle inversion, the subjects typically landed with an external hip rotation, which according to a previous study[46], puts them at a mechanical disadvantage to evenly dissipate the landing amongst the three lower body joints. When the hips were externally rotated (limiting hip ROM), and coupled with a valgus knee position, the force tended to become focused and imposed strong rotational stresses on the knee joint.[47] These results are most likely due again to the fact that during anticipated conditions, the subjects knew which direction they were going to cross step and therefore prepared themselves by leaning into the travel direction prior to landing.

The changes observed in lower extremity landing mechanics during unanticipated conditions may have supported the argument that these movements caused altered patterns causing the subjects to land with high risk mechanics, however anticipated movements produced even greater risk mechanics and provide support for previous research. This is demonstrated by more neutral landing (hips, knees and ankles all in line beneath body and with knees and toes pointed forward) stance in the unanticipated condition as well as the large difference in joint angles during the anticipated and can be attributed to the nature of the task. Previous studies involving a run and cut or leap and cut are an inherently different tasks and do not afford as much time to make postural adjustments in flight as did the current study. When the subject knew the subsequent movement direction (anticipated), ample time permitted for the lower extremities to be prepared for the landing and even begin the directional change by turning the lower limbs towards the new direction. Moreover, by preemptively turning their body in the direction prior to landing, the knee was put at a greater risk of injury when the subsequent travel direction was away from the dominant limb. It is also plausible to consider that due to the large imbalances seen in the lower limb strength ratios, knee stabilization abilities were limited by the lack of sufficient strength in the hamstrings thus permitting the knee to move into at-risk positions. Pairing the effect of anticipation with the insufficient hamstring strength, it easy to see why subjects may be at risk for injuring the knee.

Both anticipated and unanticipated conditions evoked joint kinetics and kinematics that have been previously shown to increase the risk of injury under certain conditions, especially the knee, however in the current study when the direction of travel was known and cross stepping away from the dominant limb (anticipated, push off) the knee was exposed to the most risk elevating factors. Coaches and trainers, in an attempt to prevent knee injuries, should consider including drills/programs that address strengthening the muscles used to stabilize and decelerate the body during a landing, as well as expose players to both anticipated and unanticipated game-like situations.

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Tables and Figures

Table 1. Effect on mean (SD) ground reaction force (GRF), loading rate and sagittal plane power absorption.

	Anticipated		Unanticipated	
	Push Off	Pivot	Push Off	Pivot
Vertical GRF (BW)[b,c]	2.80 (0.38)	1.42 (0.39)	2.57 (0.54)	1.89 (0.28)
Loading Rate (BW/s)	118.74 (43.20)	89.87 (40.85)	118.53 (47.32)	122.20 (82.07)
Ankle Power Absorption (W/kg)[b,c]	-21.54 (6.12)	-11.53 (3.58)	-18.99 (5.61)	-15.24 (5.96)
Knee Power Absorption (W/kg)[a,b]	-19.75 (3.72)	-17.64 (4.06)	-21.06 (2.89)	-18.40 (3.21)
Hip Power Absorption (W/kg)[b,c]	-15.47 (9.14)	-6.69 (6.70)	-12.83 (7.25)	-8.72 (4.95)

[a] Denotes significantly different between anticipation conditions *($P < 0.05$).*

[b] Denotes significantly different between directions *($P < 0.05$).*

[c] Denotes significant interaction effect between anticipation and direction *($P < 0.05$).*

BW=body weight

Table 2. Effect of anticipation on mean (SD) landing joint kinematics and moments of the ankle when cross stepping in different directions.

