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The Relationship between Dorsiflexion Range of Motion and Knee Kinematics in a Land-and-Jump Task

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THE RELATIONSHIP BETWEEN DORSIFLEXION RANGE OF MOTION AND KNEE KINEMATICS IN A LAND-AND-JUMP TASK

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MASTER'S THESIS

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Abstract

The study examined the relationship between weight-bearing and non weight-bearing dorsiflexion range of motion and frontal knee kinematics at initial ground contact and maximal knee flexion in a land-and-jump task. Thirteen male participants (age = 23 $\pm$ 2.35 y, height = 181.4 $\pm$ 5.68 cm, mass = 84.5 $\pm$ 17.2 kg) proficient in landing and jumping techniques and free from lower limb injury participated in the study. Measurement of ankle range of motion was conducted utilizing non weight-bearing and weight-bearing positions prior to participating in the land-and jump task. During the jump, a 10-camera Vicon 3D Motion Analysis System captured knee and ankle kinematics at initial ground contact (IC) and at the point of maximal knee flexion (MKF). Correlational analyses were undertaken to determine the relationships among measured dorsiflexion range of motion in non weight-bearing and weight-bearing conditions and knee alignment in the frontal plane at IC and MKF during the land-and-jump task. There was a significant correlation between weight-bearing dorsiflexion measurement and knee valgus at IC on the right side only ($r = 0.62$, $p < 0.05$). No other significant correlations were seen at any condition with the weight-bearing condition. No statistically significant correlations were noted for the non-weight bearing measurement of dorsiflexion at IC or MKF on either side of the body. Fisher z-tests showed no significant difference between the conditions of weight-bearing dorsiflexion and non weight-bearing dorsiflexion range of motion measurements and jumping kinematics for any condition tested. Establishing a relationship between a weight-bearing lunge measurement and frontal plane knee kinematics is the first step in bringing validity to the measurements as a means of identifying at risk behavior for ACL injury incidence.

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Chapter 1

Introduction

Injury risk in sports has always been a concern of coaches and athletes alike. Many athletes attempt to prevent injury, though physical training and prophylactic bracing. Injuries to the lower extremities are extremely common in athletics and are widely researched (Karas & Hoy, 2002; Murphy, Connolly, & Beynnon, 2003; Neely, 1998). Prevention of one lower extremity injury in particular, the non-contact ACL injury, has been studied in detail (Fagenbaum & Darling, 2003; Ford, Myer, & Hewett, 2003; Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005; Smith, Sizer, & James, 2009; Venesky, Docherty, Dapena, & Schrader, 2006). The non-contact ACL injury is a tear of the anterior cruciate ligament, a structure which provides support to the knee, resisting forward translation of the tibia in relation to the femur. ACL reconstruction and rehabilitation can cost on average in excess of $17,000 dollars (Ford, Myer, & Hewett, 2003), and take several months, if not years, for complete recovery to preinjury levels. Individuals who experience ACL injuries are also at increased likelihood to experience arthritic changes later in life.

The mechanism behind non-contact ACL knee injury usually involves sudden deceleration or change of direction during a cutting or landing maneuver (Ford et al., 2003). Studies of videotapes of ACL injuries have shown that 65% were non-contact, all were at foot strike with the knee nearly at full extension, and the individual was showing dynamic valgus collapse (Smith et al., 2009). The etiology of jump-landing related knee injuries is not well understood, becasue there are so many factors to consider (Elvin, Elvin and Arnoczky, 2007). Extrinsic factors related to lower extremity injury in jump landings include level of competition, skill level, shoe type, ankle bracing, and playing surface. Intrinsic factors include age, sex, previous injury, aerobic fitness, body size, limb dominance, girth, muscle flexibility, joint mobility, muscle strength, imbalance, reaction time, postural stability, anatomical alignment, and foot morphology (Murphy et al., 2003). Relevant intrinsic factors associated with this study were muscle flexibility, joint mobility, and anatomical alignment.

The ankle, or talocrural joint, is a hinge joint that attaches the distal tibia and fibula with the proximal talus bone of the foot (Karas & Hoy, 2002). Motion at the talocrural joint is in the sagittal plane in the form of dorsiflexion and plantarflexion. Concentric dorsiflexion is produced by the tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius muscles, while plantarflexion is controlled by the gastrocnemius, soleus, plantaris, peroneus brevis and longus, as well as several other deep posterior muscles.

Typically, ankle range of motion, specifically dorsiflexion, is measured with the knee extended and flexed to examine the contribution of the gastrocnemius versus soleus to ankle range of motion. Measurement also is affected by whether it is taken in a weight-bearing or non weight-bearing position. Literature is conflicting as to what the ideal range of motion at the ankle is during dorsiflexion. A review of current literature by Karas and Hoy (2002) identified talocrural maximal dorsiflexion motion between 20 and 30° in a passive, non weight-bearing measurement, and maximum dorsiflexion range of motion during gait at 10°.

The mechanism that causes decreased dorsiflexion range of motion is difficult to discern. Soft-tissue tightness of the gastrocnemius with the leg in the extended position

(DiGiovanni et al., 2002; Greisberg, Drake, Crisoco, & DiGiovanni, 2002), hypomobility of the joint itself (Karas & Hoy, 2002), or some combination of both factors seem to be the main limiting factors of ankle dorsiflexion range of motion. Muscle imbalances around the ankle joint (Gross, 1995), structural issues at the joint capsule (Neely), or osseous formation at the ankle (Gross) also affect achievable range of motion. Artificial bracing of the ankle has been a proposed reason behind limited dorsiflexion range of motion (Hodgson, Tis, Cobb, & Higbie, 2005; McCaw & Cerullo, 1999; Venesky, et al., 2006; Verhagen, van der Beek, & van Mechelen, 2001).

The relationship between dorsiflexion range of motion and injury risk has been examined in several studies, using Naval officers (Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999) and physical education students (Willems et al., 2005) as subjects. Kaufman and colleagues (1999) studied the association between foot structure and overuse injuries in Naval trainees and found a statistically significant relationship between dorsiflexion range of motion and Achilles tendinitis. Willems and associates (2005) studied physical education students over the course of a year and found a statistically significant relationship between dorsiflexion range of motion with the knee extended and risk of inversion sprains.

Research has utilized a drop jump task to replicate the physical demands placed on the lower extremities of athletes engaged in landing and jumping tasks to examine the relationship between ankle joint arthrology and injury incidence (Caulfield, Crammond, O'Sullivan, Reynolds, & Ward, 2004; Fagenbaum & Darling, 2003; Ford et al.; Kernozek et al., 2005; Smith et al., Venesky et al., 2006). Instead of examining the relationship between ankle range of motion and knee injury occurrence in jumping tasks, most research that is conducted on the etiology of knee injuries and their relationship to dynamic tasks focuses on electromyographic (EMG) activity of the muscles surrounding the knee joint (Venesky et al.).

In regards to jumping performance, the contribution of the ankle has been examined in several studies (Vanezis & Lees, 2005: Pandy & Zanjac, 1991; Lees, Varenterghem, & De Clercq, 2004). Vanezis and Lees examined the specific influence of the ankle, knee and hip during stationary countermovement jumps, with and without an arm swing. They found that high performers in the vertical jump had both a higher magnitude of force produced at the ankle, and were greater rate of force development than low performers. Pandy and Zajac found that the role of the gastrocnemius can be more than 25% of the overall muscle contribution to jump performance. Lees and colleagues found that the force delivered through the ankle joint comes from three sources: muscle contraction (27%), return of previously stored energy in the muscle tendon unit (53%), and force transferred from the knee joint via biarticular muscle action.

While it is evident that the ankle is integral for optimal landing and jumping performance, several studies have looked at the how limited ankle range of motion during landing and jumping can increase the ground reaction forces experienced at the ankle (Steele, & Milburn, 1988; Zhang, Bates, & Dufek, 2000). Steele and Milburn found a statistically significant correlation between peak vertical ground reaction forces and ankle flexibility. According to Hodgson and colleagues (2005), an increase in vertical ground reaction forces, regardless of their cause, could be potentially detrimental to the athlete by increasing the risk of lower extremity injury. Zhang and associates studied the differences in mean eccentric work between stiff, normal, and soft landing techniques.

The study found an increase in the contribution of the ankle plantarflexors during stiff landings, suggesting that the less range of motion the ankle can move through, the more likely it is to experience increased ground reaction forces.

Effect of Ankle Bracing in Dynamic Tasks

A considerable amount of the research that assesses the role of ankle range of motion during jumping tasks compares the ankle in a braced versus non-braced situation (Brizuela, Llana, Ferrandis, & Garcia-Belenguer, 1997; Hodgson et al., 2005; McCaw & Cerullo, 1999; Venesky et al., 2006). Ankle mobility restrictions have been more common with the use of ankle braces in sports in order to decrease the aforementioned risk of forced plantarflexion inversion of the foot exceeding physiological range of motion (Verhagen et al., 2001). As a result of fear of injury, some coaches now require athletes to brace their ankles because of the ubiquity of ankle injuries, even in the absence of previous injury (Pedowitz, Reddy, Parekh, Huffman, & Sennett, 2008). It is typically noted that the function of one joint can influence the behavior of neighboring joints, and that restriction or alteration of joint function can cause alterations of other joints in the kinetic chain during tasks such as the drop jump (Venesky et al.). Brizuela and colleagues (1997) noted that restricting the ankle range of motion through use of ankle support devices can lead to a decreased ability to attenuate ground reaction forces. Hodgson and colleagues found no difference in sagittal plane motion of the hip or knee between braced and non-braced jumping, although there was a decrease in the amount of dorsiflexion achieved during the landing. The researchers also noted an increase in peak vertical ground reaction forces at toe contact in the braced situation. McCaw and Cerullo

(1999) demonstrated that ankle bracing can decrease dorsiflexion by 5° at maximal knee flexion, and that the ankle increased its relative energy contribution from 37% to 50% of total energy absorbed between non-braced and braced landings, respectively. Venesky and colleagues (2006) found an increase in knee external rotation force when landing on a slanted surface in subjects who were wearing ankle braces compared to subjects without. In contrast, DiStefanco and associates (2008) found no relationship between ankle bracing and changes in lower extremity kinematics during a drop-jump task over an eight week study. Although ankle bracing is an artificial means of altering the position of the ankle, it could have a similar effect biomechanically to someone who has natural mobility restrictions of the ankle. It seems it can be deduced that restricting ankle range of motion, while possibly decreasing risk for injury to the ankle, could cause an increase in the potential for injury to surrounding joints due to increased ground reactions forces and altered joint mechanics.

