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The effects of predisposition and direction on ankle sprain risk predictive factors during jump landing

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The effects of predisposition and direction on ankle sprain risk predictive factors during jump landing

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DEDICATION

This thesis is dedicated to my parents, Howard and Jill Radley. Without their love and support, I surely would not be where I am today.

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ABSTRACT

Ankle sprains are regarded as one of the most common lower extremity injury in sports. Previous research studying ankle sprain risk factors has examined the role of anticipation on dynamic movements such as cutting and jump landing. However, no previous research has examined the role of predisposition on ankle sprain risk during jump landing. As a result, the purpose of this study was to examine the effects of jump direction and predisposition on ankle sprain risk predictive factors during jump landing. Seventeen participants participated in a jump-land-jump task in which the direction of the second jump was indicated before the task, with the possibility of the direction changing at initial landing. This produced four total conditions for the study: correct predisposed dominant (CPD), correct predisposed non-dominant, incorrect predisposed dominant (IPD), and incorrect predisposed non-dominant (IPN).

Ground reaction forces were shown to be significantly different when predisposition was incorrect. Ankle dorsiflexion significantly decreased when predisposition went from correct to incorrect in the dominant direction. The results in this study further support previous research indicating change in direction applies higher demands on the body to perform. There appears to be a tradeoff between fully committing to a predisposed direction and increasing the risk of ankle sprain injury; including decision making tasks for practice in dynamic sports is recommended.

CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

Whether it is watching the Olympics for handball, the World Cup for soccer, or the Super Bowl for American football, you will likely see an offensive player attempting to score and a defensive player attempting to stop them. As is the case with most activities, the defense attempts to anticipate the next move in order to gain an advantage. When gambling on the next move, guessing correctly usually results in an increase in performance with positive results (Henry et al., 2013). Unfortunately, guessing wrong can lead to a decrease in performance and increase in risk for injury (Fujii et al., 2014; Henry et al., 2013). In many dynamic sports like the ones listed above, ankle sprains are among the most common lower extremity injuries (Fong et al., 2007; Hootman et al., 2007; Safran et al., 1999).

Why are ankle sprains the most common injury in many sports? Previous studies have examined extrinsic risk factors such as playing surface, nearby opponents, and outside stimuli (Doherty et al., 2014; Fong et al., 2009; McKay et al., 2001; Milgrom et al., 1991; Tyler et al., 2006). Other studies have examined intrinsic risk factors such as height, weight, sex, and previous injury history. (Beynnon et al., 2002; Doherty et al., 2014; Dubin et al., 2011; Fong et al., 2007; Safran et al., 1999; Tyler et al., 2006). With new technology available, lower extremity changes between anticipated and unanticipated movements have been tested (Fuerst et al., 2017; Kim et al., 2014; Meinerz et al., 2015). However, to our knowledge the effect of incorrect predisposition on ankle sprain risk factors during unanticipated movements has not been studied.

This thesis project attempts to examine the effects of predisposed stimuli and jump direction on ankle sprain risk factors during directional jump landings. More specifically, this project attempts to answer the following research questions: 1) Does predisposition and jump direction affect ankle angles during directional jump landings? 2) Does predisposition and jump direction affect ankle joint moments during directional jump landings? 3) Does predisposition and jump direction affect ground reaction forces (GRFs) placed during directional jump landings?

Hypotheses

Based of the review of literature, it was hypothesized that incorrect predisposition would result in: 1) increased ankle inversion angles, 2) increased medial GRFs, and 3) increased ankle eversion moments as compared to correct predisposition. Similarly, it was hypothesized that the non-dominant jump direction would result in 1) increased ankle inversion angles, 2) increased medial GRFs, and 3) increased ankle eversion moments as compared to the dominant jump direction.

Thesis Organization

This thesis is written in a format centered on a publishable research manuscript. The entire thesis is broken down into three chapters. Chapter 1 consists of the general introduction and literature review covering previous research as well as identifying gaps in research. Chapter 2 contains the research manuscript examining the effects of incorrect predisposition and jump direction on ankle sprain risk predictive factors during directional jump landings. The final chapter (Chapter 3) discusses conclusions that can be deduced from the manuscript as well as indications for future directions in this line of research.

Literature Review

Introduction

One of the most common lower extremity injuries that occur in sports and everyday life is low ankle sprains (Fong et al., 2007; Safran et al., 1999). Most low ankle sprains result from excessive ankle inversion (Milgrom et al., 1991; Nelson et al., 2007; Osborne & Rizzo, 2003). High velocity ankle inversion may lead to the body not being able to counteract the moment and change in direction in time to prevent injury to the ligaments and tendons (Borowski et al., 2008; Gehring et al., 2013). Therefore, understanding the conditions in which the mechanism of injury occurs may be a vital step toward preventing low ankle sprains.

Anatomy of the ankle

The most common ankle injury is a lateral ankle sprain (Balduini & Tetzlaff, 1982). Lateral ankle sprains occur when the ankle excessively inverts and plantarflexes, also known as rearfoot supination (Ferran & Maffulli, 2006; Golanó et al., 2016). Coupled with external rotation of the tibia, ankle inversion stretches the ligaments of the lateral ankle. If this stretching exceeds the tensile strength of the ligaments, tearing or rupturing can occur (Fong et al., 2012). The three lateral ankle ligaments are the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL) (Ferran & Maffulli, 2006).

