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Susceptibility to Ankle Sprain Injury between Dominant and Non-Dominant Leg During Jump Landings

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Susceptibility to Ankle Sprain Injury between Dominant and Non-Dominant Leg During Jump Landings

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education
at the University of Kentucky

By

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Lexington, Kentucky

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Lexington, Kentucky

2019

ABSTRACT OF THESIS

Susceptibility to Ankle Sprain Injury between Dominant and Non-Dominant Leg During Jump Landings

Ankle sprains are one of the most common injuries within athletics in the United States with approximately one-million student athletes experiencing ankle sprains each year. Studies argue excessive or rapid ankle inversion occurring from jump landings may cause ankle sprains. Also, the effect of limb dominance on risk of ankle sprain is not well documented.

The aim of this study was to determine if there is an affect of leg dominance on landing mechanism of the ankle joint that predisposes either ankle joint to greater risk of ankle sprain.

Twelve recreationally active subjects were recruited and completed four maximal vertical jumps. Ground reaction force, marker position data and maximal vertical jump height were collected using two Bertec Force plates, a 10-camera motion capture system, and a Vertec Vertical Jump Trainer, respectively. Cortex and Visual3D software programs were used to process the motion capture data and to calculate peak vertical ground reaction forces(vGRF), loading rate, and ankle joint moments. There were no statistically significant differences in ankle joint moment or loading rate between limbs, but peak vGRF were significantly higher ($p<.05$) in the non-dominant ankle. The results suggest the non-dominant ankle displays higher injury potential, as the non-dominant leg accumulates a larger peak landing force.

KEYWORDS: Ground Reaction Forces, Loading Rate, Joint Moment, Leg Dominance

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CHAPTER 1. INTRODUCTION:

1.1 Introduction

Ankle sprains are one of the most common injuries to occur in athletics, especially in sports such as basketball and soccer (McGuine & Keene, 2006). In the United States approximately 28,000 ankle sprains occur daily (Kaminsk et al., 2013). The incidence of ankle sprains will likely increase as a larger portion of the youth population become involved with sports and athletics. Suggested by McGuine and Keene (2006), it is the sudden deceleration or cutting maneuvers that occurs in these sports that leads to a high frequency of ankle sprains. However, many studies argue that excessive or rapid inversion leading to ankle sprains more so occur from jump landings (Koshino et al., 2016; Brown et al., 2004). Regardless, an ankle sprain injury can lead to a lengthy absence of sport participation, excessive medical expenses, and potential to develop disability (Beynnon et al., 2008).

A secondary condition associated with ankle sprains is chronic or functional ankle instability. Up to 73% of individuals with an ankle sprain may suffer additional sprains and experience symptoms of functional ankle instability such as a frequent feeling of the ankle “giving way” (Brown et al., 2004). Koshino et al. (2016) remarks that functional ankle instability can be characterized by individuals obtaining recurring ankle sprains, and a subjective sense of ankle instability, yet the direct cause of functional ankle instability has yet to be described (Brown et al., 2004). Previous work suggests that alterations in proprioception, strength deficits, nerve damage, and anatomical instability as the main contributors to functional ankle instability (Brown et al., 2004).

Techniques such as proprioception and balance training have been studied as ways to help rehabilitate and possibly prevent ankle sprains (Eils & Rosenbaum, 2001; McGuine & Keene, 2006; Wang et al., 2008). Assessing the ankle joint mechanics and musculature during commonly used movements in athletics such as jump landings may contribute to a better understanding of ankle sprain injury mechanisms. For example, multiple studies use activities such as drop jumps, hanging drops, and various balancing and hopping tasks that are used in injury assessment protocols, and to determine the muscle activity and resultant kinetic and kinematic variables surrounding the ankle joint musculature (Aizawa et al., 2018; Brown et al., 2004; Eils and Rosenbaum., 2001; Koshino et al., 2016; Kovacs et al., 1999; McGuine and Keene., 2006; McPherson et al., 2016).

Although there appears to be no remarkable difference in injury prevalence of dominant or non-dominant lower extremities in sport (Beynnon et al., 2008; Surve et al., 1994; Van der Harst et al., 2007; Weinhandl et al., 2017; Wikstrom et al., 2006) little research has been done concerning limb-dominance specifically regarding ankle injury in jump landings. The current study will play an important role in determining differences in landing strategies that may lead to ankle sprains, and aid in understanding methods of preventing ankle injury. This study is significant in that it aims to determine what occurs biomechanically at the ankle joint during jump landings, in an effort to understand the mechanical factors that may lead to ankle sprain injury. Further understanding and knowledge of these mechanisms may help reduce the number of ankle injuries and prevalence of functional ankle instability.

1.2 Objectives

The purpose of this study was to compare biomechanical responses of the ankle joint to jump landing, between the dominant and non-dominant legs that can predispose athletes to lateral ankle sprains. The study objectives include:

- Compare peak vertical ground reaction forces following initial contact between dominant and non-dominant legs.
- Compare vertical ground reaction force loading rates between the dominant and non-dominant legs.
- Compare differences in frontal plane ankle joint moments between the dominant and non-dominant legs.

1.3 Organization of Thesis

Chapter one contains the introduction and provides background information from relevant research. Chapter two includes a literature review that details relevant studies and topics such as loading rate, and injury prevention methods. Chapter three describes the methodology utilized in collecting and analyzing data. Chapter four includes the results of the study, while chapter five contains a discussion regarding implications of the results, along with providing conclusions based on the results.