Statement of the Problem

While artificially restricting the ankle joint has been studied in depth, natural limitation of ankle dorsiflexion range of motion and its relationship to increased injury incidence has received very little attention. Research is needed to identify the relationship between ankle joint arthrology and knee kinematics in dynamic tasks. A previous study examining knee valgus motion has shown a relationship between excessive knee valgus loads during deceleration maneuvers, and increased ACL loading (Shimokochi & Schultz, 2008). Understanding more about the relationship between ankle dorsiflexion range of motion and knee valgus might allow athletic trainers, physical therapists, and strength and conditioning professionals to understand how much range of motion is necessary to identify athletes for targeted interventions aimed at improving range of motion at the ankle. This in turn can improve the screening process for athletes, and potentially save their institutions money in and medical costs.

Delimitations, Limitations, and Assumptions

Many studies that have examined lower body kinematics during drop jumps have used both female and male participants, with the researchers paying particular attention to females because of their increased incidence for ACL injury (Hewett et al., 2005). Subjects for this study will be delimited to males only. This limits the generalization of results to this population alone, and results cannot be generalized to females, non-athletic, or youth populations. Subjects were delimited to athletes at Mesa State College. This was due to the convenience of selecting athletes from this institution, with the data collection lab being located on that campus. The investigation was also limited to knee kinematics. There are other variables that could be related to ankle joint range of motion that are evident in landing and jumping, but the study was constrained to the knee only.

It was assumed that all subjects performed the test trials to the maximum of their ability and according to the directions described to them by the investigators. Verbal encouragement of maximal effort, and verbal reminders regarding performance directions were utilized as needed to encourage maximal, correct performance.

It is assumed that the use of skin markers accurately reflects the underlying joint kinematics. Landmarks were selected based on the Vicon manufacturer's specifications. A study by Taylor and associates (2005) found that errors in position of the markers were strongly associated with the amount of soft tissue coverage, with average peak errors of 8.5 mm for the femur, 2.8 mm for the tibia, and 2.0 mm with the metatarsus.

Hypothesis

It is the research hypothesis that there will be relationships between an individual’s range of motion in dorsiflexion (as measured in weight-bearing and non weight-bearing positions) and the sagittal and frontal plane positions of the knee in landing and jumping.

Chapter 2

Review of Literature

The ankle is a complex structure that takes on a great deal of stress and strain during most human movement. There are over two million individuals who suffer ankle injuries each year in the United States, with more than half of these being severe ligament sprains (Beynnon, Renstrom, Alosa, Baumhauer et al., 2001). Reactionary standards of Western medicine have led to increased use of ankle braces to assist the body in stabilizing the ankle-foot complex. Semi-rigid and laced ankle braces significantly reduce the incidence of initial and recurrent ankle sprains in both military and athletic populations (Gross & Liu, 2003). However, simply bracing the joint is not necessarily the answer to restoring proper function to the joint, and bracing could lead to a decrease in the range of motion at the ankle (McCaw & Cerrulo, 1999; Hodgson, Tis, Cobb, & Higbie, 2005). While studies that examine dorsiflexion range of motion are typically conducted with a braced versus non-braced intervention, very little research has examined natural ankle dorsiflexion range of motion and its effect on kinematic performance on dynamic tasks such as jumping. The following discussion will provide the reader with an overview of the anatomy of the ankle, assessments of ankle kinematics, compensation mechanisms of the foot and knee in relation to limited dorsiflexion, the role of the ankle in landing and jumping tasks, the risk of injury associated with impaired dorsiflexion range of motion, and suggestions for how dorsiflexion range of motion can be improved.

Anatomy of the Ankle

Osteology. According to Levangie and Norkin (2002), the ankle is referred to as the talocrural joint, and is the articulation between the distal portion of the tibia, distal portion of the fibula, and the talus. The thickened distal ends of the tibia and fibula are known as the medial and lateral malleoli, respectively (Prentice, 2006). The lateral malleolus extends further distally so more stability is created on the lateral aspect of the ankle than the medial side. The talus is the main weight-bearing bone of the articulation of the ankle, and forms the link between the lower leg and foot. The calcaneus also plays an integral role in the function of the ankle, forming the heel and providing an attachment for the supporting ligaments of the ankle and the Achilles tendon. The articulation of the calcaneus and talus is known as the subtalar joint. Non weight-bearing motion (pronation/supination) at the subtalar joint occurs around an oblique axis, which allows for tri-planar motion. The subtalar joint allows the foot to invert and evert in the transverse plane, dorsiflex and plantarflex in the sagittal plane, and abduct/adduct in the frontal plane during non weight-bearing motion. Ligamentous support for the ankle comes from three lateral ligaments and one medial ligament with three parts.

Arthrology. The ankle is considered a hinge joint, in that it has motion in the sagittal plane in the form of dorsiflexion and plantarflexion at the talocrural joint. Concentric dorsiflexion is produced by the tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius muscles, while plantarflexion is controlled by the gastrocnemius, soleus, plantaris, peroneus brevis and longus, as well as several other deep posterior muscles. It is noted that some degree of dorsiflexion is accompanied with a slight inversion of the foot, while plantarflexion is accompanied by slight eversion of the foot (Karas & Hoy, 2002).

The motions occurring at the ankle and rear foot are more complex than they appear. Although the ankle is a stable hinge joint supported by the malleoli, the position of plantarflexion or dorsiflexion alters the stability of the joint. When in dorsiflexion, the wider anterior aspect of the talus comes in contact with the narrower portion lying between the malleoli, increasing stability. As the ankle plantarflexes, the wider portion of the tibia is brought into contact with the narrower posterior aspect of the talus, which decreases the stability of the joint. This natural movement of the ankle is necessary to allow the talus to glide into the ankle mortise without restriction.

The role of another joint, the midtarsal joint, can also have an effect on the motion occurring at the ankle. Motion at the midtarsal joint occurs in two axes: the oblique and longitudinal (Karas & Hoy). The oblique axis allows a large amount of movement in dorsiflexion and abduction. The oblique axis of the midtarsal joint has a one-to-one ratio of abduction and dorsiflexion, meaning that for every degree of abduction in the joint, an additional degree of dorsiflexion occurs. The increase in dorsiflexion created at the midtarsal joint is only possible with increased pronation at the subtalar joint. However, getting dorsiflexion by means of pronation is not a good compensation, for reasons explained later.

According to Coetzee & Castro (2004), a normal ankle moves between 10° dorsiflexion and 50° plantarflexion, but several other sources have reported conflicting numbers (Kars & Hoy; Moseley, Crosbie, & Adams, 2001; Prentice, 2004; Starkey & Ryan, 2002). Dorsiflexion range of motion is dependent on whether it is administered in a weight-bearing versus non weight-bearing position. Tension in the triceps surae muscles, including the gastrocnemius and soleus, are the primary determinants of ankle dorsiflexion range of motion (Levangie & Norkin, 2001). The large articular surfaces of the ankle allow it to withstand forces up to 450% of body weight without risk of acute trauma (Czerniecki, 1988). Dorsiflexion measurements can be administered with the knee positioned at 0° and 90° of flexion to fully account for all components of the triceps surae muscle complex (Karas & Hoy, 2002). In order to measure dorsiflexion range of motion, active pressure is applied to the plantar aspect of the subject's foot while fixing the motion at the midfoot and hindfoot in order to approximate the magnitude of ground reaction forces that act on the forefoot during terminal stance phase (Gross, 1995).

Assessment of Dorsiflexion Range of Motion

Measurement Devices. Numerous methods and tools have been utilized to assess dorsiflexion range of motion (Griesberg, Drake, Crisco, & DiGiovanni, 2002; Moseley et al., 2001; Rome & Cowieson, 1996). Ankle joint range of motion can be measured with a goniometer (Moseley et al., 2001), fluid goniometer, an electrogoniometer (Rome & Cowieson), or through photography (Moseley et al.). Most studies use a plastic universal goniometer to assess ankle range of motion because of its convenience and portability. In order to measure ankle position, the proximal line of the goniometer is lined up with the head of the fibula, with the axis placed either over the lateral malleolus or positioned distal to the base of the foot (Karas & Hoy). According to Starkey and Ryan (2002), the goniometer measures the amount of plantarflexion and dorsiflexion achievable at the ankle in the sagittal plane, and can also assess inversion and eversion range of motion occurring at the subtalar joint. Rome and Cowieson (1996) looked at the intraobserver and interobserver reliability of the universal goniometer within and between clinical observers given a 60 min training session on how to use the device. The procedure was standardized for skin markings, subject position, and placement of the goniometer. Measurement was taken with the individual reclined and secured with a positioning block to place the ankle in a zero position and the subtalar joint in a neutral position. Active non weight-bearing dorsiflexion was measured by having the individual actively dorsiflex and hold the foot for 15 seconds. The study found that the standard error of the universal goniometer was $\pm$ 2.8° of ankle dorsiflexion range of motion in one session and $\pm$ 2.4° in the second session. However, the same study showed a low interobserver reliability with the same device when five observers measured five ankles over five different occasions. This study suggests that when using the universal goniometer, rigid testing protocols must be maintained in order to reduce measurement error, and that multiple testers should not assess the same patient.