		Anticipated		Unanticipated	
		Push Off	Pivot	Push Off	Pivot
Angles $^{(°)}$					
Ankle $^{(+)}$DF/PF$^{(-)}$	IC	-23.90 (4.75)	-24.43 (5.80)	-24.45 (4.68)	-24.44 (4.10)
	MA^{a,b,c}	30.28 (4.75)	27.99 (4.22)	29.96 (3.45)	25.49 (3.86)
Ankle $^{(+)}$Inv/Ev$^{(-)}$	IC^{b,c}	6.67 (5.78)	3.93 (5.94)	6.21 (5.51)	5.97 (5.75)
	MA^{a,b,c}	13.63 (3.02)	0.59 (3.96)	7.50 (5.14)	2.60 (4.69)
Moments $^{(N\ m/kg)}$					
Ankle PF$^{(+)}$	Max^{b,c}	2.31 (0.46)	1.09 (0.18)	1.99 (0.38)	1.52 (0.30)
Ankle Inv$^{(-)}$	Max^{a,c}	-0.08 (0.09)	-0.15 (0.12)	-0.17 (0.18)	-0.14 (0.16)
Ankle Ev$^{(+)}$	Max^{b,c}	0.26 (0.22)	0.05 (0.05)	0.16 (0.18)	0.12 (0.11)
Ankle Int$^{(-)}$ Rot	Max^{a,b,c}	-0.04 (0.03)	-0.08 (0.04)	-0.04 (0.02)	-0.04 (0.03)
Ankle Ex$^{(+)}$Rot	Max^{b,c}	0.39 (0.09)	0.07 (0.07)	0.26 (0.11)	0.16 (0.08)

[a] Denotes angles significantly different between anticipation conditions *($P < 0.05$).*

[b] Denotes angles significantly different between directions *($P < 0.05$).*

[c] Denotes significant interaction effect between anticipation and direction *($P < 0.05$).*

DF/PF=dorsiflexion/plantar flexion, Inv/Ev=inversion/eversion, Int/Ex=internal/external, Flex/Ext=flexion/extension, IC=initial contact, MA=max angle, Rot=rotation

Table 3. Effect of anticipation on mean (SD) landing joint kinematics and moments of the knee when cross stepping in different directions.

		Anticipated		Unanticipated	
		Push Off	Pivot	Push Off	Pivot
Angle $^{(°)}$					
Knee $^{(+)}$Flex/Ext$^{(-)}$	IC[a,b,c]	19.29 (6.21)	24.35 (6.79)	18.99 (5.84)	19.74 (5.77)
	MA[b,c]	65.09 (11.35)	78.29 (9.36)	71.71 (11.56)	75.84 (11.00)
Knee $^{(+)}$Add/Abd$^{(-)}$	IC[b,c]	-3.64 (3.13)	1.31 (4.30)	-0.93 (3.24)	-0.89 (2.97)
	MA[a]	-14.99 (4.44)	-15.02 (5.86)	-12.16 (4.42)	-13.37 (5.17)
Knee$^{(+)}$Int/Ex$^{(-)}$ Rotation	IC[b,c]	8.18 (4.69)	-6.02 (6.10)	1.07 (4.55)	0.57 (4.74)
	MA[b,c]	9.69 (3.41)	2.29 (2.85)	5.74 (3.04)	4.59 (3.50)
Moments $^{(N\ m/kg)}$					
Knee Flex$^{(-)}$	Max[b,c]	-0.25 (0.19)	-0.10 (0.10)	-0.19 (0.19)	-0.18 (0.11)
Knee Ext$^{(+)}$	Max[b]	2.61 (0.30)	2.02 (0.23)	2.63 (0.33)	2.06 (0.33)
Knee Add$^{(-)}$	Max[a,b,c]	-0.97 (0.26)	-0.53 (0.20)	-0.69 (0.22)	-0.54 (0.19)
Knee Abd$^{(+)}$	Max	0.12 (0.14)	0.16 (0.17)	0.16 (0.14)	0.15 (0.15)
Knee Int$^{(-)}$ Rot	Max[a,c]	-0.11 (0.08)	-0.14 (0.07)	-0.20 (0.08)	-0.15 (0.08)
Knee Ex$^{(+)}$Rot	Max[a,b,c]	0.38 (0.09)	0.21 (0.10)	0.17 (0.09)	0.21 (0.09)

[a] Denotes angles significantly different between anticipation conditions *($P < 0.05$).*

[b] Denotes angles significantly different between directions *($P < 0.05$).*

[c] Denotes significant interaction effect between anticipation and direction *($P < 0.05$).*

Flex/Ext=flexion/extension, Add/Abd=adduction/abduction, Int/Ex=internal/external, IC=initial contact, MA=max angle, Rot=rotation

Table 4. Effect of anticipation on mean (SD) landing joint kinematics and moments of the hip when cross stepping in different directions.