The ATFL is usually the first and most common ligament to be injured during a lateral ankle sprain. This is due to the fact that the ATFL is the first ligament to be stretched when ankle inversion occurs (Doherty et al., 2014; Hertel, 2002). The next ligament that is stretched during ankle inversion is the CFL. The least susceptible ligament to be overstretched and injured is the PTFL. One reason for this is that the PTFL is the strongest of the three as well as the deepest ligament inserted in the joint (Burks & Morgan, 1994). These ligaments passively work together and are also assisted from muscles surrounding the ankle complex.

Muscles and tendons aid the lateral ankle ligaments in preventing the foot from over-inverting. The lateral ankle ligaments are most assisted by the peroneus longus and the peroneus brevis (Dubin et al., 2011). The peroneus tendons are located on the outside of the ankle and pass behind the lateral malleolus (Moore et al., 2013). A concentric contraction of the peroneus muscles promote ankle eversion, thus helping the lateral ankle ligaments in preventing excessive ankle inversion (Dubin et al., 2011).

In addition to the peroneus muscles, the anterior compartment muscles of the lower leg (anterior tibialis, peroneus tertius, and extensor digitorum longus) help aid in dorsiflexing the ankle during dynamic movement (Hertel, 2002). These muscles contract eccentrically during forced supination of the foot and can slow ankle plantarflexion (Sinkjaer et al., 1988).

In order for the ankle complex to react and work as a cohesive unit, nerves must innervate the structure. Innervation stems from the lumbar and sacral plexus that supplies motor and sensory nerves (Hertel, 2002). The motor supply to the muscles of the foot and lower leg comes from three mixed nerves (tibial, deep peroneal, and superficial peroneal nerves) (Viladot et al., 1984). The sensory supply to the muscles comes from the three previously mentioned mixed nerves and two sensory nerves (sural and saphenous nerves) (Michelson & Hutchins, 1995). Research has shown that the ankle joint capsule and ligaments are also innovated by mechanoreceptors. These mechanoreceptors combined with muscle spindles help provide ankle proprioception (Hertel, 2002; Khin-Myo-Hla et al., 1999)

Predictive risk factors for ankle sprains

Unsurprisingly, the number one risk factor for lateral ankle sprains is having a previous ankle sprain on the same ankle (Tyler et al., 2006). The general theory is that a sprained ankle that is unable to fully heal is susceptible to tendon and/or ligament laxity, which may lead to structural degradation and chronic ankle instability (Doherty et al., 2014; Doherty et al., 2016; Fong et al., 2009; McKay et al., 2001). The weakened joint structures may then result in the ankle being more prone to future sprains. Therefore, reducing the rate of initial ankle sprains may also reduce the total amount of recurring injuries.

The role that height and body mass play in lateral ankle sprains has been debated among researchers. Different studies have concluded that athletes that were proportionally taller than average, along with higher body masses, were more prone to lateral ankle sprains (Milgrom et al., 1991; Tyler et al., 2006; Waterman et al., 2010). However, multiple studies have shown that body mass did not greatly increase the rate of lateral ankle sprain prevalence in the selected populations (Beynnon et al., 2001; Willems et al., 2005; Tine et al., 2005). One could then conclude that body mass and height does not likely play a significant role in lateral ankle sprains unless abnormally high.

Previous studies suggest that females have a higher rate of anterior cruciate ligament injuries than males (Hosea et al., 2000; Ireland, 1999; Renstrom et al., 2008; Yu & Garrett, 2007). However, there is conflicting evidence whether females have a higher rate of ankle sprains. One meta-analysis indicated that females were twice as high at risk to suffer a lateral ankle sprain (Doherty et al., 2014). A recent study found that females have higher ankle plantarflexion moments during unilateral land-and-cut maneuvers (Weinhandl et al., 2017). However, there have been multiple studies that have shown that women do not have a higher rate of ankle sprains (Beynnon et al., 2001; Hosea et al., 2000; Kobayashi et al., 2013;

Nelson et al., 2007; Omar et al., 2017). With this contrast of evidence, it is difficult to definitively say that females are more prone to an ankle sprain.

The dominant limb has been shown to be more prone to ankle injury than the non-dominant limb (Baroni et al., 2008; Ekstrand & Gillquist, 1983; Iida et al., 2011). One study indicated that the non-dominant limb has greater protective mechanics compared to the dominant limb in a drop-jump landing situation (Niu et al., 2011). However, no study we know of has examined limb dominance correlations with ankle inversion in unanticipated jump-land-jump movements.

The surrounding environment can affect the risk of ankle injury. A meta-analysis reviewed 181 prospective studies and found that indoor and court sports were at a higher risk for ankle inversion injuries (Doherty et al., 2014). An epidemiological study looked at high school athletes and found that sports involving swift changes in running and jumping near other players increased the rate of ankle injuries (Nelson et al., 2007). These results indicate a higher risk of ankle injuries associated with activities involving confined spaces that require more lateral cuts and jumps. Therefore, a prospective study examining ankle inversion during dynamic motion patterns in a restricted area may be the closest simulation to high-risk activities.

Reacting to stimuli

Reaction time is the time it takes to recognize a stimulus and initiate an action. Hick’s Law states that the more stimuli that are presented, the longer it takes to make a decision (Hick, 1952; Roberts et al., 1988). It has also been shown that previous experience with a movement can reduce reaction time (Besier et al., 2001). Following that rationale, a preplanned task will likely be acted upon faster than an unanticipated task.