Elveru, Rothstein, and Lamb (1988) also examined the intraobserver and interobserver reliability of the universal goniometer in a clinical setting. All participants in the study had neurological or orthopedic disorders. Testers were all physical therapists with a mean of 6.5 $\pm$ 3.0 years of experience in a clinical setting. The testers examined passive range of motion of the ankle by placing the individuals in a prone position with pressure applied to the forefoot in an attempt to simulate gait. One measurement of ankle range of motion in subtalar neutral position was administered. Interclass Correlation Coefficient (ICC) were calculated, where any score below 0.35 of the scale indicated poor reliability. The researchers found that the ICC values for intraobserver reliability of were 0.90, and the interobserver reliability was 0.50 for dorsiflexion range of motion, indicating that intraobserver reliability is much greater.

Patient Position. Dorsiflexion range of motion is typically assessed with the knee straight or at 90° of flexion. When assessing range of motion with the knee straight, the tester looks primarily at the contribution of the gastrocnemius muscle to ankle range of motion because gastrocnemius has attachments at the femur and calcaneus, making it a two joint muscle (Karas & Hoy, 2002). With the knee flexed to 90°, the soleus contribution to range of motion is the primary constraint to dorsiflexion.

Active versus Passive Assessment of Motion. According to Prentice (2004), active range of motion, refers to the degree to which a joint can move due to muscle contraction, while passive range of motion is the degree to which a joint can move to the end range of motion without muscle contraction. Active range of motion is not necessarily a good indicator of stiffness or looseness of a joint because it only looks at how a joint can move due to muscular contraction. Assessment of the passive stiffness of the plantar flexors is the most common measurement of passive dorsiflexion range of motion (Caroway, Sunnerhagen, Kasper, Svantesson, 2006; Moseley et al., 2001; Muir, Chesworth, & Vandervoort, 1999). Passive range of motion is the length-tension relationship of muscle when it is passively stretched (Caroway et al.) and is related to the extensibility of connective tissues in parallel with the muscle fibers. Passive range of motion is necessary for activity because it allows the individual to stretch beyond their normal limits and resist musculotendinous injury.

Normal active range of motion for the ankle through dorsiflexion is from 0° to 20° (Prentice, 2004; Starkey & Ryan, 2002). Active range of motion is typically measured with the individual sitting or lying supine with the knee flexed to at least 30° to release the triceps surae muscle group, and then repeated with the knee extended (Starkey & Ryan).

A study by Moseley, Crosbie, and Adams (2001) found passive range of motion at the ankle was found to be between 11.2° and 25° when a 12.0 N·m torque was applied to the foot with the knee extended. Moseley and colleagues found no asymmetry between dominant and non-dominant sides when measuring passive ankle dorsiflexion, and reported that individuals with limited passive dorsiflexion range were able to complete tasks similarly to those with adequate dorsiflexion range of motion. However, it was noted that limited passive dorsiflexion range of motion may cause compensatory movement strategies that could only be detected through biomechanical analysis (Moseley et al.).

There are two ways to examine passive range of motion (Moseley, Crosbie, & Adams). The most common way is to apply a single torque and then measure the degree of dorsiflexion with a goniometer, while the other more complex version involves an instrument with a load cell and a potentiometer. Usually torque is applied with the hand to the plantar portion of the foot, while fixing the midfoot and hindfoot to control for the motion at the subtalar joint.

Non Weight-bearing versus Weight-bearing Measurement. Typically, ankle joint range of motion is measured with the patient in a non-weightbearing position (Starkey & Ryan), and can be active or passive in nature. As previously stated, measurements usually have a high intraobserver reliability and a low interobserver reliability. For this reason, and to get a better idea of how the joint functions in a dynamic situation, a lunge position has been utilized to examine weight-bearing dorsiflexion range of motion (Bennell, Talbot, Wajswelner, Techovanich, & Kelly, 1998). During this test, the patient places their foot perpendicular to a wall and lunges their knee toward the wall, moving their foot backward until maximum range of ankle motion is reached before heel liftoff. The study by Bennell and associates determined the ICC for intraobserver reliability was between 0.98 and 0.99, while the interobserver reliability was 0.99, which is much higher than any observed during any non weight-bearing assessment. However, because the test primarily assesses the role of the soleus because the knee is flexed, the test is not able to determine the role of the gastrocnemius as a factor for limiting dorsiflexion. A test by Munteanu, Strawhorn, Landorf, Bird, and Murley (2009) examined ankle range of motion in a weight-bearing, knee extended position. The participants performed a "wall calf stretch" with the second toe and heel positioned over a tape line to minimize the effect of subtalar pronation. Four podiatrists acted as the assessors in the study, with one being classified as inexperienced, and undertook 15 minutes of training on test protocols prior to measurement. The study found the intraobserver reliability for the inexperienced podiatrist to be 0.89 when measuring with a goniometer, and the interobserver reliability to be 0.97.

Kinematics of the Ankle

Function in Activity. Adequate ankle range of motion is necessary for many activities. Dorsiflexion range of motion is important for activities such as standing from a seated position, reaching while standing, for dynamic balance, and normal gait. An ankle requires 10° of dorsiflexion range of motion during normal gait (Prentice, 2004) in order for the tibia to move normally over the foot. Maximal dorsiflexion during gait happens just before heel lift-off when the knee is close to full extension (Johanson, Baer, Hovermale, & Phouthavong, 2008). During sit-to-stand, stair climbing, and certain athletic movements when the limb is loaded and the knee is flexed, dorsiflexion range of motion can exceed 25° (Pratt & Bohannon, 2003). The gait cycle is divided into the stance phase and the swing phase (Prentice, 2006). According to Prentice, the stance phase starts with initial contact of the heel and ends with toe lift-off. The stance phase gives an idea of the passive dorsiflexion range of motion available at the ankle. The swing phase is the period of time where the foot is off the ground gives an idea of active dorsiflexion range of motion.

Dysfunction of the Ankle. Since dorsiflexion range of motion is assessed in many different conditions, there are many different situations for classifying functional limitations, or dysfunction. Several studies report that dorsiflexion range of motion of less than 10° during weight-bearing movements is the basis of diagnosing dysfunction (Moseley et al., 2001; Rome & Cowieson, 1996). However, a study by Kaufman and colleagues (1999) that examined non weight-bearing dorsiflexion range of motion classified limited dorsiflexion as 11.5° with the knee extended and 18.5° with the knee flexed at 90°. The study found a relationship between lack of dorsiflexion range of motion and risk for Achilles tendonitis if the individual had less than 11.5° of dorsiflexion with the knee extended. Achilles tendonitis could be caused by increased tightness of the gastrocnemius during gait, leading to increased demands of the Achilles tendon, which may eventually lead to inflammation and injury. DiGiovanni and associates (2002) reported that diagnosis of gastrocnemius equinus represents maximum ankle dorsiflexion range of motion of $\leq 5°$ with the knee extended, and Achilles tightness represents maximal dorsiflexion of $\leq 10°$ with the knee at 90° of flexion. Limited dorsiflexion range of motion can be due to a number of issues such as muscular restrictions at the gastrocnemius, soleus, or Achilles tendon (Neely, 1998), muscle imbalances around the ankle joint (Gross), structural issues at the joint capsule (Neely), or osseous formation at the ankle (Gross). Issues with the soleus or structural issues will affect the ankle's range of motion, regardless of whether the knee is bent or flexed, while a tight gastrocnemius will only be evident with the knee in full extension (Neely). As stated previously, this phenomenon is because the gastrocnemius has attachments at the femur and calcaneus, making it a two joint muscle (Karas & Hoy, 2002).

Gait Associated with Ankle Dysfunction. According to Karas and Hoy (2002), there are proximal and distal compensatory strategies that manifest in varying degrees and in different situations when dorsiflexion range of motion is impaired. Proximal compensations most often manifest in the shortening of the step length during normal walking gait, with the individual exhibiting a "step to" gait, advancing the unimpaired foot only up to the impaired foot during the swing phase. Proximal compensations typically result in a slower, more energy demanding gait because the center of gravity cannot be smoothly shifted over the foot. Distal compensations during gait include dorsiflexion and pronation at the midtarsal joint along with pronation at the subtalar joint. The authors suggest that specific compensations include early heel lift during the stance phase, which is often accompanied by increased knee and hip flexion or knee hyperextension in order to place the body weight over the foot and increased ground clearance during the swing phase of gait to allow the foot to clear during the forward swing of the leg. Stiffness of the plantarflexors could also lead to decreased dorsiflexion range of motion at the ankle during stretch-shortening cycle activities (Caroway et al., 2006), limiting an athlete's ability to store and release energy. Caroway and colleagues examined the passive stiffness of the plantarflexors in female subjects 18 to 60 years of age and found that jumping performance decreased with increasing passive stiffness. However, there was a negative correlation between age and increased passive stiffness, which could confound the relationship between passive stiffness and performance.

In contrast, a study conducted by Craib and associates (1996) looking at the passive stiffness of the ankle and performance in running found there was a negative linear correlation between runners who had less ankle flexibility and mean aerobic demand of running. This research suggested that inflexibility in posterior structures such as the gastrocnemius could possibly enhance running economy.

Dorsiflexion Range of Motion and Musculoskeletal Injury. Several studies have examined the relationship between dorsiflexion range of motion and risk of musculoskeletal injury (Kaufman et al., 1999; Willems et al., 2005). Kaufman and colleagues conducted a prospective study examining the association between foot structure and overuse injuries in 449 Naval trainees. Passive rorsiflexion range of motion at 0° and 90° of knee flexion was measured prior to participation in the study. Throughout training, the subjects were tracked for injuries. The researchers found a statistically significant relationship between dorsiflexion range of motion with the knee extended and incidence of Achilles tendinitis. Limited dorsiflexion in the study was considered to be less than 11.5° with the knee extended. This could potentially show that limited dorsiflexion range of motion can increase the incidence of overuse injuries to the lower extremity. Willems and associates conducted a cohort study on the intrinsic risk factors for ankle sprains in male subjects. The researchers evaluated 241 male physical education students over the course of an academic year. Of the subjects, 44 suffered inversion ankle injuries. The researchers found an association between dorsiflexion range of motion with the knee straight and risk for inversion sprains in the male subjects. Examining the role of the gastrocnemius dorsiflexion range of motion could potentially assist in identifying individuals at risk for inversion sprains.

