2020-01-01

A Full Collegiate Volleyball Season Does Not Influence Jumping or Landing Performance in Freshmen and Sophomore Players

Christian Noel Sanchez
University of Texas at El Paso

A FULL COLLEGIATE VOLLEYBALL SEASON DOES NOT INFLUENCE JUMPING OR LANDING PERFORMANCE IN FRESHMEN AND SOPHOMORE PLAYERS

CHRISTIAN NOEL SANCHEZ

Master's Program in Kinesiology

APPROVED:

____
Jeffrey Eggleston, Ph.D., Chair

____
Cory Smith, Ph.D.

____
John Harry, Ph.D.

____
Stephen Crites, Ph.D.
Dean of the Graduate School

A FULL COLLEGIATE VOLLEYBALL SEASON DOES NOT INFLUENCE JUMPING OR LANDING PERFORMANCE IN FRESHMEN AND SOPHOMORE PLAYERS

By

CHRISTIAN NOEL SANCHEZ, B.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Kinesiology

THE UNIVERSITY OF TEXAS AT EL PASO

December 2020

ABSTRACT

Knee injuries are devastating and typically experienced by athletes when performing jumping and landing tasks throughout a complete collegiate volleyball season. The purpose of this study was to examine changes in lower extremity strength, frontal plane knee angles and moments, jump performance during a countermovement and approach jump before and after a complete Division I collegiate volleyball season in female volleyball freshman and sophomores. Eight freshman/sophomore female collegiate volleyball players participated in the study. Lower extremity strength was assessed using an isokinetic dynamometer, kinematic and kinetic data were obtained through three-dimensional motion capture system and force platforms, respectively. Participants performed five consecutive, extension-flexion movements on the dynamometer at sixty degrees per second. Participants then completed five successful trials of a countermovement and approach jump. Data were obtained before the start of, and immediately upon completion of the season. Variables of interest included sagittal and frontal plane knee displacement and moment, average peak knee extension and flexion, and hamstring to quadriceps ratio, which were examined via two by two factorial analysis of variance while peak vertical ground reaction force, jump height, landing momentum, rate of force attenuation and loading and attenuation impulse contribution were compared via dependent *t*-tests to identify differences between time and limbs (α=0.05). Analysis revealed increased jump height for the approach jump ($p = 0.03$). No other significant differences were detected for the approach jump ($p > 0.05$). No significant changes were detected for the countermovement jump in any variables nor in lower extremity strength ($p > 0.05$). Findings suggest that a complete collegiate volleyball season has no adverse effects on lower extremity strength, landing mechanics nor compromises performance. Lack of significant changes associated with injury indicated that this group of

players were not at increased risk of injury or negative performance resulting from fatigue throughout the course of the season.

TABLE OF CONTENTS

Page

ABSTRACT ……………………………………………………………………………………… iv

TABLE OF CONTENTS ………………………………………………………………………… vi

LIST OF TABLES ……………………………………………………………………….... viii

CHAPTER 1. INTRODUCTION …………………………………………………………… 1

CHAPTER 2. LITERATURE REVIEW …………………………………………………...... 6

I. JUMPING & LANDING CHARACTERISTICS ………………………………….. 6

a. JUMPING …………………………………………………………………… 6

i. RATE OF FORCE DEVELOPMENT …………………………………. 6

ii. GROUND REACTION FORCE ……………………………………….. 7

b. LANDING …………………………………………………………………… 8

i. FORCE ATTENUATION ……………………………………………… 8

ii. GROUND REACTION FORCE ……………………………………….. 9

iii. JOINT KINEMATICS ………………………………………………… 10

iv. JOINT KINETICS …………………………………………………... 12

II. LOWER EXTREMITY STRENGTH ……………………………………………... 15

a. CONTRIBUTION TO JUMPING MECHANICS …………………………….. 15

b. CONTRIBUTION TO LANDING MECHANICS ……………………………. 16

III. KNEE INJURY ………………………………………………………………… 17

a. FACTORS ASSOCIATED WITH INJURY ………………………………….. 18

CHAPTER 3. METHODS ……………………………………………………………………….. 20

CHAPTER 4. RESULTS ……………………………………………………………………… 26

DISCUSSION ………………………………………………………………………... 31

CONCLUSION ………………………………………………………………………. 36

REFERENCES ………………………………………………………………………… 37

VITA ……………………...…………………………………………………………….. 43

LIST OF TABLES

Page

Table 1: PRE and POST Height and Weight ………………………………………………….. 26

Table 2: PRE and POST Jump Height and vGRF Data for Approach Jump ………………….. 26

Table 3: PRE and POST Knee Kinematics and Kinetics for the Approach Jump …………….. 27

Table 4: PRE and POST Jump Height and vGRF Data for Countermovement Jump ………… 28

Table 5: PRE and POST Knee Kinematics and Kinetics for the Countermovement Jump …… 29

Table 6: PRE and POST Lower Extremity Strength Values ………………………………….. 30

INTRODUCTION

Injury to the internal structures of the knee joint can be one of the most devastating injuries experienced by athletes depending on the type of movement performed (Sinsurin, Srisangboriboon, & Vachalathiti, 2017; Venesky, Docherty, Dapena, & Schrader, 2006). Many injuries have been reported as non-contact injuries, occurring when an athlete suddenly changes direction or when performing a jumping and landing task followed by a secondary movement. Injuries may occur due to various movements in sports requiring coordinated muscular efforts to improve accuracy and performance based on the end goal of the task being performed, resulting in biomechanical changes, such as altered force attenuation and application as well as altered hip, knee, and ankle joint mechanics (Barker, Harry, & Mercer, 2018; Dufek & Bates, 1991; Hewett & Myer, 2011; Mason-Mackay, Whatman, Reid, & Lorimer, 2016; Zahradnik, Jandacka, Farana, Uchytil, & Hamill, 2017).