With longer reaction times in unanticipated movements, the body may be placed in positions that result in an increased risk of injury. One study examined the change in ankle dorsiflexion angle when a condition went from anticipated to unanticipated. Ankle dorsiflexion angles significantly increased from 21.9° to 26.1° in side-cutting and 17.7° to 20.6° in cross-cutting during the unanticipated condition (Kim et al., 2014). This increase in dorsiflexion angle may protect the ankle when the direction is unknown. Following that rationale, incorrect predisposition may place an athlete in a position with decreased ankle dorsiflexion angles that are more dangerous than in unanticipated conditions. Further research should be done on examining whether predisposition increases or decreases dorsiflexion angles in directional jump-land-jump movements.

Previous research has shown that increased ankle internal rotation can lead to a greater risk of suffering an acute lateral ankle sprain (Ferran & Maffulli, 2006; Kristianslund et al., 2011). One study showed that ankle internal rotation in the submaximal landing phase significantly increased from 3.7° to 7.6° during the unanticipated condition (Meinerz et al., 2015). One case report examining an accidental lateral ankle sprain during maximal effort cutting movements observed that the injury trial had 8° of ankle internal rotation (Kristianslund et al., 2011). This may indicate that unanticipated jump landings with maximal effort may increase ankle internal rotation angles to a point that injury can occur.

One study showed that ankle internal rotation angles did not have a significant change when the stimulus was presented at different times. Ankle internal rotation only increased from 3.3° to 4.0° when the stimulus was presented later (600 ms before foot strike) than when the stimulus was presented sooner (900 ms before footstrirke) (Fuerst et al., 2017).

However, individuals can react faster than 600 ms and therefore lack of increases in joint angles may be due to the stimulus being presented too early.

A study examining ankle internal rotation reported total range of motion average increased from 3.7° to 7.6° in the unanticipated condition (Meinerz et al., 2015). The difference in timing presentation may explain why there was an increase of ankle internal rotation angle. One study examining anticipation time threshold in knee kinematics discovered that in order to keep the movement unanticipated, a stimulus needs to be provided no later than 300 ms before ground contact (Stephenson et al., 2016). Therefore, future studies presenting a stimulus closer to initial foot contact may elicit significant increases to ankle joint angles.

Ground reaction forces (GRF)

Athletes who participate in multi-directional sports such as football, basketball, and soccer are required to change directions often (Beynnon et al., 2002; Renstrom et al., 2008). This change of direction requires an athlete to absorb braking forces from the original movement and translate force to move in the new direction while also maximizing speed for performance (Meinerz et al., 2015). These different types of forces are conveyed in ground reaction forces (GRF) to the body. Changes in GRF can have an impact in risk of injury as well as performance.

Greater GRF have been shown in cutting movements when compared to straight ahead running movements (Havens & Sigward, 2015; Houck et al., 2006). Mediolateral GRF in one study decreased from 80% of body weight (BW) to 58% BW when the side-cutting movement was unanticipated (Kim et al., 2014). This study also showed vertical GRF also decreased from 2.76 to 2.32 BW. These changes in GRF may stem from a natural mechanism to guard the ankle joint with lower forces decreasing the risk of overloading the ankle.

Further research should examine changes GRF when a participant is predisposed to an incorrect direction when preparing for a directional jump landing.

Ankle inversion/eversion

Ankle inversion has been shown to be one of the most common mechanisms of injury for lateral ankle sprains (Ferran & Maffulli, 2006; Fong et al., 2007; Fong, 2009; Fong et al., 2012; Kristianslund et al., 2011). As of now, the research currently published examining ankle inversion in unanticipated movements does not show significant changes between anticipated and unanticipated movements (Fuerst et al., 2017; Meinerz et al., 2015). This may be due to the timing of the stimuli and the movements analyzed in the studies, so further testing should be done before conclusions can definitively be made.

Anticipation effects on lower extremity

Previous research has shown that premotor time is reduced in anticipated movements when compared with unanticipated movements (McLean et al., 2010). This is due to the preselection of the desired movement and as a result, the time it takes to respond to a stimulus is greatly reduced. When an athlete is in an unanticipated movement environment, premotor time is increased because there is no preplanned selection available (Mache et al., 2013).

Preplanned movement allows for pre-activation of muscles, which helps to prevent faulty movement patterns such as excessive ankle inversion (Besier et al., 2001; Besier et al., 2003a; Brown et al., 2009; McLean et al., 2010; Riley et al., 2013). It has been shown that ankle inversion in lateral cutting movements takes place between 30-50 ms, whereas the reaction time for the peroneus muscles occurs after 60 ms (Stacoff et al., 1996; Ebig et al., 1997; Karlsson et al., 1992). For this reason, researchers have hypothesized that there is not enough time for the peroneal muscles to prevent ankle inversion in an unanticipated lateral cut. Therefore, pre-muscle activation before initial ground contact is also likely unavailable during unanticipated directional jump landings because the stimulus is not displayed early enough.

The injury risk of reduced pre-muscle activation was indicated in a recent simulation model focused on sudden ankle inversions with 60 ms latency in muscle co-activation. The model showed that co-muscle activation 62% or higher was necessary to prevent ankle inversion moments from exceeding the injury threshold limit (DeMers et al., 2017). However, forces placed on the body may be much higher in maximal effort sports performance, so further testing should be done in more ecologically valid settings (Duysens & Levin, 2010).