		Anticipated		Unanticipated	
		Push Off	Pivot	Push Off	Pivot
Angle (°)					
Hip	IC	30.01 (7.53)	30.85 (7.31)	29.66 (6.93)	30.39 (7.25)
(+)Flex/Ext(-)	MA[b]	56.14 (15.14)	63.79 (15.21)	61.13 (16.29)	65.62 (15.59)
Hip	IC	-9.86 (2.96)	-8.89 (5.04)	-8.54 (3.26)	-8.24 (3.23)
(+)Add/Abd(-)	MA	-6.21 (4.09)	-8.36 (5.09)	-7.06 (349)	-6.01 (4.19)
Hip (+)Int/Ex(-)	IC[b,c]	-0.06 (7.03)	-4.86 (7.72)	-2.75 (4.66)	-2.75 (5.21)
Rotation	MA	-8.88 (6.24)	-8.40 (5.43)	-10.11 (4.58)	-6.99 (4.67)
Moments (N m/kg)					
Hip Flex(-)	Max[a]	-2.09 (0.24)	-2.02 (0.26)	-2.37 (0.48)	-2.26 (0.37)
Hip Ext(+)	Max[b,c]	2.68 (0.87)	0.84 (0.87)	2.26 (0.84)	1.39 (0.57)
Hip Add(-)	Max[a,b,c]	-0.77 (0.31)	-0.35 (0.17)	-0.35 (0.18)	-0.39 (0.11)
Hip Abd(+)	Max	0.52 (0.35)	0.64 (0.39)	0.68 (0.38)	0.54 (0.26)
Hip Int(-) Rot	Max[b,c]	-0.74 (0.17)	-0.27 (0.18)	-0.46 (0.20)	-0.43 (0.19)
Hip Ex(+) Rot	Max[b,c]	0.86 (0.27)	0.29 (0.11)	0.69 (0.27)	0.45 (0.15)

[a] Denotes moments significantly different between anticipation conditions *($P < 0.05$).*

[b] Denotes moments significantly different between directions *($P < 0.05$).*

[c] Denotes significant interaction effect between anticipation and direction *($P < 0.05$).*

Flex/Ext=flexion/extension, Add/Abd=adduction/abduction, Int/Ex=internal/external, IC=initial contact, MA=max angle, Rot=rotation

Figure Captions

Figure 1- Illustrations of landing and cross stepping maneuvers.

Figure 2- Interaction effect (Anticipation x Direction) for Peak Vertical Ground Reaction Force. ANC=anticipated, UNC=unanticipated

Figure 3- Interaction effects (Anticipation x Direction) for knee angles at initial contact. ANC=anticipated, UNC=unanticipated, FLX/EXT=flexion/extension, ADD/ABD=adduction/abduction, INT/EX=internal/external, Positive angles represent knee flexion, adduction and internal rotation.

Figure 4- Interaction effects (Anticipation x Direction) for peak knee flexion/extension angles.

Figure 5- Interaction effects (Anticipation x Direction) for peak knee abduction/adduction angles.

Figure 6- Interaction effects (Anticipation x Direction) for peak knee rotation moments. ANC=anticipated, UNC=unanticipated, INT/EX=internal/external

Figure 1:

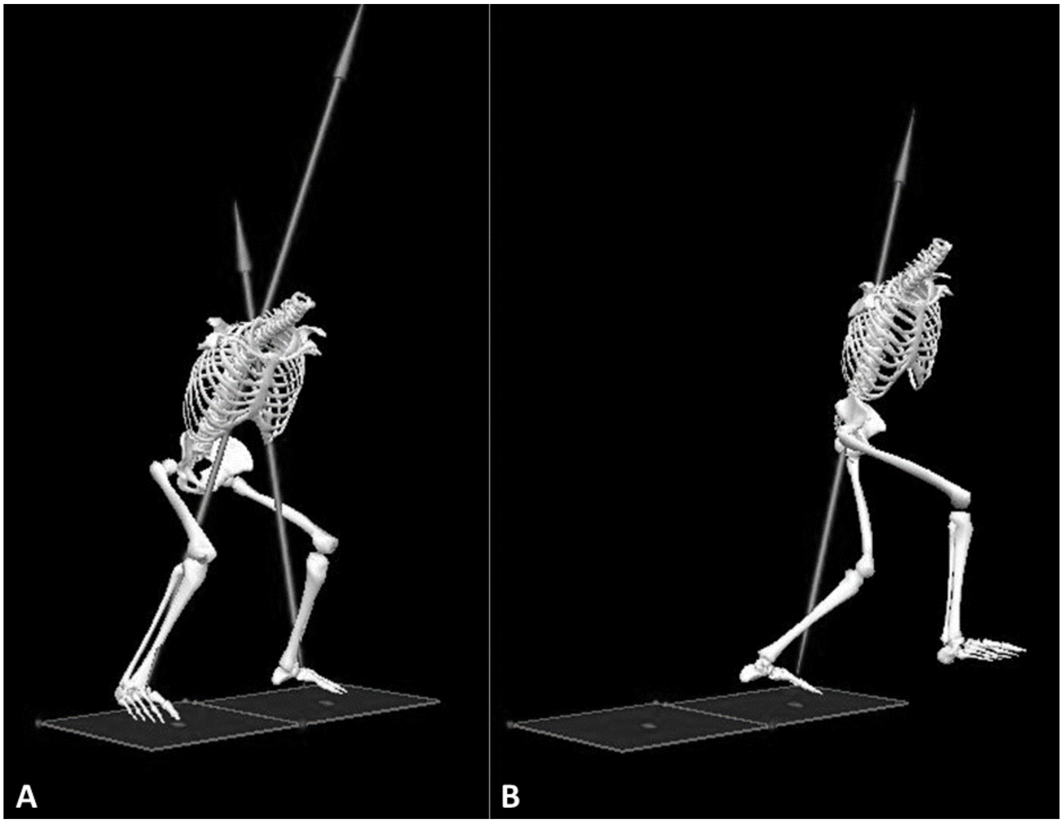


Figure 2:

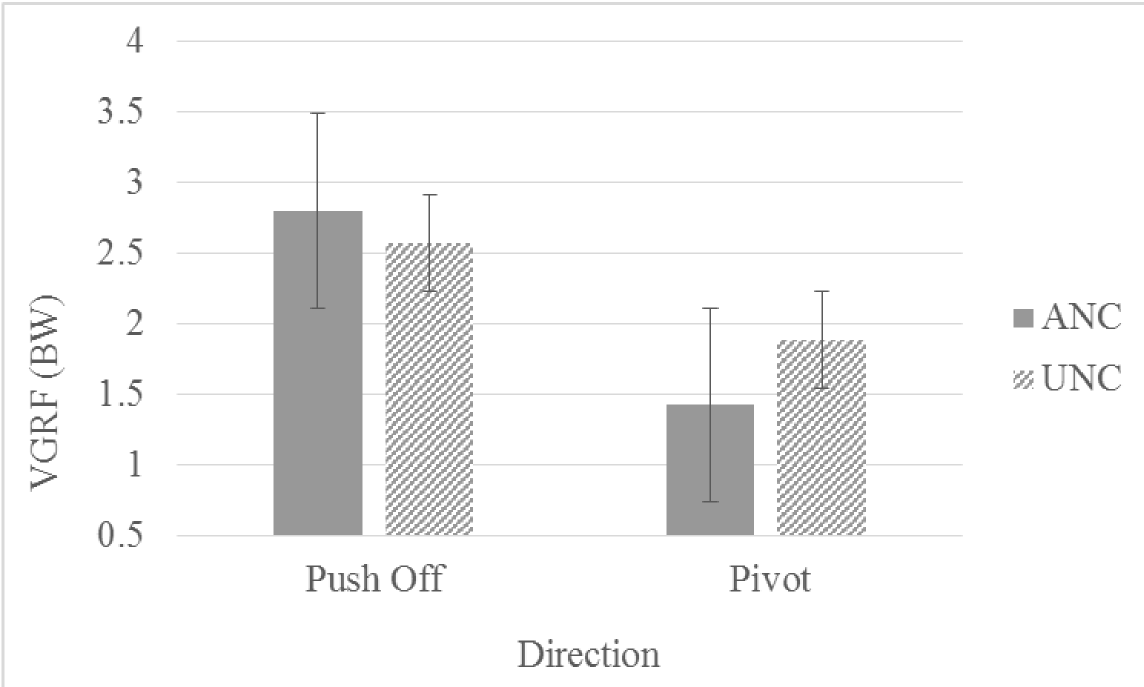
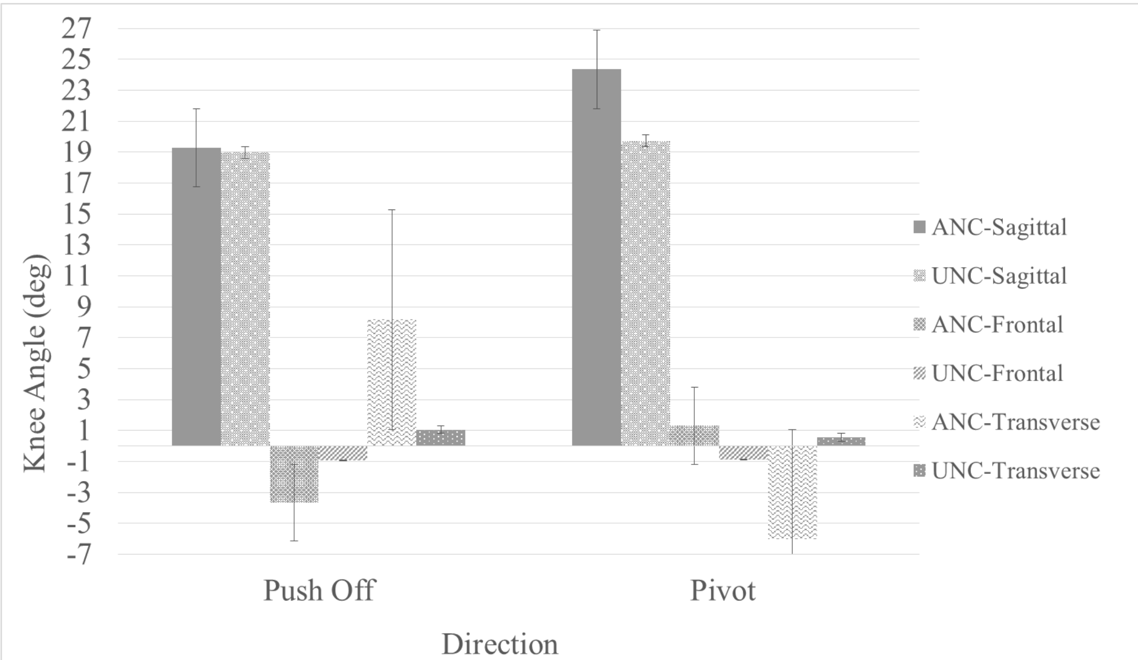