CHAPTER 2. LITERATURE REVIEW

2.1 Bilateral vs Unilateral Jump Landings

One of the factors that plays a potential role in ankle sprain injury during jumping is whether an individual lands unilaterally or bilaterally. Weinhandl et al. (2010) studied the effects between gender and unilateral versus bilateral landings, and corroborated multiple studies (Nagano et al., 2009; Pappas et al., 2007) indicating that a single leg landing introduces additional injury risk. At initial contact, a unilateral landing resulted in increased peak plantarflexion moment, and inversion at the ankle joint compared to bilateral landing (Weinhandl et al., 2010). Not only were there frontal plane movement increases in unilateral landings at the ankle, but the hip and knee both experienced higher peak extension and abduction moments, potentially putting the hip and knee at a higher risk of impact injury as well (Weinhandl et al., 2010). McPherson et al. (2016) studied unilateral versus bilateral countermovement jump landing and in assessing hip, knee, and ankle sagittal range of motion (ROM) did not find any differences in asymmetry between legs when landing unilaterally. When assessing bilateral landing however, the non-dominant leg experienced greater knee flexion and hip flexion at instant contact, while the dominant leg experienced higher knee and hip flexion excursion (McPherson et al., 2016).

A study was concerned with proprioceptive differences at the knee and ankle joints between obese and non-obese pre-pubescent aged males (Wang et al., 2008). In the study, 27 obese and 26 non-obese subjects performed two practice trials of identifying movement at the ankle using the custom-made kinesthesis testing device, and then completed six (three flexion-three extension, three dorsiflexion-three plantarflexion) random trials for the kinesthesis testing at both the knee and ankle, where subjects would determine the initiation of range of motion. Results of the study demonstrated that although knee extension and ankle movements showed no significant changes in proprioception to the control group, the obese group of subjects had significant deficits in knee flexion proprioception. These findings have implications relating to postural control of younger obese populations. This study is associated with a specific population, however various literature is concerned with proprioceptive capability and physical characteristics that can be a predisposition to experiencing recurrent ankle sprains. Similarly, athletes who have had ankle sprains in the past are more likely to obtain multiple, or recurring sprains (Brown et al., 2004; Koshino et al., 2016). This is, however, an arguable topic on what changes occur that predisposes the ankle to chronic injury.

Eils & Rosenbaum (2001), state that muscle weakness, proprioceptive deficits and loss of coordination, can occur following re-injury and lead to instability of the ankle. Previous work by Tyler et al. (2008) sought to determine the association between body mass index, previous ankle sprain history, and the risk of obtaining a recurrent non-contact ankle sprain. One hundred and fifty-two high school football players from four different teams were recruited and tested for this longitudinal study. Before each season, weight, height, prior ankle sprain, and use of ankle braces were recorded. During the study, 15 recurrent non-contact ankle sprains occurred within the study population. Players with previous ankle sprains ($p<0.001$) as well as higher body mass index ($p<0.05$) exhibited a higher incidence of undergoing a second ankle sprain. The study concluded that overweight players with a history of ankle sprains had a 19-times higher risk of non-contact ankle sprain re-occurrence, than a normal weight player with no previous ankle sprain. This study reveals the importance of finding prevention methods as athletes develop a much higher risk for ankle sprains and complications, from prior injury and other predispositions such as obesity.

Literature has utilized proprioceptive testing as an injury prevention technique in athletes. Eils and Rosenbaum (2001) aimed to examine the effects of a six-week multi-station proprioceptive exercise program that could be implemented along with regular training programs. Thirty subjects with age ranging from 14 to 47 were placed into either an experimental group or control group. The experimental group participated in the six-week program while the control group participated in the before and after testing procedures. Both groups completed testing procedures prior to and after the six-week experimental period including joint position sense, postural sway, and muscle reaction time tests. The exercise program involved 12 variations of single leg and double leg stance balancing, uneven walking, and resistance band holds utilizing exercise mats, a swinging platform, Biodex Isokinetic Dynamometer, ankle disc, exercise bands, air squab, wooden inversion-eversion boards, mini-trampoline, uneven walkway, and an aerobic step. Upon completion of the intervention, subjects within the experimental group demonstrated significant improvements in their joint position sense, postural sway, and muscle reaction time. These results are supportive of the use of proprioceptive training as a preventative measure to reduce the incidence of ankle sprains by improving reaction time and postural capabilities of the musculature surrounding the ankle.

In attempting to quantify functional ankle instability, other researchers are doing work with joint position sensing, and muscle reaction timing. Brown et al. (2004) studied subjects with and without functional ankle instability and aimed to determine differences in joint position sense, time to stabilization, and electromyography of the ankle musculature between the two groups during jump landings. No differences were found in joint position sense, where passive range of motion and foot angle reproduction methods were used. Using a functional forward vertical jump technique where subjects would land on the specified leg (stable or unstable), Brown et al. (2004) found that subjects with functional ankle instability presented a longer time to stabilization in the anterior-posterior plane, and a significantly lower mean EMG amplitude of the soleus in the initial 1000 ms following landing. This study again brings forth the importance of understanding what happens during sport movements such as jump landings, and how adjusting and understanding these movements plays a role in the ankle sprain dilemma.

One important way researchers can further observe sports-like jump landings is to look at differences of the foot position at landing. Koshino et al. (2016) hypothesized that landing with the foot in a 'toe-in' position could lead to a more compromised landing mechanics and lead to lateral ankle sprain. The Koshino et al. (2016) study examined the effects of a toe-in or toe-out position on the ankle inversion motion and moment during a single leg jump landing. Eighteen participants completed single leg jumps from a 30-cm high box, and performed three landing techniques; a natural landing, a toe-in landing, and a toe-out landing. Ankle inversion angle and angular velocity as well as external ankle inversion moment during the first 200ms following initial contact were compared between landing styles. Results showed that ankle inversion angle and angular velocity as well as ankle inversion moment were all highest during the toe-in landings. The study indicated large effect sizes between these ankle kinematic and kinetic differences, although there were no statistical differences in ground reaction forces between the three landing conditions. The key take away from the study is that the ankle joint undergoes abnormal mechanical loading when landing with an excessive toe-in position. Kovacs et al. (1999) also investigated foot placement when landing during drop jumps. The study was concerned with determining kinematics, kinetics, and muscle activity of the lower extremity when comparing a heel-to-toe landing, versus a forefoot landing mechanism. When utilizing a heel-to-toe position, the study participants exhibited a 3.4 times higher vertical ground reaction forces (vGRF) and a 3.8 times larger loading rate of force compared to the forefoot landing technique (Kovacs et al., 1999). In addition, the heel-to-toe technique was associated with a 23% decrease in plantarflexor muscle activity at the ankle, contributing to an increased vGRF impulse at landing (Kovacs et al., 1999). A similar study sought to assess drop jump landing techniques, particularly during parkour. Puddle and Maulder (2013) concluded that parkour landing techniques were safer than a traditional jump landing style by increasing time to peak vGRF, and decreasing peak vGRF, thus decreasing vGRF loading rates. When assessing differences between bilateral and unilateral landings, foot placement, and landing technique, leg dominance or symmetry was not considered.