In contrast to the results above, one study found no relationship between dorsiflexion range of motion and the incidence of ankle injury (Beynnon et al., 2001). Beynnon and colleagues conducted a prospective study examining the factors associated with ankle injuries in 118 Division I (50 male) athletes. The study looked at genders independently to establish gender-specific risk factors. The researchers found a significant linear relationship between talar tilt and ankle injury, and were unable to establish a relationship between dorsiflexion range of motion and ankle injury incidence in males. Talar tilt is an assessment of the laxity of the joint, and is assessed with the ankle at 10° of plantarflexion. Potentially, only looking at males could have limited the association between dorsiflexion range of motion and ankle injury.

Compensatory Joint Issues Associated with Dorsiflexion Limitations

Compensations in the Foot / Ankle Complex. The body must make up for the lack of motion at the ankle by forcing motion on the surrounding joint structures. One area where compensations are noted is at the foot. Karas and Hoy (2002) looked at the typical compensation patterns that occur at the foot when adequate dorsiflexion range of motion cannot be achieved. The primary compensation that occurs is at the midtarsal joint, where a compensatory dorsiflexion occurs, which is accompanied by pronation at the subtalar joint (Karas & Hoy). DiGiovanni and colleagues (2002) looked at patients who had existing metatarsalgia or related midfoot or forefoot issues. The researchers found that the group that had existing foot pathologies had on average 4.5° ± 4.5° range of motion in dorsiflexion, while the control group had on average 13.1° ± 8.2° of dorsiflexion range of motion with the knee at 0° of flexion. Since there is so much overlap in the data, it is difficult to distinguish whether the foot pain is caused by gastrocnemius tightness, or by some other influence. Gross (1995) also studied the relationship between insufficient dorsiflexion range of motion and compensation patterns in the foot. The study found that patients with insufficient dorsiflexion range of motion compensated by decreasing the step length of the contralateral leg, increasing dorsiflexion range of motion at the forefoot, or exhibiting a toe-out gait in order to decrease dorsiflexion demands during the terminal phase of gait.

Effect of Artificial Stabilization of the Ankle Joint. Several studies that examined range of motion of the ankle employed artificial means for stabilizing the ankle joint to study the effects. This allows researchers to isolate the joint and examine what happens when ankle range of motion is restricted. It is thought that while ankle bracing can decrease the sagittal plane range of motion available at the ankle, it can control the extent of inversion and eversion movements when landing (Verhagen, van der Beek, & van Mechelen, 2001). Ankle braces typically include one of three methods: taping, lace-up braces, or semi-rigid braces. Cordova, Ingersoll, and LeBlanc (2000) examined the effects of different levels of bracing on ankle dorsiflexion range of motion before and after exercise. The researchers found in terms of dorsiflexion range of motion restriction, the condition that restricted motion the most was taping. No data were collected on the kinematics of the knee with bracing. McCaw and Cerullo (1999) looked at how prophylactic ankle stabilizers affected the ankle during drop landings, examining five female and nine male college students. The study found that wearing ankle stabilizers reduced dorsiflexion range of motion by an average of 5°, as well as decreasing the maximum ankle angular velocity, suggesting that the muscles supporting the ankle were not doing their job as eccentric force absorbers. The question that arises from this study is whether artificially decreasing dorsiflexion range of motion changes force patterns in the knee and hip joints. A study by Brizuela, Ferrandis, and Garcia-Belenguer (1997) examined the influence of high-top shoes had versus low-top shoes on the ankle's ability to act as a shock attenuation mechanism. The researchers used two shoe prototypes: one with a high top, heel counters, and a rearfoot lacing system, and one with a low top and no heel counters or rearfoot lacing system. Individuals were tested on vertical jump performance and time in an obstacle course run. The study found that high top shoes restricted dorsiflexion range of motion, increased impact forces on landing after jumping at the forefoot, and decreased jumping performance by 3% in a vertical jump task. Again, it can be suggested that the increased shock transmission is due to the restriction of the ankle joint range of motion, which disrupts the eccentric force absorption capability of the ankle when landing (Brizuela et al.).

At least one study found no relationship between ankle prophylactic use and increased ground reaction forces during a jump landing (DiStefano, Padua, Brown, & Guskiewicz, 2008). The researchers in this study found that while bracing the ankle restricted the available dorsiflexion range of motion at the ankle, it caused no changes in vertical ground reaction forces. Subjects in this study experienced greater knee flexion angles during initial ground contact in the braced condition, as well as a decrease in knee flexion joint displacement, hinting that lack of ankle range of motion can lead to changes in knee kinematics. The researchers also found that wearing the braces did not change the kinematics that were already present during the braced condition. The brace led to some changes acutely compared to the non-braced, but these changes are the same after 12 weeks.

Compensations at the Knee. Numerous studies have been conducted to examine how inadequate dorsiflexion range of motion may lead to acute and overuse injuries at the knee. Siegmund, Huxel, & Swanik (2008) looked at jumping patterns in basketball players with patellar tendonitis. They found that individuals with jumper's knee showed significantly less ankle dorsiflexion when landing from a running layup jump, with 50% of the subjects demonstrating a flatfoot landing technique (Siegmund et al.). However, it is impossible to assume that the lack of ankle dorsiflexion led to patellar tendonitis, or if patellar tendonitis caused a lack of dorsiflexion range of motion. Another study conducted on knee kinematics used an artificial stabilizer at the ankle to examine changes at the knee during a drop jump (Venesky et al., 2006). Participants hung from a bar and dropped onto a slanted surface to simulate landing on someone's foot. The study found that knee valgus torque was no different between a braced and non-braced condition. The researchers hypothesized that decreased range of motion at the ankle could lead to increased forces and torques exerted at the knee, but were unable to find evidence from the study. Although bracing the ankle could simulate the loss of natural dorsiflexion range of motion experienced in some individuals, it difficult to make the jump from ankle brace conditions and natural restrictions of dorsiflexion.

Reduced range of motion at the ankle has been shown to increase proximal loading on the knee, particularly at the patellar tendon (Zhang et al., 2000). It was hypothesized that the athletes may have landed in more of a flat foot position to avoid loading the tendon and place more stress on the ankle (Siegmund et al.), which can lead to greater risk of injury to the ankle itself. Landing toe first and going into a greater range of dorsiflexion could possibly allow the athletes to avoid overloading the patella tendon by allowing force absorption to happen over a longer period of time.

Role of the Ankle in Jumping

Performance. Numerous studies have been conducted in order to distinguish the characteristic of superior jumpers (Ham, Knez, & Young, 2007; Laffaye, Bardy, & Durey, 2005; Vanezis & Lees, 2005; Yamauchi & Ishii, 2007). These studies all investigated the contributions of the ankle in jump performance. Ham and associates studied stationary and running vertical jumps off one and two legs, and found that successful performance was the result of several factors, including running speed and reactive strength for single-leg, running jumps, and concentric power of the lower body for double-leg, stationary jumps. Laffaye and colleagues found that lower body force production and lack of lower limb stiffness were the most significant contributors to superior vertical jump height when looking at a run-and-jump test. Vanezis and Lees looked at the specific contributions of the ankle, knee and hip during stationary countermovement jumps, with and without an arm swing. They found that high performers in the vertical jump had both a higher magnitude of force produced at the ankle, and were able to produce power much sooner than low performers. Yamauchi and Ishii concluded that maximum speed of knee-hip extension as measured by a servo-controlled dynamometer was more correlated to vertical jump performance than maximal force produced.

The ability to produce force rapidly is a characteristic of the stretch-shortening cycle, where a rapid eccentric action is immediately followed by a concentric action. Jumping utilizing countermovement has been shown to be more effective at producing superior vertical jump heights (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Gerodimos et al., 2008) because of the utilization of the stretch-shortening cycle. Through a rapid eccentric muscle action, the jumper is able to store elastic energy, and the following concentric action allows the jumper to utilize the stored energy. Restricting the ability for the ankle to maximally dorsiflex to store energy in the plantarflexors could lead to a decrease in jumping performance.

Two studies that looked at the specific contributions of the ankle, knee and hip to jump performance (Fukashiro & Komi, 1987; Hubley & Wells, 1983) found conflicting results. Fukashiro and Komi found that the hip contributed the most to jump height (51%), followed by the knee (33%) and ankle (16%). In contrast, Hubley and Wells found the knee contributed the most to the positive work done by the lower body joints (49%), followed by the hip (28%) and ankle (23%). Although both studies demonstrated that the ankle contributed the least when compared to the hip and knee during vertical jump performance, it is still a critical contributor to jump performance.

Landing. While vertical jump performance is an indicator of success in various athletic tasks, the ability to execute a proper landing from a jump is almost as important from the standpoint of injury prevention. One study reported (Elvin, Elvin, & Arnoczky, 2007) that the forces created from landing can be up to eight times the body weight of the jumper. These forces can lead to severe knee issues, such as tendinosis, cruciate and collateral ligament injuries, and osteoarthritis (Murphy, Connolly, & Beynnon, 2003). Several studies have examined the landing strategies of different populations when coming out of a jump (Devita & Skelly, 1992; Elvin, Elvin, Arnoczky, & Torry, 2007; Kernozek, Torry, Van Hoof & Cowley, 2005; Steele, & Milburn 1988; Zhang et al., 2000). Devita and Skelly, as well as Elvin, Elvin, Arnoczky, and Torry looked at the internal forces in the knee during jump landing. The researchers found that as knee flexion increased, ground reaction forces decreased, suggesting a protective effect. Kernozek and colleagues examined the difference in landing mechanics between males and females, and found that although females exhibited greater peak knee valgus angles, they showed greater ankle dorsiflexion range of motion, suggesting they were able to better absorb energy at the ankle during landing. Steele and Milburn examined the landing mechanics of netball athletes, and found that players typically possessed less dorsiflexion range of motion in their non-dominant ankle, and experienced greater vertical ground reaction forces (VGRF) in the more inflexible ankle. This information is significant because an increased in VGRF can lead to increased demands on the lower extremity ligaments, which can possibly lead to trauma or acute injury risk. Zhang and associates looked at landing strategies during soft, normal, and stiff landings. They found that while the knees were consistent contributors to energy dissipation, the ankle plantarflexors contributed more during stiff leg landings, while the hip extensors were more active during normal landings (Zhang et al.). This information could show how the ankle is more susceptible to injury when landing in a stiff leg position because of the increased force absorption demands.