Figure 3:



27
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-1
-3
-5
-7
Knee Angle (deg)
Push Off
Pivot
Direction
ANC-Sagittal
UNC-Sagittal
ANC-Frontal
UNC-Frontal
ANC-Transverse
UNC-Transverse

Figure 4:

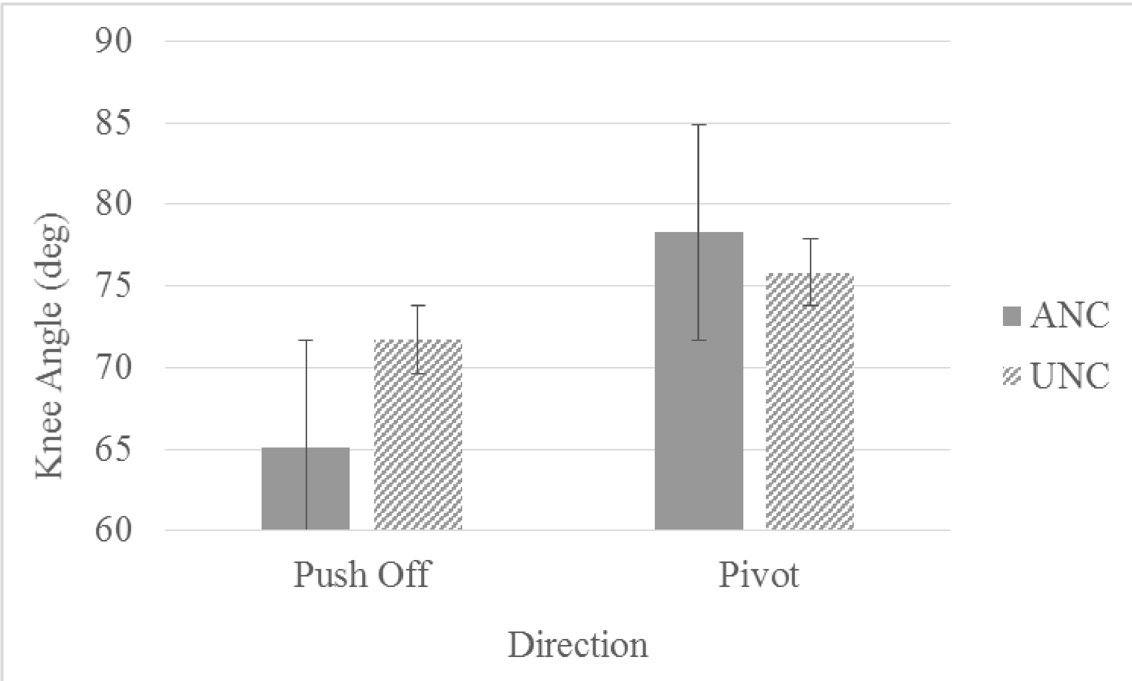

90
85
80
75
70
65
60
Knee Angle (deg)
Push Off
Pivot
Direction
ANC
UNC

Figure 5:

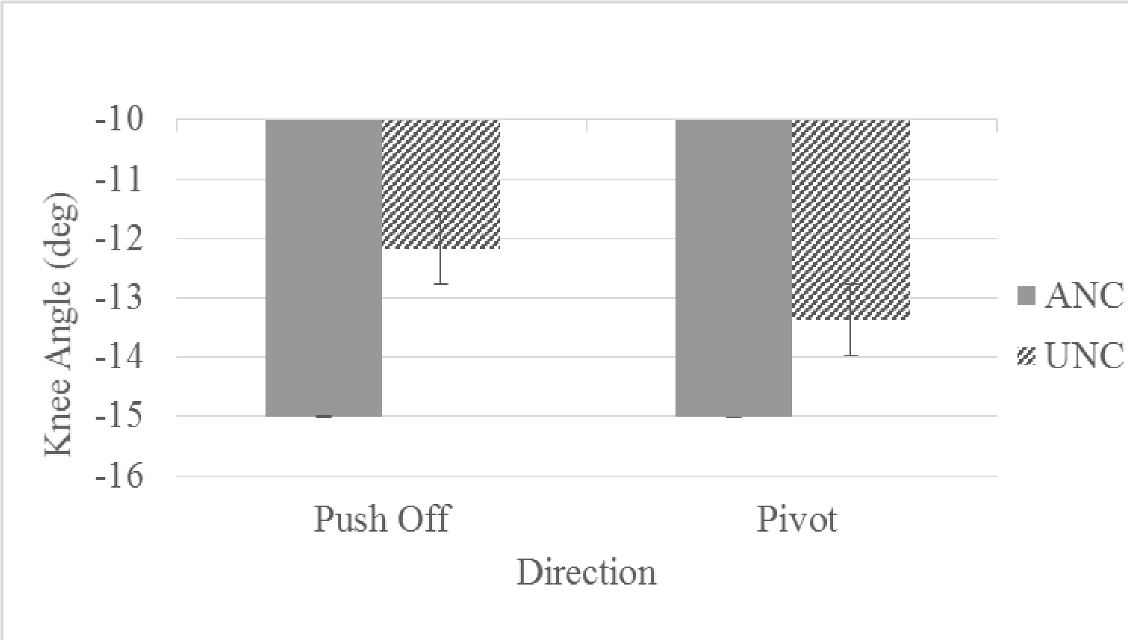
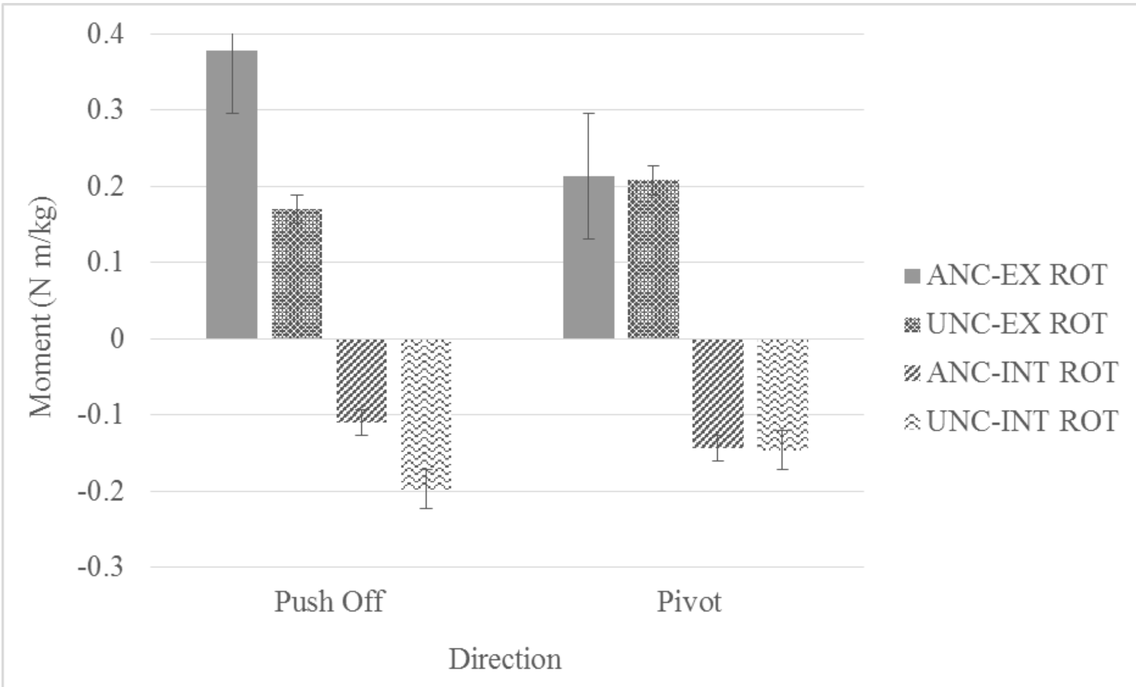