Directional planning may be the main benefit of anticipation. Research has shown that altering foot placement is the optimal strategy for changing directions in anticipated movements (Patla et al., 1999). However, when the cue is not presented early enough, the body enacts a trunk-roll motion that reorients the COM prior to moving in the new direction (Patla et al., 1999). Recent research further noted changes in lower extremity movement strategy due to performance constraints involving timing, jump height, and jump distance (Dai et al., 2016). Therefore, a person may alter trunk and lower extremity movement strategy in order to compensate for performance constraints placed in an activity. Thus, studies examining movements with no performance constraints in maximal effort movements may show overly conservative results in lower extremity changes.

. One study examined the effects of available time to react (ATR) on lower extremity changes in a jump-land-jump scenario. The participants in the study changed to a neutral landing pattern when the ATR was below the Hick's Law threshold (Stephenson et al., 2018). This was reasoned to be due to an injury defense mechanism in unanticipated situations. In unanticipated conditions, an individual may switch to a safer landing pattern that allows for lateral changes in directions, but increases ground contact time and reduces jump distance/height. This reduction in performance may not be acceptable in highly competitive activities (Dai et al., 2016; Demers et al., 2017; Stephenson et al., 2018). Preplanning of direction change may lead to higher risk of injury and failed movements (going in the wrong direction) when the predisposition is incorrect.

The gap

The current gap in the literature is the effect of stimulus predisposition, particularly misleading stimuli, on ankle injury risk during an unanticipated movement. In sports, the defender must react as fast as possible to the offensive player's movement in order to increase performance and prevent a negative result. However, the offensive player has a preplanned movement plan and can present a 'fake' or misleading stimulus in an attempt to have the defender incorrectly react. As a result, a defender that is predisposed to a misleading stimulus may be in a worse position to react to an unanticipated movement than in a situation with no prior stimulus. Therefore, future research should examine whether reaction to an unanticipated movement with a misleading stimulus has a negative impact on performance and an increased risk for injury.

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CHAPTER 2: THE EFFECTS OF PREDISPOSITION ON ANKLE SPRAIN RISK PREDICTIVE FACTORS DURING JUMP LANDING

Introduction

Ankle sprains are among the most common lower extremity injuries in sports (Fong et al., 2007; Milgrom et al., 1991; Safran et al., 1999). An estimated two million ankle sprains occur per year in the United States at a cost of two billion dollars (Waterman et al., 2010). Movement patterns such as excessive ankle inversion has been associated with lateral ankle sprain (Beynnon et al., 2002; Dubin et al., 2011; Duysens & Levin, 2010; Ferran & Maffulli, 2006; Fong et al., 2009; Purevsuren et al., 2018; Tyler et al., 2006). Prevention is critical since previous ankle sprain is a risk factor for subsequent ankle sprain (Doherty et al., 2016; Hertel, 2002; Tyler et al., 2006). Ankle sprain can lead to functional ankle instability (FAI) and chronic ankle instability (CAI) (Doherty et al., 2014, 2016; Hertel, 2002; Michelson & Hutchins, 1995).

Movements involving changes in direction commonly occur during sport activities that involve offensive and defensive players (Fujii et al., 2014; Seminati et al., 2017). What direction a player moves in and whether or not the player changes direction may affect ankle sprain risk factors. For example, ankle inversion angles were found to be higher in side-cutting than cross-cutting movements (Kim et al., 2014). Another study found higher braking ground reaction forces (GRF) when changing directions and maintaining speed during cutting maneuvers (Havens & Sigward, 2015). Therefore, one might expect that ankle inversion angles and medial GRF would increase when changing direction during a jump landing. Increases in these measures would be consistent with increased risk of ankle sprain.

Anticipated direction changes are known at the initiation of the movement, while unanticipated direction changes involve stimuli presented after movement initiation. The ability to correctly anticipate direction changes provides an individual additional time for movement planning. Pre-planned movements allow for muscle activation before ground contact, which can prevent risky movement patterns such as excessive ankle inversion angles (Besier et al., 2001; Besier et al., 2003; Brown et al., 2009; McLean et al., 2010). This is essential to injury prevention because peak ankle inversion angles may occur within the first 30-50 ms of ground contact, while peroneus muscle activation occurs at 60 ms or later (Ebig et al., 1997; Karlsson et al., 1992; Stacoff et al., 1996). Thus, unanticipated direction changes may lead to higher ankle inversion angles and increased risk of ankle sprain.

Research examining anticipated vs. unanticipated lateral cutting has shown conflicting results in terms of ankle sprain risk factors (Fuerst et al., 2017; Kim et al., 2014; Meinerz et al., 2015; Müller et al., 2013). Conservative results may be due to unanticipated conditions presenting stimuli earlier than Hick's Law response time requirements, thus allowing for pre-planned movements to occur (Hick, 1952; Roberts et al., 1988). One study examining unanticipated jump landings indicated that participants revert to a generic bilateral landing when not given sufficient time for pre-planned movement strategies (Stephenson et al., 2018). Therefore, in order to challenge response time, the timing of stimuli needs to be close enough to the direction change that insufficient time is provided for pre-planned movements.

Stimuli may change during the execution of a directional jumping movement in a dynamic environment. Incorrect predisposition occurs when initial stimuli indicates a movement direction, but the stimuli changes to a different direction. In many sports involving a defensive and offensive player, a defender will utilize pre-cues and anticipate the offensive player's direction in order to gain a performance advantage (Brault et al., 2010;

Bideau et al., 2012; Fujii et al., 2014). However, if the defender is incorrect, a negative performance with stumbling can result (Brault et al., 2010). Incorrect predisposition may lead to a pre-planned movement in the incorrect direction that requires correction. It is expected that changing direction after incorrect predisposition will lead to higher ankle sprain risk factors.