Mechanisms for Improving Dorsiflexion Range of Motion

Stretching Interventions. As discussed, the range of motion available for dorsiflexion has been proposed to have an effect on not only performance variables, but also possible injury risks. Numerous studies have looked at the effects of attempting to improving ankle mobility (Mahieu, McNair, Muynck et al., 2007; McNair, Dombriski, Hewson, & Stanley, 2000; Pratt, & Bohannon, 2003) through static and ballistic stretching protocols. Static stretching is the act of slowly lengthening and holding a stretch, while ballistic stretching is bouncing or using momentum to lengthen tissue (Mahieu et al.). Mahieu and associates examined the differences between static and ballistic stretching in altering ankle range of motion, passive resistive torque of the plantar flexors, and stiffness of the Achilles tendon. The subjects were randomized into a static stretch, a ballistic stretch, and a control group. The stretching groups performed a six-day stretching protocol for the gastrocnemius, with the static stretch group holding the classic wall calf stretch, while the ballistic group would move the knee up and down once per second, completing the stretch five times per leg for 20 seconds. The study found that after six weeks, participants in both stretching groups improved overall dorsiflexion range of motion, while the ballistic stretching group decreased Achilles tendon stiffness and the static stretching group experienced a slight decrease of the passive resistive torque of the plantar flexors. Proposed mechanisms behind why the changes occurred were due to the increased strain placed on the Achilles tendon at rest in the ballistic group, and structural changes in the contractile elements of the plantarflexors in the static stretched group, but the exact reasons for the changes are not known (Mahieu et al.).

McNair and colleagues investigated the interaction between different stretching protocols and their effect on ankle joint stiffness and force production capability over a four-week period. All subjects underwent a stretching protocol of a 60 second hold, three 30 second holds, four 15 second holds, or a continuously held passive motion for 60 seconds, randomly alternating between each condition over the time frame of the study. The researchers found, using a Bonferonni contrast method, that there was a significant difference between the 60 second passive motion and all other stretching protocols, suggesting that passive motion was more effective at decreasing joint stiffness of the ankle. This study suggests that a held stretch is less effective at improving ankle mobility than a continuous motion, which can be achieved through something like a dynamic warm-up or a repetitive movement, such as jogging.

Pratt and Bohannon (2003) examined how a passive intervention stretching protocol altered ankle dorsiflexion range of motion. The passive stretch was administered by having the individual stand with their heels suspended from a platform for three minutes, for three consecutive days. While the range of motion improved temporarily after the stretch was finished, there were no observable changes after the three day stretching intervention. This study suggests that the duration of the intervention could have been the limiting factor for making permanent changes in passive dorsiflexion range of motion. It is also practical information for researching, because it implies that one may change the dorsiflexion range of motion of the test subjects through three minutes of a passive stretch and retest them to see if any changes occur in lower body kinematics.

Muir and researchers (1999) observed that stretching protocols may not work for some populations, such as individuals with pathological limitations in dorsiflexion range of motion.

Muir and associates conducted a within-subjects stretching intervention between a group of 20 healthy men, randomly assigning one of their ankles to the control or intervention group using a block randomization procedure. The subjects then conducted four static stretches, held for 30 seconds, and then measured passive resistance of their plantarflexors as a means for assessing dorsiflexion range of motion. The researchers found that short-term static calf stretching did not help to improve passive ankle dorsiflexion range of motion, suggesting that long-term stretching intervention may be necessary to produce significant improvements in passive dorsiflexion range of motion.

In conclusion, it is evident the ankle plays a crucial role in jumping and landing, and that range of motion limitations can lead to problems both locally and up the kinetic chain as force must go somewhere. However, there are many questions that need to be addressed, such as how much or little dorsiflexion range of motion causes changes in knee kinematics and vertical ground reaction forces. Through this review of literature, it has been demonstrated that the ankle is a complex joint and that dorsiflexion limitations may have ramifications of proximal landing strategies. The purpose of this study is to examine whether there is a correlation between the range of motion available at the ankle and the motion at the knee during a land-and-jump task.

Chapter 3

Methods

This study examined the relationship between ankle dorsiflexion range of motion and knee alignment at initial contact and maximal knee flexion during a land-and-jump task. The following sections provide detailed explanations of the participants, instrumentation, and procedures utilized in this study to answer the research question.

Participants

A convenience sample of thirteen healthy, physically active athletes from Mesa State College were used in this study. Previous studies on jumping utilized as few as six (Fagenbaum & Darling, 2003) and up to thirty-four subjects (Ford, Myer, & Hewett, 2003), with an average of 13 (Caulfield et al., 2004; DiStefano et al., 2008; Fagenbaum & Darling; Ford et al., 2003; Kernozek et al., 2005; Smith et al., 2009; Venesky et al., 2006). Previous studies showed differences in jumping and landing strategies between males and females (Fagenbaum & Darling, 2003; Ford, Myer, & Hewett, 2003; Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005; Smith, Sizer, & James, 2009). Therefore, to reduce the limitations due to sex, this study utilized only male subjects. In order to meet the eligibility requirements to participate in this study, the athletes met several conditions. The athletes were between the ages of 18 and 27, competed in a high school or collegiate sports currently or in the past, and were free of any injury or illness which limited their performance. This information was collected through verbal inquiry prior to physical testing.

Instrumentation

The study utilized a 10-camera Vicon 3D Motion Analysis System (Oxford, UK) for capturing data. The system sampled at a rate of 370 Hz. High resolution (4 megapixel) infrared cameras (Model T40) captured marker coordinates, which were then reconstructed to model the performance using the Vicon Workstation software.

Vertical ground reaction forces were collected using a force plate (AMTI OR6-5-2000, SGA-6 amplifier, Watertown MA). Ground reaction force data was sampled at 1000 Hz and synchronized with the Vicon motion analysis system. Ground reaction force data were filtered using a low-pass Butterworth digital filter.

Ankle dorsiflexion range of motion was measured with a standard 8-inch (20.32 cm) Universal goniometer (Zimmer Ltd, Blackpool, UK) prior to jumping. The goniometer consisted of two overlapping clear disks measuring 360°, each with a total length of 30.5 cm (12 in). One disk was graduated in degrees, with the other having a reference line across the diameter extending to the moving arm (Rome and Cowieson, 1996). Rome and Cowieson reported the mean standard deviation to be between ± 2.4° and ± 2.8° on different occasions for the universal goniometer. In order to assess the angle of tibia in relation to vertical for the weight-bearing measurement of dorsiflexion, a standard bubble inclinometer was used. The study by Rome and Cowieson found the mean standard deviation for the fluid goniometer to be between ± 2.4° and ± 3.4°.

A thin yoga mat (2' x 6') was be placed over the force plate to increase the friction of the surface on the feet of the subject. Subjects stepped from a box and descended to the floor, landing on and immediately jumping from a force plate. For the selection of the height of the box for the drop jumps, literature was varied. Caulfield and associates (2004) used a box height of 40 cm (15.7 in) to analyze ankle-muscle activation patterns during drop jump landings. Fagenbaum and Darling (2003) had subjects perform drop jumps from two boxes, one of 25.4 cm (10 in) and 50.8 cm (20 in) to examine landing strategies between males and females. Ford, Myer, and Hewett (2003) conducted a similar study, using a box height of 31 cm (12 in.) for their study on the relationship between knee valgus motion and sex during drop jumps. Kernozek and associates (2005) used a 60 cm (23.6 in) box for another study on gender differences in drop landings. Smith, Sizer, and James (2009) used a 50 cm (19.6 in) raised platform to study the relationship between fatigue and frontal plane knee motion between genders during a drop jump. This study utilized a box height of 18 in (45.7 cm), similar to the one used by the Smith, Sizer, and James study. This height also represented a common height of a commercially available plyometric box used in a training setting.

Procedures

Static and dynamic calibration of the Vicon System was conducted each testing day prior to subject arrival, according to the procedures outlined in the Vicon Manual (Tebbutt, Wood, & King, 2005). Briefly, for the static calibration, a T-Frame composed of two metal rods placed at 90° from each other was placed on the desired force plate origin. Reflective markers of fixed location on the T-Frame are recorded by the Vicon cameras, calibrating the recording volume with a common orientation. For dynamic calibration, a calibration 'wand' provided by the manufacturers was waved through the entire recording volume, and its position recorded simultaneously by all 10 cameras. This allowed for the position of each camera relative to each other to be determined. Viewing the dynamic calibration recording allowed the investigator to ensure that there was sufficient overlap of the recording space between cameras (Tebbutt et al.). Performing these calibration procedures also ensured that extraneous reflective surfaces which might be identified by the system as markers were identified and removed from the recording space.

Before participation in the study, athletes were approached by the Monfort Human Performance Lab director. General information regarding the nature of the study and data collection procedures were presented verbally to the athletes and the consent forms were distributed. Before any data are collected, the nature of the study and the procedures were again explained to the subjects. Any questions that the athletes still had were answered at that time.

The day of data collection, the subjects wore tight-fitting shorts in order to facilitate good data collection by the infrared camera system. Appropriate shorts were provided by the investigators to athletes who did not have their own. The athletes were allowed to wear footwear and t-shirts for the warm-up; however, they were required to be barefoot and shirtless for the actual jumping portion of the study. Various studies on footwear allude to altered mechanics while wearing shoes. Several studies that examined landing kinematics had their participants barefoot (Caulfield et al.; Smith et al., 2000), while several other studies had their subjects wear shoes (Fagenbaum & Darling, 2003; Kernozek et al., 2005). Brizuela, Ferrandis, and Garcia-Belenguer (1997) showed that wearing basketball shoes can reduce ankle inversion range of motion, which could alter the natural ankle range of motion during our testing.