2.2 Dominant Vs. Non-Dominant Landing Mechanics

A key attribute to many of the aforementioned studies is the assumption of bilateral symmetry, in that results can be accounted for equally between lower extremities. Schot et al. (1994) sought to determine potential error in this assumption, by completing a study concerned with lower extremity bilateral asymmetry and variability. Using hanging drop landings as a predetermined symmetrical activity, the study compared vGRF and joint moments between right and left legs. Study results indicated that asymmetry or mean differences between right and left were highest between vGRF, indicating that bilateral differences in lower extremity mechanics during a landing task exist and should be accounted for in future studies (Schot et al., 1994). While Schot et al. (1994) were concerned with uncovering lower extremity asymmetry, previous literature has found no significant difference in lower limb postural stability (Wikstrom et al., 2006) or ankle sprain prevalence as an effect of leg dominance, which can both be a natural cause or result of asymmetry (Woods et al., 2003; Beynnon et al., 2001). Despite this information, multiple analyses and studies show trends that the dominant ankle joint is more prone to injury, and is injured more often than the contralateral ankle joint (Ekstrand and Gillquist, 1983; Weinhandl et al., 2017; Yeung et al., 1994). In addition, a study by Niu et al. (2011) demonstrated that when landing from different heights, the dominant ankle joint displayed higher abduction and dorsiflexion angular velocities, while the non-dominant ankle showed higher muscle activity of the tibialis anterior, both pre and post-landing (Niu et al., 2011). This mechanical pattern supports the notion that the dominant ankle joint utilizes a mechanism that may be less effective in preventing ankle sprains during double legged jump landing. As jump landings are a high impact activity it is important of course to consider the entirety of the lower extremity in assessing injury potential, not only to the ankle joint, but to the hip and knee joints as well.

2.3 Hip and Knee Biomechanics During Landing

Kinetics and kinematics of the hip and knee also play a large role in force absorption and injury potential from jump landing activities. Yeow et al. (2009) studied lower extremity frontal plane biomechanics during landings and determined healthy subjects have the most energy absorption at the hip joint. They found that both the knee and hip play a large role in energy dissipation, and that the knee and hip joints provided more joint power and eccentric work throughout a typical landing phase than the ankle joint (Yeow et al., 2009). Yu et al. (2006) found that controlled and deliberate hip and knee flexion at initial contact play a large role in reducing impact forces during stop jump landings. Adequate hip and knee flexion range of motion during the landing process may be critical in reducing the likelihood of anterior cruciate ligament (ACL) injury (Yu et al., 2006). While hip and knee mechanics play a large role in ACL injury potential, they may also contribute to ankle joint injury, especially when considering differences between unilateral and bilateral landing, and utilization of the dominant or non-dominant leg during landing. As mentioned previously, McPherson et al. (2016) investigated lower extremity differences in leg dominance between single leg and double leg jump landings. While the unilateral jump landings did not display any significant differences in landing mechanics, bilateral landings exhibited higher hip and knee flexion in the non-dominant leg at initial contact, but the dominant hip and knee had greater total excursion. These results suggest that leg dominance and symmetry may have some degree in lower extremity landing mechanics and injury susceptibility.

An interesting concept regarding leg dominance is if there are any proprioceptive or balance differences as a result of preference. McGuine and Keene (2006) implemented a balance training program starting in pre-season and continuing the program during the season, to assess if there would be a reduction in ankle sprains in the group participating in the program. Seven hundred and sixty-five male and female high school soccer and basketball players were randomly split into two groups: one that only participates in regular practice, and an experimental group, which along with practice participated in a balance training program. Athletic trainers were present for every practice and recorded injuries. A questionnaire concerning previous ankle injury was completed by the athletes prior to the season. The balance program was implemented in five phases, the first two involving only exercises on the floor, and the last three using wooden ankle boards. Exercises varied from having the subjects open or close their eyes, and included activities such as a single leg stance, swinging of the leg in single leg stance, single leg squats, and single leg stance while performing basketball- or soccer-related functional activities. Compared to a control group, they found that the balance program led to a significant (9.9% vs 6.1%; $p = 0.04$) decrease in rate of ankle sprains (McGuine & Keene, 2006). These results indicate that a balance training program may be used to reduce the incidence of ankle sprains in competitive sport. Using unilateral and bilateral jump tasks could also infer the role that balance and proprioception play in ankle joint injury potential. Since balance training closely correlates with proprioception, these types of programs and research of their impact are important in understanding the mechanisms involved in ankle sprains.

Limb-dominance and the role it plays in injury is still unclear throughout biomechanics literature. Although there are some contradictions and inconclusive findings, many studies (Ekstrand and Gillquist, 1983; Niu et al., 2011; Weinhandl et al., 2010, 2017; Yeung et al., 1994) found that the dominant leg exhibits an increased likelihood of injury. Based on previous research, variables such as the peak vGRF, loading rate, angular segment velocities, and flexion angles, can be utilized to predict lower extremity injury patterns and occurrence.

Using information gathered from previously mentioned studies gives reason to observe the jump landing task and identify risk factors and cause for potential ankle joint injury. This study is novel in that it investigates and compares kinetic variables between dominant and non-dominant leg in a bilateral stop-jump action, while other studies have only utilized other landing maneuvers, compared kinematic variables, or unilateral landings. It is likely that this study will further support previous research in observing that the dominant ankle may be more susceptible to ankle joint injury during the jump landing task. In studying this question, practical applications regarding injury prevention, rehabilitation, and implications of the role of limb-dominance in risk of ankle joint injury can be further understood.