The purpose of this study was to investigate kinematic and kinetic changes in a jump-land-jump task as a function of jump direction and correct vs. incorrect predisposition. It was expected that a change of direction (non-dominant direction) would increase ankle sprain risk factors as compared to continuing in the same direction (dominant direction). Therefore, it was hypothesized that a non-dominant jump direction would result in higher ankle inversion angles, medial GRFs, and ankle eversion moments than a dominant jump direction. Incorrect disposition was also expected to increase ankle sprain risk factors due to the inability to properly pre-plan the directional jumping movement. Similarly, it was hypothesized that incorrect disposition would result in higher ankle inversion angles, medial GRFs, and ankle eversion moments than correct disposition.

Methods

Participants

17 participants (all right foot dominant, 14 males/3 females, age 21.7 ± 2.4 yr, height 176.9± 7.4 cm, mass 79.3 ± 11.1 kg) volunteered for this study. Participants were classified as moderately active to active by the Center for Disease Control (CDC) exercise guidelines. Exclusion criteria included a history of lower extremity surgery or recent injury that would affect jump-land-jump performance. Power analysis performed on a previous ankle inversion study (Meinerz et al., 2015) indicated that a sample size of 20 participants was necessary to

maintain a type I-error level of 0.05 and a Type II-error level of 0.20. Iowa State University's Internal Research Board (IRB) approved the study. Each participant signed a written informed consent document before participating.

Experimental protocol

Before collecting data, participants were led through a warm-up protocol starting with a light, self-selected jogging pace on a treadmill for five minutes. This was followed by a series a dynamic stretches designed to reduce the risk of injury and increase performance. Participants then practiced a jump-land-jump protocol that was modified from previous studies investigating ACL injury risk (Dai et al., 2014; Stephenson et al., 2017). The participants stood on a 30cm tall box and waited to observe an LED light to indicate which direction to move in (left or right). The participant then jumped at a distance 50% of their body height at an angle 60˚ from the anterior direction and toward their dominant side. The 60˚ entry angle was chosen to induce greater forces on the dominant limb as well as to create a movement pattern that would mimic challenging sports movements.

Upon landing bilaterally onto force platforms (AMTI, Watertown, MA), the participants then jumped fluidly in the direction currently indicated by the LED lights. Participants were instructed to maximize jump-land-jump performance by minimizing ground contact while on the force platforms and maximizing distance for the second jump. The angle of the second jump was 60˚ from the anterior to the left or right and was indicated by red tape on the floor. Four specific conditions were used in this study: Correct Predisposed Dominant (CPD), Correct Predisposed Non-Dominant (CPN), Incorrect Predisposed Dominant (IPD), and Incorrect Predisposed Non-Dominant (IPN). Correct predisposed conditions were when the LED light continued in the initially indicated direction. Incorrect predisposition conditions were when the LED light switched directions at ground contact.

The participants were familiarized with the movement and directional stimuli by practicing each condition. Participants then performed a block of 30 trials (10 CPD, 10 CPN, 5 IPD, 5 IPN) with 30 seconds of rest in between each trial in order to combat fatigue. The block was randomized via a Durstenfeld shuffle technique (Durstenfeld, 1964) that blinded both the participant and researcher to each trial. If the participant did not successfully complete at least three trials for each condition in the block, extra trials of the incomplete conditions were proportionally added and reshuffled. Only successful trials were analyzed for each of the four conditions. Successful trials were defined as each foot landing completely within the boundary of a separate force platform and the second jump completed in the correct direction.

An Arduino Uno microcontroller (Smart Projects, Strambino, Irvea, Italy) was used to control condition order and display visual stimuli for the second jump (Stephenson *et al.*, 2015). This device continuously looped a custom program that monitored the vertical forces from the force platforms. This allowed for the direction to switch at ground contact for the IPD and IPN conditions. The direction of the second jump was indicated by two LED lights 155 cm off the ground and 255 cm away from the anterior edge of the force platforms. The two lights were separated by 60 cm horizontally to indicate left and right directions. One of the two lights was illuminated before the participant initiated the first jump to indicate the direction of the second jump. In the IPD and IPN conditions, the lights would switch at initial ground contact to indicate a change in direction.

Timing of the incorrect predisposition visual stimuli was analyzed before initial participant data collection. The average latency (post-landing) of the system across 30 trials was shown to be 13.3 ms with a standard deviation of 4.3 ms. This time is representative between the detection of initial ground contact during jump landing to the time that the lights switch directions in the IPD and IPN conditions.

Data collection

Each participant wore tight fitting, non-reflective clothing and athletic shoes for testing. Retro-reflective markers were placed on the participant's left and right acromia, C7 vertebrae, anterior superior iliac spines, posterior superior iliac spines, sacrum, and greater trochanters. Retro-reflective markers were also placed on the dominant leg at lateral and anterior mid-thigh, medial and lateral femoral condyles, lateral and anterior mid-calf, medial and lateral malleolus, calcaneus, distal end of the 1st toe, and the base of the 5th metatarsal-phalangeal joint. Previous landing research indicated that the dominant lower extremity limb was at a greater risk for an ankle injury and as a result, only the dominant limb was examined in this study (Niu, *et al*., 2014). Lower extremity dominance was self-indicated by the participant as the preferred kicking leg.