Before testing, the birthdate, height and weight were recorded. The subject rode on a cycle ergometer at a self-selected pace and resistance for five minutes. The subjects were sweating by the end of the cycling period, as determined by the researchers. An additional five minutes was provided for the subjects to perform warm-up activities as desired to prepare to jump maximally.

Measurement of ankle range of motion was conducted utilizing a non weight-bearing and weight-bearing position. In one method, the subject assumed a standing, split-leg lunge position (Bennell, Talbot, Wajswelner, Techovanich, & Kelly, 1998). The athlete was instructed to bend at the knee and ankle using the forward leg, leaning as far forward as possible without allowing the heel to come off from the ground. At this position, a bubble inclinometer was placed on the shin to measure the angle of the shin from vertical. This procedure was repeated two times on each leg. The weight-bearing lunge measurement has been shown to be a reliable indicator of dorsiflexion range of motion (Hoch & McKeon, 2011; O'Shea & Grafton, 2013). For the second method, the athlete was seated on a table with his legs bent at the knee and dangling from the table (Norkin & White, 2003). The investigator manually bent the subject's foot toward his shin, with the talus fixed at neutral, causing dorsiflexion at the ankle. At the end-point, a plastic goniometer was used to measure the angle at the ankle. This procedure was performed twice on each leg. Before testing, the investigator performed more than 50 measurements of both weight-bearing and non weight-bearing dorsiflexion with a qualified clinician in order to become comfortable with the testing procedures. Intratester reliability is reported in the results section. A reliability value of 0.7 or higher indicated a good reliability for intratester dorsiflexion measurement (Elveru, Rothstein & Lamb, 1988).

Following the dorsiflexion measurements, the athlete was instrumented with reflective markers to enable data recording by the motion analysis system. Fifty-two retroreflective spherical markers (9 mm diameter) were secured to the skin surface using double-sided tape. Markers were positioned on both the left and right sides at the following anatomical locations, in accordance with the Figure 1 (Tebbutt, Wood, & King, 2005).

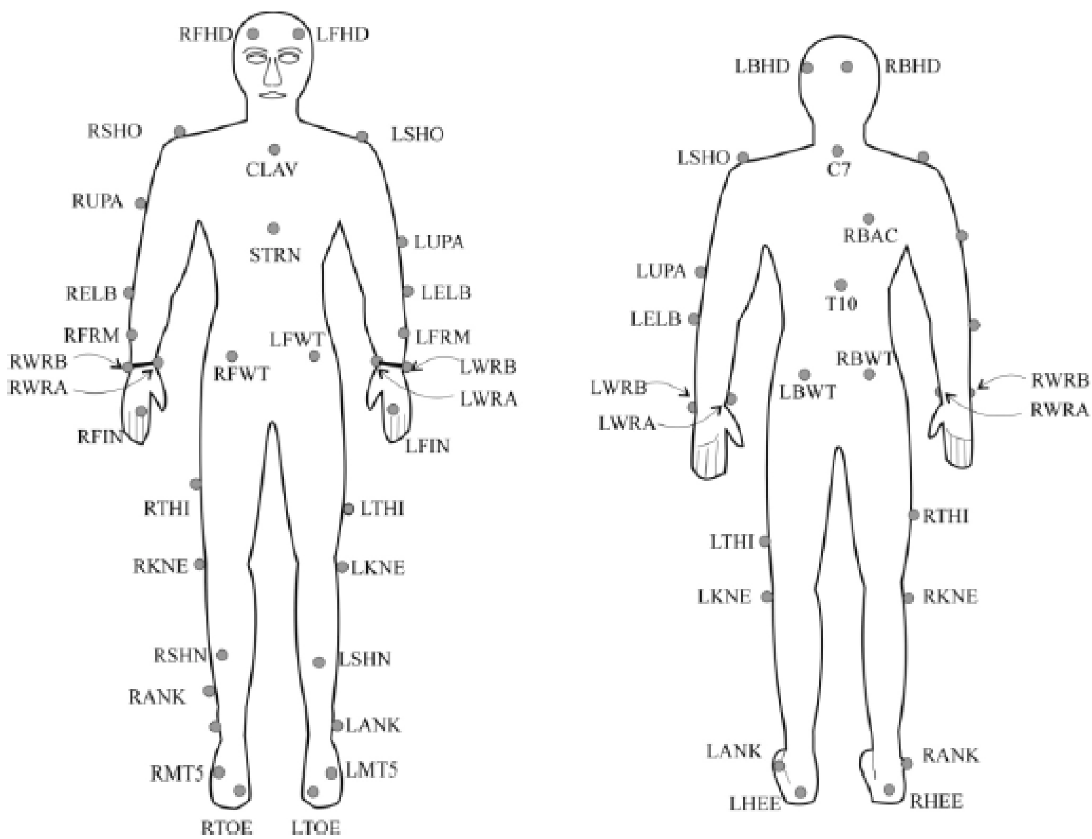

Figure 1: Vicon Marker Placement (Tebbutt et al.)

To obtain initial position information, the subject stood in the camera recording area with arms outstretched sideward and legs spread slightly (‘T-pose’). The computer made an initial recording of the markers in this reference stance position. Static calibration was conducted for each subject according to the procedures described in the Vicon manual (Tebbutt et al.). Static calibration allowed for the recording of individual anatomical alignment, as well as aligned the participant with the global coordinate system.

Next, the subject was instructed on the land-and-jump task. An investigator demonstrated the movement and then the subject performed up to five practice trials. The land-and-jump task began with the subject standing on an 18 inch (45.7 cm) platform. The subject stepped from the platform and descended in an upright position toward the floor. Upon landing on both feet, he bent his legs and immediately jumped upwards from the floor as high as possible. The subject returned to land on both feet on the force plate following the jump.

Athletes performed three recorded trials of maximal effort. They had at least 30 sec of rest between each attempt, and took more time if necessary. Verbal encouragement was given to ensure maximal effort on every jump. If they did not feel like they performed a maximal attempt, they were allowed an additional attempt. Following the final trial, the subject was allowed to view his trials on the computer screen. Finally, the reflective markers were removed and the subject’s participation was complete.

During the experiment, values were obtained for the relative orientation of the foot and ankle in the x, y and z-axes. These values corresponded to the nature of movement at the aforementioned joints, whether in the sagittal, frontal or transverse plane. In order to examine ankle dorsiflexion versus plantarflexion in the x-axis, the Vicon system measured the angle between the sagittal axis of the shank and the foot. A positive number corresponded to dorsiflexion. When looking internal versus external rotation of the foot-ankle complex in the y-axis, an angle between the foot vector and the sagittal axis of the skank was projected into the foot transverse plane. A positive value corresponded to internal rotation at the foot-ankle complex. When examining the knee, the Vicon system provided information about the orientation of the joint in the sagittal and frontal planes. In order to provide feedback on the extension versus flexion of the knee, a sagittal shank axis was projected into the plane perpendicular to the knee flexion axis. Knee flexion was the angle in the sagittal plane between this projection and the sagittal thigh axis. In this case, a positive value corresponded to a flexed knee. When looking at the varus and valgus alignment of the knee, the Vicon system measured in the plane of the knee flexion axis and the ankle center. The angle created by the plane was between the long axis of the shank and the long axis of the thigh. A positive value corresponded to a varus alignment.

Data Analysis

Ankle dorsiflexion and knee angles in the sagittal and frontal planes were determined at initial ground contact (IC) and at the point of maximal knee flexion in the landing portion of the task (MKF) (Smith, Sizer, & James, 2009). Knee abduction/adduction position were reported as a difference from each subject's initial position recorded in the static trial (Nagano, Sakagami, Ida, Akai, & Fukubayashi, 2008).

Initial ground contact was defined as the time ground reaction forces exceeded 5 N during the landing from the jump (DiStefano et al., 2008).

All statistical analyses were performed using SPSS® for Windows® version 21.0. Descriptive statistics were calculated for age, height, mass, weight-bearing and non weight-bearing ankle dorsiflexion range of motion, weight-bearing ankle dorsiflexion range of motion at initial foot contact and maximum knee flexion, knee angles in the sagittal and frontal planes during initial contact and maximum knee flexion, and overall jump height. Correlational analyses were undertaken to determine the magnitude and direction of relationships among ankle and knee variables. Correlational analyses assumed linearity, normality, and homoscedasticity of the data. These assumptions were tested to ensure we had valid data for conducting a correlational analysis. The study examined the relationship between weight-bearing and non weight-bearing dorsiflexion range of motion and sagittal and frontal knee angles at initial ground contact and maximal knee flexion. Pearson correlation coefficients were computed between weight-bearing and non weight-bearing ankle dorsiflexion angles, and knee kinematic variables, yielding a total of 30 correlations. Statistical significance of correlations was determined using two-tailed t-tests, with an alpha level of 0.05. To test for differences in the relationships found between weight-bearing and non weight-bearing ankle dorsiflexion angles and the knee kinematic variables, Fischer z-tests were used (Elvin, Elvin, & Arnoczky, 2007).

Chapter 4

Results

Dorsiflexion Range of Motion

Thirteen male subjects (age = 23 ± 2.35 y, height = 181.4 ± 5.68 cm, mass = 84.5 ± 17.2 kg) proficient in landing and jumping techniques and free from lower limb injury participated in the study.

Range of motion measurements were all collected by the same investigator and showed a high degree of reliability (RL: ICC = 0.97, TEM = 1.29; LL: ICC = 0.98, TEM = 1.21; RS: ICC = 0.99, TEM = 0.53; LS: ICC = 0.99, TEM = 0.48). The intraclass correlation score demonstrates excellent correlation of measurements (O'Shea & Grafton, 2013). Data from all the ankle measurement conditions were analyzed for reliability using Chronbach's Alpha, revealing high internal consistency (r = 0.96-0.98) across trials. One-way ANOVAs conducted on the trials data demonstrated no significant differences across trials for any dorsiflexion measurement ($p > 0.05$).