CHAPTER 3. METHODS:

3.1 Data Collection

3.1.1 Subjects

Twelve healthy male subjects were recruited through University of Kentucky's Intramural sports leagues, and the Lexington Sport and Social Club. Subjects were required to read and provide written informed consent. All research procedures were approved by the university IRB. Only participants who were free of lower extremity injury were included for participation in the study. Those with a positive history of lower extremity surgery were excluded from participation. In order to reduce variation and sex differences, only male subjects were recruited for this study. To be eligible to participate, subjects were required to be between the ages of 18-35y old. Additionally, subjects were deemed to be recreationally active, through participation in recreational sports for at least two seasons a year, however there were no body mass index (BMI) restrictions. The dominant leg was chosen as the test leg in this study. Leg dominance was self-reported by subjects, by indicating their preferred leg to kick a soccer ball for maximum distance (Wikstrom et al., 2006; Yeow et al., 2009).

Table 3.1. Displays subject demographics including BMI components, preferred kicking leg, and max jump height, which signifies the highest number reached by each subject.

Table 3.1 Subject Demographics.

Subject	Height (m)	Mass (kg)	Age (years)	Body Mass Index (kg/m^2)	Max Jump Height (cm)	Self Selected Dominant Leg
1	1.90	78.30	32.00	21.70	55.88	Right
2	1.85	77.60	23.00	22.70	48.26	Right
3	1.72	96.60	23.00	32.70	50.80	Right
4	1.96	89.90	24.00	23.40	55.88	Right
5	1.88	69.60	23.00	19.80	46.99	Right
6	1.78	90.70	27.00	28.60	50.80	Right
7	1.68	65.70	25.00	23.30	46.36	Right
8	1.85	70.70	25.00	20.70	50.80	Left
9	1.70	64.90	26.00	22.50	49.53	Right
10	1.80	85.00	25.00	26.20	64.77	Right
11	1.73	75.12	26.00	25.10	60.96	Right
12	1.75	63.00	25.00	20.60	63.50	Right
Mean	1.80	77.26	25.33	23.94	53.71	
SD	0.08	10.69	2.36	3.73	2.52	

3.1.2 Data Acquisition and Processing

Equipment used in this study includes two Bertec (Bertec Corporation, Worthington, OH) force plates, a 10-camera motion capture system (Motion Analysis Corporation, Rohnert Park, CA), Visual 3D software (C-Motion Inc, Germantown, MD), and a Vertec (Sports Imports, Columbus, OH) jump height assessment tool (Young et al., 1997). All subjects wore a standardized pair of tennis shoes (Nike, 602171404, Beaverton, OR) during the jump landing task.

Once in the lab the procedures required the subject to have reflective markers placed on anatomical landmarks. A modified Cleveland Clinic marker set consisting of 46 retro-reflective markers was used to track 3D segment position. Five-marker clusters were placed on the right thigh and shank, and four-marker clusters denoted the left thigh and shank. Markers were placed on anatomical landmarks of both the right and left lower extremity including: Anterior Superior Iliac Spine, Inferior Iliac Crest, Posterior Superior Iliac Spine, L5S1 of the spine, medial and lateral condyle of the knee joint, lateral and medial malleolus of the ankle joint, first and fifth metatarsal heads, the distal tip of the big toe, and an offset marker on the forefoot to identify the right foot. Anthropometrics such as height, weight, age, and self-reported dominant leg were obtained, and then the subject was instructed to perform a warmup to get comfortable with the procedure in a lab setting. For this warmup, subjects were instructed to complete three practice maximal jumps and to jump as high as possible with their natural form utilizing a step-up to the force plate. A vertical jump trial was considered clean and was used for analysis if each foot during both the takeoff and landing, was completely on the separate force plates.

Each study participant was asked to perform trials of the step-up jump task until four clean jump-landings were completed. The goal of each trial was to reach the highest slat on the Vertec tool as possible. Subjects were provided with 30 – 60 seconds of rest between trials to reduce any effects of fatigue. The bilateral jumps utilized a step-up up to the force plates of each foot so that when each subject performed toe-off, they would be jumping vertically off of the center of the force plates. Subjects were simply instructed to jump and try to reach the highest slat possible, while utilizing form that came natural to them in a jumping activity. The Vertec jump assessment tool was used to standardize trials to maximal jump height, and for the subjects to be familiarized with the functional jump landing movement (Koshino et al, 2016).

Three-dimensional marker position and ground reaction force data were collected at 200Hz and 1000Hz, respectively. A five-second static standing trial was obtained at the beginning of each data collection. All raw marker position and ground reaction force data were filtered using a low-pass filter at 10 Hz and 60 Hz, respectively. The static standing trial was used to form a 7-segment musculoskeletal model consisting of the pelvis, bilateral femurs, shanks and feet using Visual 3D. Joint angles were normalized to the static standing calibration trial, with segments utilizing an X, Y', Z'' component sequence. The knee and ankle joint coordinates were defined within Visual 3D as the center point of the line between the medial and lateral condyles, and the medial and lateral malleoli respectively.

Utilizing the force plates, toe-off was defined as the point when vGRF were equal to zero and the subject leaves the ground, while initial contact was defined as the point where vGRF is no longer zero as the subject lands and contacts the ground. The force plates were used to determine differences in peak vertical ground reaction forces (vGRF) of the jump landings which were normalized and expressed as a proportion of bodyweight, and to determine differences in time to peak vGRF of the participants following initial contact of the landing. The 3D motion capture system collected kinematic and kinetic data to determine differences between subject's resultant external ankle joint moments in the frontal plane. Peak ankle joint moments were calculated in the Medio-lateral direction between the subjects and standardized to percentage of task completion. Loading rate

(BW/s) was determined by dividing peak vGRF values by the time to peak vGRF, from the moment of initial contact up to instant of peak vGRF.