Participants performed a static trial by standing with their feet shoulder width apart. Markers were then removed from the medial malleolus and medial femoral condyle so that they did not interfere with jumping movements. The removed markers were recreated during the dynamic trials based on the relative position and orientation from the remaining markers on the segment. Three-dimensional kinematic data were collected via eight infrared cameras (Vicon Motion Systems Ltd, Oxford, UK) at a sampling frequency of 160Hz. Ground reaction forces (GRF) data were collected via two force platforms at a sampling frequency of 1600 Hz (AMTI, Watertown, MA). Both kinematic and GRF data were recorded and synchronized using Vicon Nexus (Oxford, UK) for subsequent analysis. Kinematic and GRF data were filtered via a 4th-order low-pass Butterworth filter at 15Hz.

Data analysis

A custom MATLAB (MathWorks, Natick, MA) program was used to calculate joint angles and joint moments during the first 150 ms of the landing phase. Initial contact for the landing phase was defined when the vertical GRF exceeded 35 N (approximately 5% body weight). The ankle joint center was calculated as the midpoint between the lateral and medial malleoli and the knee joint center as the midpoint between the medial and lateral femoral epicondyles. Ankle joint angles were estimated using an Euler/Cardan rotation order of dorsiflexion/plantarflexion, eversion/inversion, and internal/external rotation. Joint moments were estimated using inverse dynamics. The foot segment mass, center of mass, and moment of inertia was individually estimated (de Leva, 1996). Joint moments were transformed to the distal segment coordinate and reported as internal moments

Statistical analysis

The dependent variables measured in this study focused on movement and loading of the ankle and foot: ankle dorsiflexion angle, ankle inversion angle, posterior GRF, medial GRF (with respect to the dominant leg), vertical GRF, ankle plantarflexion moment, and ankle eversion moment. The maximum value of these dependent variables was determined during the first 150 ms of the landing phase from the first jump. Maximum values were averaged across three trials per condition. A repeated measures analysis of variance (ANOVA) was performed in SPSS to compare the CPD, CPN, IPD, and IPN conditions. The level of statistical significance was set at $\alpha < 0.05$. When significant main effects were detected, pairwise comparisons with Bonferroni adjustments were utilized to test for significant differences between conditions.

The effect of predisposition was analyzed by comparing correct and incorrect predisposition conditions within the same direction conditions. The effect of direction was observed by comparing dominant and non-dominant conditions within in the same predisposition conditions.

Results

Repeated measures ANOVA revealed a significant main effect of jump-land-jump condition ($p < 0.001$). Univariate ANOVA further indicated significant main effects of jump-land-jump condition on maximum ankle dorsiflexion angle ($p < 0.001$), ankle inversion angle ($p = 0.043$), posterior GRF ($p < 0.001$), medial GRF ($p < 0.001$), vertical GRF ($p < 0.001$), and ankle plantarflexion moment ($p = 0.004$). Jump-land-jump condition did not have a significant effect on maximum ankle eversion moments ($p = 0.230$)

Joint Angles: Pairwise comparisons indicated that maximum ankle dorsiflexion angle was significantly higher for the CPD condition as compared to the IPD ($p = 0.001$) and IPN ($p = 0.031$) conditions (Table 1). In addition, maximum ankle dorsiflexion angle was significantly higher for the CPN condition than the IPD condition ($p = 0.019$). There were no significant differences in maximum ankle inversion angles when comparing jump-land-jump conditions.

Ground reaction forces: Pairwise comparisons indicated that maximum posterior GRF was significantly higher for the CPN ($p = 0.002$), IPD ($p < 0.001$), and IPN ($p < 0.001$) conditions as compared to the CPD condition (Table 2). Similarly, maximum medial GRF was significantly higher for the CPN ($p < 0.001$), IPD ($p = 0.001$), and IPN ($p = 0.003$) conditions than the CPD condition. In addition, maximum medial GRF was significantly higher for the CPN condition than the IPN condition ($p = 0.015$). Maximum vertical GRF was significantly higher for the CPN ($p < 0.001$) and IPD ($p = 0.001$) conditions than the

CPD condition. Maximum vertical GRF was also significantly higher for the CPN condition than the IPN condition (p = 0.007).

Table 1. Mean ± standard deviation of maximum joint angles during the first 150 ms of landing as a function of jump-land-jump condition (n = 17).

	Jump-Land-Jump Condition			
Joint Angle	**CPD**	**CPN**	**IPD**	**IPN**
Ankle Dorsiflexion (°)	26.2 ± 6.0^{CD}	23.3 ± 5.8^{C}	20.1 ± 6.2	21.8 ± 6.4
Ankle Inversion (°)	11.6 ± 6.9	14.1 ± 6.7	13.2 ± 6.1	13.5 ± 5.8

Abbreviations: CPD – Correct Predisposed Dominant, CPN – Correct Predisposed Non-Dominant, IPD – Incorrect Predisposed Dominant, IPN – Incorrect Predisposed Non-Dominant. C- significantly greater than IPD, D- significantly greater than IPN. Statistical significance at $p < 0.05$.

Table 2. Mean ± standard deviation of maximum GRF during the first 150 ms of landing as a function of jump-land-jump condition (n = 17).

	Jump-Land-Jump Condition			
GRF	**CPD**	**CPN**	**IPD**	**IPN**
Posterior (N)	215 ± 52	251 ± 46^{A}	271 ± 50^{A}	258 ± 45^{A}
Medial (N)	336 ± 141	579 ± 92^{AD}	544 ± 85^{A}	502 ± 84^{A}
Vertical (N)	1189 ± 258	1584 ± 220^{AD}	1489 ± 226^{A}	1386 ± 243

Abbreviations: CPD – Correct Predisposed Dominant, CPN – Correct Predisposed Non-Dominant, IPD – Incorrect Predisposed Dominant, IPN – Incorrect Predisposed Non-Dominant. C- significantly greater than IPD, D- significantly greater than IPN. Statistical significance at $p < 0.05$.