The data were then checked for normality using the Shapiro-Wilk test of normality. All values are presented in Table 1. All data were normally distributed ($p > 0.05$) other than a statistical outlier that was found for average right seated dorsiflexion range of motion condition for subject 10. Based on these results, the data were averaged across both trials to get the mean score for all dorsiflexion range of motion variables for subject 10 (Henry, 1950; Henry, 1967; Kroll, 1967).

Table 1. Shapiro-Wilk Normality for Ankle Dorsiflexion Measurements

Variable		Sig (> 0.05)
Weight-bearing dorsiflexion range of motion (deg)		
	Right leg	0.90
	Left leg	0.93
Non weight-bearing dorsiflexion range of motion (deg)		
	Right leg	0.47
	Left leg	0.24

Once reliability and normality were established, descriptive statistics were conducted on the ankle range of motion conditions. Descriptive statistics for non weight-bearing and weight-bearing dorsiflexion conditions are presented in Table 2.

Table 2. Descriptive Statistics for Ankle Dorsiflexion Measurements

Variable		Mean $\pm$ SD	95% CI
Weight bearing dorsiflexion range of motion (deg)			
	Right leg	41.4 $\pm$ 5.5	38.0-44.7
	Left leg	41.5 $\pm$ 5.0	38.5-44.5
Non weight-bearing dorsiflexion range of motion (deg)			
	Right leg	7.9 $\pm$ 5.2	4.8-11.0
	Left leg	7.6 $\pm$ 4.2	5.1-10.1

Jumping Kinematics

Chronbach's Alpha was calculated for all three trials of knee and ankle sagittal and frontal variables, as well the percentage of the jump range of motion where maximal knee flexion occurred, vertical velocity, flight time, contact time, and jump height. Chronbach's Alpha revealed that all variables tested were internally consistent across trials (r = 0.70-0.99). One-way ANOVA results across trials showed that the left and right knee at initial contact in the sagittal plane were found to be statistically different ($p < 0.05$). The data were averaged across all three trials because of the high degree of reliability revealed by the Chronbach's Alpha test.

All average ankle and knee conditions during jumping were tested for normality using the Shapiro-Wilk test ($p > 0.05$). A significant outlier was found with the vertical velocity and jump height for subject 13. Therefore, the data for subject 13 were averaged using trial 1 and 2 to create a new trial 3 because the jump performance on trial 3 was most likely an anomaly in the study.

Descriptive statistics were calculated by averaging the three trials of data for all weight-bearing dorsiflexion range of motion conditions, knee angles in the frontal and sagittal plane at initial contact and maximal knee flexion, as well as jump height. Results are presented in Table 3.

Table 3. Average Ankle and Knee Measurements at Initial Contact and Maximal Knee Flexion, Jump Height

Variable	Mean $\pm$ SD
Weight-bearing dorsiflexion range of motion (deg)	
Right ankle, initial contact, sagittal	-20.56 $\pm$ 4.6
Right ankle, maximal knee flexion, sagittal	28.92 $\pm$ 5.87
Left ankle, initial contact, sagittal	-17.29 $\pm$ 5.32
Left ankle, maximal knee flexion, sagittal	30.91 $\pm$ 8.35
Knee orientation (deg)	
Right knee, initial contact, sagittal	26.99 $\pm$ 8.65
Right knee, initial contact, frontal	6.44 $\pm$ 4.94
Right knee, maximal knee flexion, sagittal	93.44 $\pm$ 20.59
Right knee, maximal knee flexion, frontal	18.12 $\pm$ 16.29
Left knee, initial contact, sagittal	29.51 $\pm$ 8.37
Left knee, initial contact, frontal	4.46 $\pm$ 8.2
Left knee, maximal knee flexion, sagittal	93.77 $\pm$ 20.00
Left knee, maximal knee flexion, frontal	11.47 $\pm$ 21.62
Average Flight Time (sec)	0.48 $\pm$ 0.08

Ankle Dorsiflexion Range of Motion and Jumping Kinematics

Simple Pearson correlations were conducted on all average dorsiflexion measurement conditions. Pearson correlations were used to determine the relationships between the measured dorsiflexion range of motion conditions (weight-bearing and non weight-bearing) and the various ankle and knee orientation data collected during the study. Relationships were examined between ankle dorsiflexion range of motion measured in a non weight-bearing and weight-bearing manner and ankle dorsiflexion alignment in the sagittal plane at initial contact and maximal knee flexion, as well as knee alignment in the frontal plane at initial contact and maximal knee flexion in a landing and jumping task. Correlation coefficients and probability statistics for the non weight-bearing and weight-bearing dorsiflexion range of motion assessments are presented in Table 4.

Table 4. Correlations for Weight-Bearing and Non Weight-Bearing Ankle Dorsiflexion Range of Motion and Jumping Kinematics

Criterion Variable	*r*	*P* Value
Non Weight-Bearing Dorsiflexion Range of Motion		
Left ankle dorsiflexion at initial contact	-0.61	0.03[a]
Left ankle dorsiflexion at maximal knee flexion	0.48	0.10
Left knee flexion at initial contact	0.19	0.53
Left knee flexion and maximal knee flexion	0.39	0.19
Left knee valgus at initial contact	0.28	0.36
Left knee valgus at maximal knee flexion	0.16	0.60
Right ankle dorsiflexion at initial contact	0.44	0.13
Right ankle dorsiflexion at maximal knee flexion	0.75	0.003[a]
Right knee flexion at initial contact	0.32	0.29
Right knee flexion at maximal knee flexion	0.34	0.25
Right knee valgus at initial contact	0.17	0.58
Right knee valgus at maximal knee flexion	-0.06	0.85
Weight-Bearing Dorsiflexion Range of Motion		
Left ankle dorsiflexion at initial contact	-0.60	0.03[a]
Left ankle dorsiflexion at maximal knee flexion	0.45	0.12
Left knee flexion at initial contact	0.28	0.36
Left knee flexion and maximal knee flexion	0.44	0.13
Left knee valgus at initial contact	0.31	0.31
Left knee valgus at maximal knee flexion	0.22	0.48

Criterion Variable	*r*	*P* Value
Weight-Bearing Dorsiflexion Range of Motion		
Right knee flexion at initial contact	0.52	0.07
Right knee flexion at maximal knee flexion	0.44	0.13
Right knee valgus at initial contact	0.62	0.03[a]
Right knee valgus at maximal knee flexion	0.22	0.46

[a] Two-Tailed

Significant correlations were seen between the non weight-bearing dorsiflexion measurement and ankle dorsiflexion range of motion at initial contact on the left side (r = -0.61, $p < 0.05$) and ankle dorsiflexion range of motion at maximal knee flexion on the right side ($r = 0.75$, $p < 0.05$), demonstrating that increased mobility in a non weight-bearing measurement correlated with greater ankle range of motion in landing. Correlations were also noted for weight-bearing dorsiflexion measurement and ankle dorsiflexion range of motion at initial contact on the left side ($r = -0.60$, $p = < 0.05$) as well as ankle dorsiflexion range of motion at maximal knee flexion on the right side (r = 0.68, $p < 0.05$), showing that active range of motion measurements were also related to available range of motion during the dynamic task. In addition, there was a correlation between weight-bearing dorsiflexion measurement and knee valgus at initial contact on the right side ($r = 0.62$, $p < 0.05$), showing that as active dorsiflexion increased, the negative value of the knee alignment in the frontal plane increased, leading to a positive correlation.

There was no statistically significant relationship noted between non weight-bearing dorsiflexion measurements and knee valgus at initial contact on the left ($r = 0.28$, $p < 0.05$) or right sides ($r = 0.17$, $p > 0.05$), as well as at maximal knee flexion on the left ($r = 0.16$, $p > 0.05$) or right sides ($r = -0.06$, $p > 0.05$). When examining weight-bearing dorsiflexion range of motion, there was no statistically significant relationship between weight-bearing measurement and knee valgus at initial contact on the left side ($r = 0.31$, $p < 0.05$), as well as knee valgus at maximal knee flexion on the left ($r = 0.22$, $p < 0.05$) or right sides ($r = 0.22$, $p < 0.05$), while the relationship seen between weight-bearing dorsiflexion range of motion and knee alignment at initial contact or the right side represented a varus alignment.

Once Pearson correlations were calculated, Fisher z-tests were conducted to test for differences in the relationships found between weight-bearing and non weight-bearing ankle dorsiflexion measurements and the knee kinematic variables. Results are presented in Table 5. There were no significant differences between the conditions of weight-bearing dorsiflexion and non weight-bearing dorsiflexion range of motion measurements and jumping kinematics for any condition tested.

Table 5. Fisher Z Tests for Dorsiflexion Range of Motion and Knee Kinematics

Criterion Variable	*z*	*p* Value[a]
Dorsiflexion Condition and Jump Kinematic Variable		
Left ankle dorsiflexion at initial contact	0.02	0.98
Left ankle dorsiflexion at maximal knee flexion	0.09	0.93
Left knee valgus at initial contact	-0.07	0.94
Left knee valgus at maximal knee flexion	-0.13	0.90
Right ankle dorsiflexion at initial contact	-0.21	0.83
Right ankle dorsiflexion at maximal knee flexion	0.04	0.73
Right knee valgus at initial contact	-1.23	0.22
Right knee valgus at maximal knee flexion	-0.64	0.52

Chapter 5

Discussion and Conclusions

Early identification of risk factors associated with traumatic injury incidence is imperative to the health and safety of individuals participating in athletic endeavors. Epidemiologic studies examining the incidence of ACL injuries among adolescents have found that the incidence of ACL injury has sharply increased in the past two decades, particularly in athletes under the age of 18 (Hewett et al., 2005). There is growing evidence that individuals who experience ACL injuries are at risk for long-term health issues, including the development of degenerative arthritis of the knee (LaBella, Hennrikus & Hewett, 2014). While appropriate screening and treatment programs continue to be developed in order to combat this growing epidemic, it is just as important to develop standardized, repeatable protocols to identify individuals at risk of injury. New and more focused evaluation procedures will allow researchers and practitioners to detect relevant factors associated with increased knee valgus at initial contact in a dynamic task, thus identifying one of the ACL injury risk factors.