3.1.3 Statistical Analysis

Data analysis and statistics were completed using Microsoft Excel. Paired sample t-tests (significance level set at 0.05) were used to compare differences between dominant and non-dominant ankle joint mechanics. Cohens D effect sizes were also calculated in Microsoft Excel (Brown et al, 2004). All data are reported as mean ± SD unless otherwise noted.

CHAPTER 4. RESULTS AND DISCUSSION:

4.1 Results

4.1.1 Ground Reaction Forces

Values for peak vGRF can be found in Table 4.1. The non-dominant leg (2.98 ± 0.40 BW) exhibited a significantly higher peak vGRF than the dominant leg (2.31 ± 0.58BW; p = 0.01) and an effect size of 1.35.

Table 4.1 Mean (SD) Peak vGRF Between Dominant and Non-Dominant Leg.

Mean Peak vGRF(BW)		
Subject	Dominant	Non-Dominant
1	1.42 (0.25)	3.23 (0.35)
2	2.46 (0.39)	2.76 (0.18)
3	2.39 (0.14)	2.65 (0.39)
4	2.01 (0.73)	3.42 (0.47)
5	1.57 (0.13)	2.34 (0.15)
6	2.16 (0.12)	2.99 (0.44)
7	2.78 (0.42)	3.51 (0.46)
8	3.39 (0.63)	2.23 (0.77)
9	2.80 (1.11)	3.14 (0.22)
10	1.68 (0.33)	3.14 (0.33)
11	2.71 (0.33)	3.16 (0.41)
12	2.32 (0.45)	3.18 (0.55)
Mean	2.31 (0.58)	2.98 (0.40)*

* p = 0.01

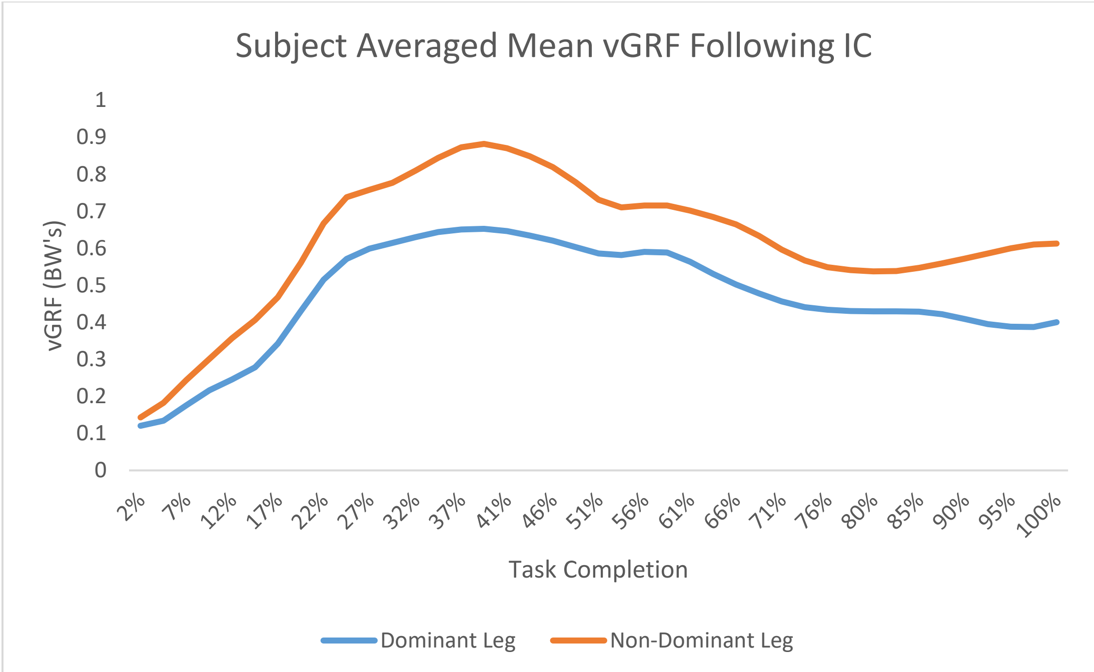

Figure 4.1 vGRF Following IC through completion of jump task.

An ensemble curve of mean vGRF data from initial contact to follow-through and the end of the landing process is depicted in Figure 4.1.

4.1.2 Loading Rate

Although statistically similar (p=0.25), the time to peak vGRF within the dominant leg (53.0 ± 27.0ms) occurred sooner than the non-dominant leg (63.0 ± 17.0ms).

Table 4.2 Mean (SD) Time to Peak vGRF between Dominant and Non-dominant Leg.

Mean Time to Peak GRF (ms)		
Subject	Dominant	Non-Dominant
1	30.0 (29.0)	60.0 (11.0)
2	50.0 (26.0)	60.0 (11.0)
3	30.0 (23.0)	60.0 (7.00)
4	40.0 (37.0)	80.0 (4.00)
5	111 (9.00)	90.0 (9.00)
6	20.0 (1.00)	40.0 (30.0)
7	80.0 (11.0)	70.0 (8.00)
8	70.0 (8.00)	60.0 (8.00)
9	70.0 (11.0)	60.0 (13.0)
10	30.0 (29.0)	80.0 (5.00)
11	70.0 (5.00)	30.0 (22.0)
12	50.0 (26.0)	60.0 (13.0)
Mean	50.0 (30.0)	70.0 (20.0)

The vGRF loading rates between the dominant (54.51±33.10 BW/s) and non-dominant legs (52.58±22.40 BW/s) were similar ($p = 0.85$). The time to peak vGRF and the vGRF loading rate for all study subjects are shown in Table 4.2.

Table 4.3 Mean (SD) Loading Rate Comparison.