Joint moments: Pairwise comparisons indicated that maximum ankle plantarflexion moment was significantly higher for the CPN condition as compared to the CPD condition (p = 0.019, Table 3). As mentioned previously, there were no significant differences in maximum ankle eversion moments when comparing jump-land-jump conditions.

Table 3. Mean ± standard deviation of maximum joint moments during the first 150 ms of landing as a function of jump-land-jump condition (n = 17).

	Jump-Land-Jump Condition			
Joint Moment	**CPD**	**CPN**	**IPD**	**IPN**
Ankle Plantarflexion (Nm)	93 ± 31	111 ± 30[A]	109 ± 33	99 ± 30
Ankle Eversion (Nm)	15 ± 7	17 ± 7	13 ± 5	14 ± 6

Abbreviations: CPD – Correct Predisposed Dominant, CPN – Correct Predisposed Non-Dominant, IPD – Incorrect Predisposed Dominant, IPN – Incorrect Predisposed Non-Dominant. C- significantly greater than IPD, D- significantly greater than IPN. Statistical significance at $p < 0.05$.

Discussion

The hypotheses were that ankle sprain risk factors would increase when comparing incorrect to correct predisposition and when comparing non-dominant to dominant jump directions. Specifically, it was hypothesized that maximum ankle inversion angle, medial GRF, and ankle eversion moment would be higher during incorrect disposition and in the non-dominant jump direction.

The hypothesis that maximum ankle inversion angle would increase with incorrect disposition and in the non-dominant jump direction was not supported (Table 1). These results alleviate some concerns for lateral ankle sprain risk with excessive ankle inversion (Ferran & Maffulli, 2006; Fong, 2012; Kristianslund et al., 2011). Previous research indicated that there is an increased amount of ankle inversion in side-cutting compared to cross-cutting (Kim et al., 2014). Our differing results may be due to differences between directional jumping and cutting movements. Ankle dorsiflexion was significantly lower when comparing correct to incorrect predisposition when jumping in the dominant direction. This may indicate a more conservative movement pattern and potentially reduced performance when the visual stimuli is incorrect during directional jumping.

The hypothesis that maximum medial GRF would increase with incorrect disposition and in the non-dominant jumping direction was partially supported (Table 2). Medial GRF was significantly higher when comparing incorrect to correct predisposition in the dominant direction and when comparing the non-dominant to the dominant direction with correct predisposition. Similar results were found for posterior and vertical GRF. These results are of concern as higher braking, directional, and impact forces may increase ankle injury risk.

Previous research on cutting maneuvers indicated greater braking forces were required in order to change directions with enough speed to maintain performance (Havens & Sigward, 2015). Of interest in the current study is the lack of differences when comparing the dominant to non-dominant jump direction with incorrect predisposition. This may indicate a more conservative symmetric loading strategy with incorrect visual stimuli rather than preferentially loading one leg in an attempt to increase performance.

The hypothesis that maximum ankle eversion moments would increase with incorrect disposition and in the non-dominant jumping direction was not supported (Table 1). Similar to a lack of changes in ankle inversion angles, these results are not consistent with an increased risk of ankle sprain. Ankle plantarflexion moments were higher when jumping in the non-dominant than the dominant direction with correct predisposition. Higher ankle plantarflexion moments for the leg opposite the direction of movement may facilitate changing directions when jumping. The lack of differences in ankle plantarflexion moments between the non-dominant and dominant directions with incorrect disposition supports this idea. As with the GRF results, these results may indicate a more conservative loading strategy and potential reduced performance with incorrect disposition.

Previous research proposed a generic bilateral landing pattern when insufficient time was provided to plan a movement during jump-land-jump maneuvers (Stephenson et al., 2018). In the current study, posterior, medial, and vertical GRFs increased, while ankle dorsiflexion angles decreased with incorrect predisposition in the dominant direction. Increased GRFs are of potential concern for increased ankle sprain risk, while decreased plantarflexion moments may be associated with decreased performance. It is difficult to determine whether these changes increase injury risk and/or indicate a conservative symmetrical strategy with incorrect stimuli. There may be a tradeoff between fully committing to a preplanned motion for increased performance and increasing risk of ankle injury if a late direction change is required.

There were limitations to the generalizability of the results in this study. One limitation is that only successfully completed trials were analyzed. As a result, the incorrect predisposition conditions may have conservative results since injuries may occur during movements that were considered unsuccessful and not analyzed. Another limitation is that although measures were taken to reduce the likelihood of guessing the jump direction, participants may still have chosen to ignore the initial directional stimulus. Participants also may have chosen to adopt a more conservative landing strategy after failing incorrect predisposition trials instead of maximizing performance. Future studies may benefit from implementing additional measures to increase the benefit of maximizing performance and reducing the likelihood of guessing by the participant.

Conclusions

The results in this study indicated that GRFs and ankle plantarflexion moments were higher when jumping in the non-dominant direction with correct disposition. In addition, GRFs increased and ankle dorsiflexion angles decreased with incorrect predisposition when jumping in the dominant direction. The combination of results may indicate increased ankle sprain injury risk in the leg opposite the jump direction and/or adjustments to increase performance with correct stimuli. When presented with incorrect stimuli, the results may indicate increased ankle sprain injury risk and/or adjustments to increase symmetry with potentially decreased performance. It is suggested that the development of training programs that involve decision making and multiple jump directions may be beneficial for injury reduction and increasing performance.