The goal of this study was to identify an association between weight-bearing and non weight-bearing ankle dorsiflexion range of motion and knee kinematics in a dynamic land-and-jump task in male collegiate athletes. The results indicated no statistically significant relationships between measurements of both non weight-bearing and weight-bearing dorsiflexion range of motion and knee-flexion displacement at maximal knee flexion. This relationship is contrary with other literature that has examined the relationship between these variables (Fong et al., 2011; Hagins et al., 2007; Kernozek, Torry, Van Hoof & Cowley, 2005). However, Fong and colleagues utilized a passive measure of dorsiflexion similar to what was utilized in this study and also found no statistically significant relationship. They hypothesized this was due to the removal of the impact of the gastrocnemius in the force attenuation experienced during a landing and jumping task within the range of motion experienced during the task. Since no measurement of dorsiflexion with the knee at 0° of flexion was included in the study, it is impossible to infer whether a similar relationship would have been observed in our study.

Similarly when examining the correlation between ankle range of motion conditions and knee flexion at initial contact of the jump, no relationships were found to exist between measured dorsiflexion range of motion and knee flexion. The ankle-foot complex begins the interaction of the body to the ground and has tremendous impact over the execution of the following task from a biomechanical perspective. Exposure of the knee to three dimensional forces during landing and twisting without proper dynamic stabilization by the knee extensors, primarily the hamstrings and gastrocnemius, can increase the torques and forces experienced in the joint (Hewett et al., 2005). By allowing the joint to move through an optimal range of motion, the ankle dictates the balance of muscular interaction in the landing process in the sagittal plane, ensuring a balance of recruitment rather than overrecuitment of anterior musculature. Correlations were not seen at a statistically significant level between both non weight-bearing and weight-bearing dorsiflexion and knee flexion conditions (maximal flexion and initial contact) in this study. This could be due to the condition of land-and-jump task. Edwards and colleagues (2012) found that individuals engaging in a stop- jump task experienced reduced knee flexion at initial contact on their dominant limb, suggesting that limiting knee flexion during a jump can be a strategy for improved performance.

Landing with decreased knee flexion can increase the forces experienced at the ACL (Yu, Lin, & Garrett, 2006), but there is no evidence to suggest that decreased knee flexion angles lead to increased knee valgus occurrence.

A significant correlation between weight-bearing dorsiflexion range of motion and knee alignment in the frontal plane was seen on the right ($r = 0.62$, $p < 0.05$) side of the body only. The reason for statistical significance of only one side of the body could be due to the various landing strategies adopted by the subject, who was not instructed on how to land from the box, but were rather told to land and jump off the force plate. Landing strategies can be significantly impacted by variables such as footfall pattern (Elvin, Elvin, Arnoczky, & Torry, 2007; Fong et al., 2011; Kernozek, Torry, Van Hoof & Cowley, 2005; Steele, & Milburn 1988; Zhang et al., 2000) and landing surface stiffness (Devita and Skelly, 1992). This same relationship was not observed during non weight-bearing dorsiflexion range of motion. Measurements of weight-bearing dorsiflexion range of motion have been shown to be reliable assessing the kinematics of the ankle joint. This information is important to practitioners and medical personnel (Chisholm et al., 2012). Establishing a relationship between a weight-bearing lunge measurement and frontal plane knee kinematics is the first step in bringing validity to the measurements as a means of identifying at risk behavior for ACL injury incidence.

The association between weight-bearing dorsiflexion range of motion and knee valgus at initial contact on the right side of the body but not the left leaves some important questions, especially considering the fact that the measured dorsiflexion range of motion was almost identical between sides in the subjects (41.4 ± 5.5 right; 41.5 ± 5.0 left). Edwards and colleagues (2012) examined the kinematics and kinetics of the lower limbs of a stop-jump task with 16 male athletes and found that the participants' dominant lower limb displayed significantly less knee flexion at initial contact and greater knee external rotation during the entire landing phase. This could suggest that there is a biomechanical difference in how someone lands, even when their measured dorsiflexion range of motion is similar. Niu and researchers (2011) examined the biomechanical differences of limbs during a drop landing maneuver, determining that the non-dominant ankle demonstrates an altered landing strategy when compared to the dominant limb. Although our jumping task is different than what was tested in these studies, it could explain the discrepancy seen between limbs. Limb dominance was not assessed in this study so it would be impossible to examine the difference in landing strategies between dominant and non-dominant limbs.

There was no statistically significant relationship observed between weight-bearing ankle range of motion and knee alignment in the frontal plane at maximal knee flexion. While there was a weak association, it was not statistically significant, in contrast to our initial hypothesis. The lack of a statistical relationship between measured ankle dorsiflexion and frontal plane knee kinematics could be due to a lack of stratification between subjects' measured dorsiflexion measurement. The range of weight-bearing dorsiflexion range of motion on the right side was 21.5° (31°-52.5°), a difference of 41% between low and high performers. Potentially stratifying the groups, or placing individuals in high and low clusters for dorsiflexion range of motion could have changed the relationship between ankle kinematics and knee displacement in the frontal plane at initial contact and maximal knee flexion in the land-and-jump task by identifying whether correlations are seen in extreme situations of limited or excessive dorsiflexion. Bell and colleagues (2008) used a stratification process to examine if there was a statistically significant relationship between individuals who did or did not exhibit medial knee displacement in a squat pattern and passive dorsiflexion range of motion, measured with the knee bent. Although groups were not stratified based on ankle range of motion characteristics, it was found there was a statistically significant difference between passive ankle range of motion between the control group and the medial knee displacement cohort. Whiting and colleagues (2012) stratified a group of men based on passive ankle dorsiflexion stiffness and passive weight-bearing dorsiflexion range of motion. The researchers grouped the men based off their level of dorsiflexion stiffness to determine how passive ankle dorsiflexion stiffness affected ankle mechanics during single limb drop landings at different vertical descent velocities. Stratifying the cohort into low and high performers based on measured dorsiflexion range of motion could potentially increase the statistical significance of the observed relationships between dorsiflexion and knee kinematics during a land-and-jump task. A small study population could have potentially limited the statistical significance of the correlations observed in the study. Increasing sample size is a commonly accepted method for improving statistical power and precision (Maxwell, Kelley, & Rausch, 2008).

The sample cohort could have accounted for the lack of statistical significance in supporting our hypothesis. While the population was made up of current or former athletes at the collegiate level, several of the athletes were collegiate cyclists. While there are a great deal of athletic qualities necessary to be successful at the sport of cycling, none involves landing and jumping tasks in order to be successful. The nature of the procedure was most likely novel to these athletes, and their execution may have been compromised by their lack of understanding of how to execute the land and jump maneuver. Future studies should be encouraged to use athletes who are familiar with executing a land and jump task, such as volleyball players or track and field jumpers. Alkjaer and colleagues (2013) found that drop jump performance improved over a 4 week learning, showing effects of motor leaning. Athletes such as volleyball, basketball and track and field athletes who have been participating in land-and-jump activities for their sport would most likely exhibit better performance due to factors such as motor learning, improved biomechanics and altered neuromuscular recruitment strategies (Alkjaer et al., 2013).

Additionally, the nature of the dorsiflexion measurement (weight-bearing and non weight-bearing dorsiflexion with no measure at 0°) and knee position could have altered the results of our study. Fong and colleagues (2011) included a measurement of dorsiflexion at 0° knee flexion in order to assess the extensibility of both the gastrocnemius and soleus in the land and jump task. Our study did not include a similar measurement, although Fong and researchers believe the extended-knee position may provide a better indication of range of motion restriction placed on dorsiflexion displacement during a landing task because of the nature of the gastrocnemius as a two-joint muscle and its impact on the range of motion of the ankle up to 30° of knee flexion.

Landing height may have had an impact on the observed relationships seen in the study. Numerous studies have investigated various box heights and their influence on ground reaction forces (Caufield et al. 2004; Ford, Myer & Hewett, 2004; Fagenbaum & Darling, 2004; Kernozek et al., 2004; Smith, Sizer & James, 2009), with one assessing the impact of various box heights on landing strategies (Niu et al., 2011). As box height increases, vertical ground reaction forces increase, thus changing the landing strategies adopted during a land-and-jump task. Future studies may choose to look at whether a landing and jump task from different box heights impacts the observed relationship between dorsiflexion range of motion and knee kinematics.

Our study was able to demonstrate a relationship between weight-bearing dorsiflexion range of motion and knee alignment in the frontal plane at initial contact on the right side in a land-and-jump task. The results support and extend previous research that looked at similar land-and-jump tasks (Fong et al., 2011), and are applicable to a male cohort. While the study does show a correlation between limited dorsiflexion range of motion and knee valgus at initial contact, it is not enough to state that restricted dorsiflexion range of motion will lead definitively to an ACL injury, nor that increased dorsiflexion range of motion will reduce the risk for ACL injury.

While beyond the scope of the current study, future studies might be interested in examining the role of fatigue in the relationship between dorsiflexion range of motion and knee kinematics. Melnyk and Gollhofer (2007) looked at the role of submaximal fatigue exercises of the hamstring and their effect on anterior tibial translation. The hamstrings play a significant role in the stability of the knee joint and minimizing the effect of sheer forces on the ACL. The test had 15 subjects standing with their knees flexed at a 30˚ angle and measured tibial translation while applying sheering force. The study found that after inducing hamstring fatigue, reflexive response to anterior tibial translation decreased, increasing the risk for ACL tear. Fatigue could reasonably have an effect on the relationship between dorsiflexion range of motion and knee alignment in the frontal plane, and it would be interesting to create a study that looked at multiple response jumps and knee alignment, similar to the fatigue experienced in an athletic competition.

Additional extrinsic risk factors, such as hamstring-to-quadriceps strength ratio and neuromuscular coordination can all contribute to injury incidence. Prospective studies should be encouraged to evaluate the ability of dorsiflexion range of motion measures to discern knee kinematics in dynamic tasks, as well as examine the effects of protocols for increasing ankle dorsiflexion range of motion on ACL injury incidence.

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