-10
-11
-12
-13
-14
-15
-16
Knee Angle (deg)
ANC
UNC
Push Off
Pivot
Direction

Figure 6:



0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Moment (N m/kg)
Push Off
Pivot
Direction
ANC-EX ROT
UNC-EX ROT
ANC-INT ROT
UNC-INT ROT

Chapter 4: Summary and Conclusions

Previous research has demonstrated that anticipation alters landing movement patterns, primarily increasing knee extension, abduction and internal/external rotation angles at contact as well as larger peak abduction and internal/external rotation moments. The present study sought to investigate primarily the knee angles and loads at initial contact and peak knee flexion due to the implications of injury.

During the current study, it was demonstrated that both the anticipated and unanticipated movements elicited biomechanical adaptations to the landing technique that resulted in the subject moving the lower extremities into positions that may elevate knee injury risk. Both anticipation and direction played a role in the changes, but anticipated trials produced the highest risk positions, particularly when the subject was preparing to travel away from the dominant limb, results contradictory to previous research. At initial contact the knee was near full extension, in abduction and internally rotated. This knee positioning alone has been shown in previous research to increase the loading on the knee, however the subjects in the current study also landed with an external hip rotation and a large peak ankle inversion, a landing position that puts them at an even greater risk.

It is plausible that the results produced were primarily due to the nature of the task and landing itself. To simulate a real game, players were asked to land and move laterally as natural as possible, but this lead to unique variations of the movement, possibly decreasing validity. The subjects recruited all utilized similar, yet mechanically different landing and cross stepping techniques. With the lack of strict landing procedures, large differences in joint angles and moments during the anticipated movement were seen. This may be due to the ample time subjects had to move their body into position for the landing by leaning into the new direction prior to ground contact. During the unanticipated conditions, the smaller differences in joint angles and moments were likely caused by the lack of knowledge of the new travel direction. The fact that the legs were performing two completely different tasks based on direction likely attributed to the differences seen between directions of travel as well as anticipated.

This study also presented several limitations with regards to the testing protocol, subject population and individual landing techniques. This study primarily looked at the effects of anticipation on landing mechanics, which have shown in previous studies to alter the lower extremity kinematics. Anticipation was manipulated through the use of timing gates and a direction screen placed in front of the subject. An arrow was used to indicate the direction of travel which forced the subjects to associate a non-volleyball relevant symbol with a directional change. In a real game situation, the player uses an opposing player's shoulder or trunk, rather than an arrow, to predict the direction of travel and therefore may have made the transition from visual input to muscular output slower thereby decreasing external validity. Additionally, only female, college-level volleyball players were used in this study.

Future research should consider including a greater number of athletes from other sports, both sexes, as well as other age and skill levels. This would enhance our understanding of anticipation and the possible risk for injury. This information should be taken into consideration when designing a testing protocol for screening purposes and may be useful to sport coaches, strength and conditioning coaches, athletic trainers and other clinicians in establishing injury prevention strategies in regards to the inherent nature of a sport to being unpredictable and requiring decision-making.

Chapter 5: References

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