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CHAPTER 3: GENERAL CONCLUSIONS

The purpose of this thesis was to investigate the effects of correct and incorrect predisposition and jump direction during directional jump landing situations. Lateral ankle sprains are among the most common lower extremity injuries in sports (Ferran & Maffulli, 2006; Fong et al., 2007; Hootman et al., 2007; Kofotolis & Kellis, 2007; Safran et al., 1999; Waterman et al., 2010). Unanticipated changes in direction have been shown to increase the risk of lateral ankle sprains (Gehring et al., 2013; Kim et al., 2014; Kristianslund et al., 2011; Meinerz et al., 2015). The study for this thesis addressed the question, does incorrect predisposition and non-dominant jump direction increase ankle sprain risk factors during directional jumping?

Previous research has examined the mechanism of injury for lateral ankle sprains (Fong, 2012; Fong et al., 2009; Kristianslund et al., 2011; Purevsuren et al., 2018), predictive factors that increase the likelihood of ankle sprain injury (Beynnon et al., 2002; McKay et al., 2001; Milgrom et al., 1991; Waterman et al., 2010), and scenarios that can increase the risk of injury (Doherty et al., 2014; Fu et al., 2014; Tyler et al., 2006; Waterman et al., 2010). Research has examined unanticipated lateral cutting or jumping on ankle sprain risk factors, although in some studies, the unanticipated conditions may be longer than the Hick's Law threshold (Fuerst et al., 2017; Hick, 1952; Meinerz et al., 2015; Müller et al., 2013; Roberts et al., 1988). This thesis study examined whether incorrect predisposition and the non-dominant jump direction increases ankle sprain risk factors.

The stimuli in the study consisted of a light illuminating the direction the participant is supposed to jump after landing on the force platforms. The light stimulus may suddenly change directions at ground contact, resulting in the participant needing to rapidly react and jump in the new direction. The entry angle from the 30 cm box to the force platforms was 60° from the non-dominant side, which is different from previous studies in which the initial jump direction was in the anterior direction (Stephenson et al., 2018; Stephenson et al., 2016; Stephenson & Gillette, 2017). The reason for the change in initial angle was to induce greater forces on the dominant leg upon landing as well as to simulate defensive scenarios commonly scene in sports (Fujii et al., 2014; Seminati et al., 2017).

Significant differences were found for maximum ankle dorsiflexion angle; posterior, medial, and vertical GRFs; and ankle plantarflexion moments. Significant changes were seen when comparing correct and incorrect predisposition and when comparing dominant and non-dominant jump directions. Changes as a function of jump direction were consistent with previous literature indicating significant differences between dominant and non-dominant lateral cutting directions (Kim et al., 2014).

One limitation in the design of the study was that participants might revert to a neutral landing pattern after failing multiple trials. A previous study indicated that knowing a pre-cue would be incorrect 80% of the time resulted in a slower, more cautious response than 50% or 100% pre-cue accuracy (Cameron et al., 2013). This is supported by another study examining various signal timing on anterior cruciate ligament (ACL) injury risk factors during jump-land-jump movements (Stephenson et al., 2018). That study proposed that participants reverted to a generic, bilateral landing movement pattern when not given enough time to pre-plan the secondary jump. Although measures were taken to reduce the likelihood of guessing, future studies may benefit by measuring performance to lessen chance of participants ignoring the initial stimulus.

When considering the GRF results, incorrect predisposition during directional jump landings may increase ankle sprain risk. This falls in line with previous research examining decision making accuracy in offensive versus defensive player scenarios in sports (Brault et al., 2010; Fujii et al., 2014; Henry et al., 2013). These studies indicated a cost-benefit tradeoff when the defender anticipated the offensive player's plan of direction. If the defender predicted correctly, then there was an increase in performance. If the defender guessed incorrectly, then a decrease in performance resulted. Therefore, anticipating directional stimulus change results in three possible scenarios: correct anticipation, incorrect anticipation, or disregarding any anticipation and reacting to the change when it happens. Future research should examine these three scenarios in greater depth.

It should be noted that the results indicate changing direction regardless of predisposition may increase the risk of ankle injury. This makes sense in that changing direction at high velocities, regardless of predisposition, requires the absorption and translation of high forces placed on the body. Research examining different entry and exit jump direction angles may result in different findings and therefore should be taken into consideration for future studies. It would also be interesting to see if the results would be replicated when participants start the trials on their non-dominant side.

The clinical message from this research is that reducing the rate of incorrect predisposition in directional jump landings may reduce the rate of lateral ankle sprains. Changing direction clearly places high loads on the body, and incorrectly anticipating the direction can compound the problem. These results were from a healthy population that did not suffer from functional ankle instability (FAI) or chronic ankle instability (CAI) so any extrapolations should be made with caution.

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APPENDIX. IRB APPROVAL MEMO

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 3/13/2018

To: Caleb Radley
245 Forker

CC: Dr. Jason Gillette
245 Forker Bldg

From: Office for Responsible Research

Title: The Effects of Predisposed Stimuli on Ankle Sprain Risk Factors during Jump Landings

IRB ID: 18-027

Approval Date: 3/12/2018 **Date for Continuing Review:** 3/11/2020

Submission Type: New **Review Type:** Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp.**
- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.