	Loading Rate (BW/s)	
Subject	Dominant	Non-Dominant
1	47.99 (30.65)	51.46 (13.68)
2	45.46 (42.69)	42.87 (8.06)
3	78.38 (45.37)	44.76 (11.97)
4	54.28 (64.14)	43.45 (7.45)
5	13.72 (2.00)	25.44 (2.45)
6	148.8 (6.59)	74.19 (73.35)
7	35.63 (9.33)	50.65 (11.55)
8	51.68 (12.00)	35.19 (16.99)
9	42.64 (12.75)	52.19 (7.57)
10	50.39 (41.81)	41.63 (5.93)
11	41.44 (2.83)	112.9 (56.53)
12	43.74 (43.16)	56.19 (16.85)
Mean	54.51 (33.10)	52.58 (22.40)

4.1.3 Joint Moment

Eleven subjects had kinetic analysis completed during the jump trials, (one subject's kinetic data was omitted from analysis because of complications during calibration prior to collection). The non-dominant ankle joint (-0.26±0.18 Nm/kg) exhibited a higher peak inversion moment compared to the dominant ankle joint (-0.21±0.14 Nm/kg) although this failed to reach statistical significance ($p = 0.37$).

Table 4.4 Peak External Inversion Ankle Joint Moments in the Medio-lateral Direction.

	Medio-lateral Peak Ankle Moment (Nm/kg)	
Subject	Dominant	Non-Dominant
1	*	*
2	-0.27 (0.05)	-0.50 (0.06)
3	-0.43 (0.29)	-0.33 (0.23)
4	0.01 (0.01)	0.01 (0.01)
5	-0.38 (0.43)	-0.01 (0.01)
6	-0.17 (0.16)	-0.30 (0.30)
7	-0.37 (0.27)	-0.39 (0.26)
8	-0.01 (0.01)	0.01 (0.01)
9	-0.21 (0.29)	-0.29 (0.11)
10	-0.19 (0.19)	-0.39 (0.31)
11	-0.14 (0.09)	-0.27 (0.21)
12	-0.14 (0.17)	-0.38 (0.28)
Mean	-0.21 (0.14)	-0.26 (0.18)

*Subject calibration invalid

4.2 Discussion

This study aimed to compare biomechanical responses of the dominant and non-dominant limbs in response to bilateral landing from a step-up jump. Peak vGRF was higher during jump landing in the non-dominant leg than in the dominant leg in this study. Time to peak vGRF, loading rate, and peak external ankle inversion moments were similar between the dominant and non-dominant legs across all subjects. The vGRF results based from this study appear to conflict previous studies indicating the dominant ankle joint may be more susceptible to injury during jump landings (Ekstrand and Gillquist, 1983; Niu et al., 2011; Weinhandl et al., 2017; Yeung et al., 1994). However, our findings agree with those of Schot et al. (1994) who demonstrated that there is apparent asymmetry in bilateral landings arising from leg dominance. Interestingly a study by Aizawa et al., (2018) does support the findings of the current study. When performing lateral drop jumps on consecutive days, subjects displayed higher peak mediolateral GRF, and a higher vGRF at the time of peak medial GRF in the non-dominant leg (Aizawa et al., 2018). The previous study identifies the importance of not only vGRF, but forces in the lateral direction as well. This is especially important to consider as many sports such as volleyball and football require athletes to land unilaterally with a large amount of medial-lateral force (Aizawa et al., 2018). While the vertical jump task primarily resembles a completely anterior landing such as occurs in landing from drop jumps and drop-hangs, depending on subject's vertical trajectory, as well as any rotations in the air from reaching for height, a lateral GRF aspect could have been introduced. This could potentially explain the similarities in result to Aizawa et al. (2018).

As noted in Kovacs et al. (1999) vGRF is an important indicator of energy absorption during the landing movement. Yeow et al. (2009) compared vGRF and power when landing from different heights and found that falls from all heights tested led to the hip and knee performing much more eccentric work during landing than at the ankle joint. As subjects dropped from higher platforms and generated larger vGRF, the hip and knee took on the most energy dissipation (Yeow et al., 2009). Taking this information into consideration could be useful when comparing vGRF and energy absorption in multiple joints from vertical jump landings. Applying this information to the question of limb-dominance at not only the ankle, but the entire lower extremity could potentially find meaningful results.

Time to peak vGRF and loading rate results did not have statistical difference and therefore did not support the hypothesis that there is an underlying mechanism putting the dominant ankle at a predisposition for injury. Aizawa et al. (2018) also did not observe any statistical differences between loading rate when comparing gender, limb asymmetry, or mediolateral versus vGRF, but did find that mediolateral GRF were higher in the non-dominant leg than the dominant. One important reason loading rate is a key variable stems from Puddle and Maulder (2013) and implications of their results. It was argued that the rate of force development is more crucial than the peak vertical force accumulated when implicating injury from jump landings (Puddle and Maulder, 2013). In the study by Puddle and Maulder (2013), three different styles of jump landings were researched, and found that newer parkour techniques significantly reduce loading rates compared to a more traditional jump landing used in sport. These implications relate directly to the loading rate results in identifying if the dominant or non-dominant limb presents a higher exposure for ankle joint injury, since loading rate has been studied and considered a factor for injury. Time to peak force and loading rate data are especially confounding when considering the work by Niu et al. (2011) which found no differences between dominant and non-dominant legs in loading rate, peak vGRF, and time to peak vGRF, and attributed this finding to the adaptions of the neuromuscular system, as a way of preventing leg asymmetry. Further study could utilize different heights, jump styles, and landing techniques, specifically targeting a relationship between loading rate limb-dominance, to provide better insight in this regard.

Frontal plane ankle joint moment was another key element researched which did not support the hypothesis or produce statistical significance. The lack of statistical difference in joint moment in the current study was backed however by Van der Harst et al. (2007). Using single leg hops to determine differences between healthy dominant and non-dominant leg kinetics and kinematics, only peak hip extension and hop length were different between the dominant and non-dominant legs (Van der Harst et al., 2007).

Various studies concluded no statistical differences of kinetic and kinematic variables, or ankle injury prevalence between dominant and non-dominant side (Beynnon et al., 2001; Van der Harst et al., 2007; Weinhandl et al., 2017). A large role in this particular result may stem from the consideration of the dominant limb being primarily responsible for postural stability and strength, rather than mobility and fine movements. Niu et al (2011) noted that the non-dominant limb tends to be utilized more so for posture and stabilization, whereas the dominant leg is commonly active in a mobilization role (Wikstrom et al., 2006). Since the vertical jump task requires the subjects to produce a powerful movement, limb dominance in this case could very well be defined as the stronger leg utilizing the force plates. However, certain sport specific jumps tend to lead athletes to jump off a preferred leg based on other factors like hand dominance when reaching for the highest vertical slat.

Additional variables that could provide this study with a better wealth of results, include assessing electromyography of the associated ankle joint musculature. Identifying differences in timing of muscle activation during the landing process may better explain the differences in force and stress absorption, as well as accumulation of such forces. For example, in Niu et al. (2011) the tibialis anterior muscle showed larger activation both pre and post landing in the non-dominant leg compared to the dominant. The tibialis anterior plays a crucial role in ankle dorsiflexion, a crucial eccentric aspect of landing. This matches the results displaying a larger dorsiflexion angular velocity in the dominant ankle, supporting the overall hypothesis that the dominant leg has an impaired protective landing mechanism (Niu et al., 2011). Future research possibilities may offer more substantial outcomes when pairing muscular activity information, further joint moment data, and supplementary kinematic description of foot placement at landing. Comparing the results of previous studies concerned with foot placement (Koshino et al., 2016; Kovacs et al., 1999; Puddle and Maulder, 2013;) to the result of this study could allow for stronger conclusions about the effect of foot position at instant of landing, as well as stronger collaboration with vGRF and loading rate data.

While this study lays groundwork for additional research to be completed, there were some limitations to be considered. Human error in anatomical marker placement of the foot and ankle, as well as miniscule calibration factors could be cause of discrepancies in ankle moment results, as no reliability testing was completed. A better understanding in athletes jump patterns, as well as leg dominance and the role it plays in the vertical jump take-off may lead to a clearer understanding of what the data represents. Involving a larger subject pool is a key attribute in gaining a higher likelihood in the results having larger power and confidence in displaying statistical significance. Sex differences could also be looked at, in determining if the role of leg dominance is exacerbated between genders. Variations in jump technique and subject jump height are sure to play a role in athletes landing mechanics. Studying these differences and involving more variables and variety to the jump task at hand may prove efficient in determining more succinct information about underlying mechanisms related to ankle injury at landing. At the same time, minimizing variability in the jump task and increasing the number of trials and assessing additional biomechanical variables may allow for clearer results, and interpretations.

CHAPTER 5. CONCLUSION

5.1 Conclusion

When landing from maximal vertical jumps, the non-dominant leg was found to experience a greater amount of vGRF. Conversely, the dominant leg accumulated force quicker, as shown through larger vGRF loading rates, but with no statistical significance. When considering trends in previous literature, a higher loading rate pairs with larger vGRF, so regarding the present study it is unclear whether the rate of vGRF accumulation plays a larger role in ankle joint injury prevalence, than which leg lands with the highest force. Ankle joint moments were also larger in magnitude in the dominant limb, but with no statistical significance, could also be an effect of a vertical component in the landing, or from contention of how leg dominance is selected in a jumping activity. These results may only represent inferences and implications more so than concrete conclusions, but still prove valuable in determining limb-dominance and its role in lower extremity injury. Until further research corroborates the hypothesis at hand, or identifies a clear mechanism relating to limb dominance, the results of this study only add to the muddle regarding this research question. Moving forward with the inclusion of additional variables, data, and perspective, this study in the future may produce important information that can be utilized by additional researchers, coaches, trainers, and clinicians, regarding injury prevention.

APPENDICES

Appendix 1. Visual 3D Pipeline

A manual pipeline of instructions was created in visual 3D with filtering and template info to create a model to be used in calculating and exporting joint moment data. The pipeline instructions were as follows: File New-Set Pipeline Parameter-file open-create hybrid model-lowpass filter-lowpass filter-apply model template-assign model file-set subject mass-set subject height-compute model based data-compute model based data-metric maximum-metric maximum-export data to ascii file-export data to ascii file.

Appendix 2. Consent Form

Consent to Participate in a Research Study

KEY INFORMATION FOR DOMINANT VERSUS NON-DOMINANT ANKLE MECHANISMS DURING VERTICAL JUMP LANDINGS:

You are being invited to take part in a research study about the possible differences in landing between the dominant and non-dominant limb ankle, when landing from a vertical jump. You are being invited to take part in this research study because you are a physically active recreational athlete, between 18 and 36 years of age, and do not have any recent lower extremity injuries. If you volunteer to take part in this study, you will be one of about 15 people to do so.

WHAT IS THE PURPOSE, PROCEDURES, AND DURATION OF THIS STUDY?

By doing this study, we hope to learn if there are factors that may influence ankle movements during the landing process of a jump. Your participation in this research will last about one and a half hours during one single visit.

WHAT ARE REASONS YOU MIGHT CHOOSE TO VOLUNTEER FOR THIS STUDY?

Participating in this study may broaden your perspective of what research entails, and how the overall process is done. We hope to find valuable information regarding how the ankle functions that may be useful for coaches, trainers, or clinicians. For a complete description of benefits, refer to the Detailed Consent.

WHAT ARE REASONS YOU MIGHT CHOOSE NOT TO VOLUNTEER FOR THIS STUDY?

There is minimal risk for this study, however you may not want to volunteer for this study if you cannot commit to up an hour and a half of time to collect data, have previously sustained a lower limb injury, or feel physically impaired to complete multiple vertical jumping tasks. For the most accurate data collection, subjects may be required to remove their shirts and wear tight fitting shorts or spandex. For a complete description of risks, refer to the Detailed Consent.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any services, benefits, or rights you would normally have if you choose not to volunteer. As a student, if you decide not to take part in this study, your choice will have no effect on your academic status or class grade(s).

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS OR CONCERNS?

The person in charge of this study is Riley Pashak of the University of Kentucky, Department of Kinesiology and Health Promotion. If you have questions, suggestions, or concerns regarding this study or you want to withdraw from the study his/her contact information is: PN: 989-891-6859, Email: riley.pashak@uky.edu.

If you have any questions, suggestions or concerns about your rights as a volunteer in this research, contact staff in the University of Kentucky (UK) Office of Research Integrity (ORI) between the business hours of 8am and 5pm EST, Monday-Friday at 859-257-9428 or toll free at 1-866-400-9428.

DETAILED CONSENT:

ARE THERE REASONS WHY YOU WOULD NOT QUALIFY FOR THIS STUDY?

A subject may be excluded from participation if they are younger than 18 years of age, or older than 36, and subjects will be exclusively males. Subjects may not qualify to participate if they have sustained any lower limb injury in the past two years or have undergone major lower limb surgery. Participants may also not qualify if they do not participate in at least two intramural/ recreational/ social/ sport seasons per year.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research project will be conducted at the Biodynamics Laboratory in the Multidisciplinary Sciences Building at the University of Kentucky. You will need to come to the Biodynamics Laboratory (room #161 – Multidisciplinary Sciences Building) on one occasion. This visit is expected to last approximately one and a half hours in duration. The total amount of time you will be asked to volunteer for this study is one and a half hours.

WHAT WILL YOU BE ASKED TO DO?

The following procedures may be performed. After you arrive at the Biodynamics Laboratory you will be asked to review this document and provide informed consent to continue as a participant in this study. If you agree to participate in this study, you will be provided with a pair of tennis shoes and asked to put them on. You should wear your own sports clothing (tight fitted t-shirt and shorts) and socks.

You will be asked to warm up, and then perform four individual vertical jumps. We will measure your body movement patterns (biomechanics) during each of the jumps.

Anthropometric Measurements

Your body weight and standing height will be measured on a scale. You will be measured without your shoes while you have light-weight clothing (shorts and a t-shirt). These measures will be performed in the biodynamics lab.

Motion Analysis

Small reflective markers will be placed on your skin using double sided tape to identify boney landmarks of the trunk and lower body. Also, we will attach some clusters of markers to your legs and thighs using tape and elastic bands. A ten camera, motion capture system (Motion Analysis Corp, Santa Rosa, CA) will be used to capture the position of the small reflective markers. No identifiable images will be collected.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

There are minimal risks associated with this study.

Skin irritation: Tape will be used to attach the reflective markers and special adhesive tape will be used to attach the muscle sensors on your skin. It is possible that your skin may become mildly irritated following the application/removal of the tape. This is uncommon. In the event that this happens it is recommended to wash the affected area with soap and water.

General risks of exercise: Since this study involves jumping, the same general risks apply as those typically associated with jumping activities. There is a small chance you may lose your balance, or become sore due to exercise.

In addition to the risks listed above, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

You will not receive any direct benefit from taking part in this study. Your willingness to take part may, in the future, help society as a whole better understand this research topic.

WHAT WILL IT COST YOU TO PARTICIPATE?

You may have to pay for the cost of transportation to and from the study site.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

We will make every effort to keep confidential all research records that identify you to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. All paper records will be stored in a locked filing cabinet located in the Biodynamics Laboratory that is only accessible by members of the research team. Furthermore, all electronic records will be stored on a password protected server that is only accessible by members of the research team.

We will keep private all research records that identify you to the extent allowed by law. However, there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court or to tell authorities if you pose a danger to yourself or someone else. Also, we may be required to show information which identifies you to people who need to be sure we have done the research correctly; these would be people from such organizations as the University of Kentucky.

CAN YOU CHOOSE TO WITHDRAW FROM THE STUDY EARLY?

You can choose to leave the study at any time. You will not be treated differently if you decide to stop taking part in the study.

If you choose to leave the study early, data collected until that point will remain in the study database and may not be removed.

The investigators conducting the study may need to remove you from the study. You may be removed from the study if you are not able to follow the directions, or if we find that your participation in the study is more risk than benefit to you.

ARE YOU PARTICIPATING, OR CAN YOU PARTICIPATE, IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study. It is important to let the investigator know if you are in another research study. You should discuss this with the investigator before you agree to participate in another research study while you are in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you become hurt or get ill because of something due to this study and it is an emergency, please dial 911 prior to contacting Riley Pashak (989-891-6859).

You may, also, contact Ben Johnson PhD (859-257-5826), the adviser of this study, to report any injuries or illness due to this study.

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

Medical costs that result from research related harm can not be included as regular medical costs. Therefore, the medical costs related to your care and treatment because of research related harm will be your responsibility.

You do not give up your legal rights by signing this form.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will not receive any rewards or payment for taking part in the study.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

You will be informed if the investigators learn new information that could change your mind about staying in the study. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

WHAT ELSE DO YOU NEED TO KNOW?

If you volunteer to take part in this study, you will be one of about 15 people to do so.

The primary investigator is being guided in this research by Ben Johnson, PhD. There may be other people on the research team assisting at different times during the study.

FUTURE USE OF YOUR INFORMATION:

Your information collected for this study will NOT be used or shared for future research studies, even if we remove the identifiable information like your name, clinical record number, or date of birth.

INFORMED CONSENT SIGNATURE PAGE

You are a participant or are authorized to act on behalf of the participant. This consent includes the following:

- Key Information Page
- Detailed Consent
- List Appendices included with this consent, if applicable

You will receive a copy of this consent form after it has been signed.

____ ______________________

Signature of research subject Date

____

Printed name of research subject

____

____

____

Printed name of [authorized] person obtaining informed consent Date

____

Signature of Principal Investigator or Sub/Co-Investigator

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VITA

Riley Pashak:

EDUCATION

University of Kentucky – Kinesiology and Health Promotion, MS (In progress)

Grand Valley State University – Clinical Exercise Science, BS

PROFESSIONAL EXPERIENCE

Health Coach – Noom Inc

Logistics Account Executive – Total Quality Logistics

Graduate Teaching Assistant – University of Kentucky

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