Athletes are frequently required to perform maximal effort vertical jumps as part of sport participation and performance. In order to achieve a greater vertical jump height, individuals must produce a large magnitude of force at take-off in order to maximize their take-off velocity, thus resulting in a greater jump height (Harry, Lanier, Nunley, & Blinch, 2019). Increasing vertical ground reaction force (vGRF) production during the eccentric phase of the jump has been considered a positive characteristic for increasing maximal jump height (Harry, Barker, & Paquette, 2019; McHugh, Hickok, Cohen, Virgile & Connolly, 2020). Changes in vGRF magnitude has been shown to influence the overall outcome of jump performance, which is primarily dependent upon the frequency of training and jump mechanics (Simpson et al., 2013). Typically, if an athlete does not have sufficient downward velocity during the eccentric phase, the subsequent upward movement during the concentric phase can be negatively affected, leading to decreased maximal jump height (Barker et al., 2018; Harry et al., 2019). Downward velocity during the eccentric phase is largely determined by an increased rate of force production during the unloading and eccentric phases (Dufek & Bates, 1991; Harry et al., 2019). Therefore, when the rate of force production is increased during the eccentric phase, there should be a requisite increase of jump height (Laffaye & Wagner, 2013). Athletes and performance professionals commonly focus on increasing force production and rate of force development as a means of increasing sports performance, specifically in sprinting, change of direction, jumping and landing (Harry et al., 2019; Simpson et al., 2013). These changes in vGRF become more apparent in sports that require frequent jumping and landing.

Although most types of landings are vertical, three-dimensional lower extremity kinematics and kinetics are combined to ensure a stable and safe landing depending on the movement performed upon landing (DiStefano, Padua, Brown, & Guskiewicz, 2008; West et al., 2014). For instance, three-dimensional alterations in joint kinematics have been observed during take-off and landing in order to optimize performance and to reduce risk of injury, however these changes become more pronounced during landing than during the jumping phase of a movement (DiStefano et al., 2008; Pollard, Sigward, & Powers, 2010). Due to the vertical nature of jumping and landing tasks, lower extremity joints experience greater amounts of sagittal plane displacement from initial ground contact until the individual terminates downward motion in an attempt to attenuate force produced during landing (DiStefano et al., 2008; Simpson et al., 2013; Wulf & Dufek, 2009). Changes in the frontal and transverse planes have also been reported during landing, however these changes can have a positive or negative effect on landing depending on the type of jump performed (Simpson et al., 2013; West et al., 2014). Current literature has identified increased changes in frontal plane mechanics upon landing when performing a secondary movement immediately upon landing in order to respond to a change in an athlete's environment (Mason-Mackay et al., 2016; West et al., 2014). Moreover, excessive alternations in sagittal and frontal plane landing mechanics have been attributed to lower extremity injuries over an extended period of time (Nordin & Dufek, 2019).

Playing volleyball requires athletes to constantly perform maximal-effort vertical jumps during practice and competition which are typically followed by a subsequent movement upon landing (West, Ng, & Campbell, 2014). Knee injuries commonly occur while playing volleyball as a result of the movements following the landing (Sinsurin et al., 2017; West et al., 2014). Previous research suggested that female athletes are at an increased injury risk due to a variety of different factors, such as increased frontal plane knee moment and decreased knee flexion at peak vGRF and decreased strength in both the quadriceps and hamstrings in addition to diet and hormone changes (Dufek & Bates, 1991; Nordin & Dufek, 2019; Venesky, Docherty, Dapena, & Schrader, 2006). Current research has suggested that performing multiple jumping and landing tasks may have an effect on the athlete's overall mechanics resulting from overuse and fatigue during a complete season (Hewett et al., 2005; Nordin & Dufek, 2019). An athlete's ability to attenuate force rapidly during landing is arguably equally as important as the ability to apply force rapidly during sports performance as it contributes to changes in the lower extremity mechanics. For instance, immediately upon ground contact, a rapid increase in vGRF represents the external impact loading as a result of the athlete's downward momentum during landing (Harry et al., 2019). Force attenuation can be observed when the peak vGRF is rapidly reduced and continues until the athlete has terminated downward motion. Force attenuation is achieved by a coordinated distribution of muscular effort throughout the lower extremity kinematic chain (Harry et al., 2019; Nordin & Dufek, 2019). Consequently, if an athlete is incapable of achieving adequate force attenuation upon landing, the chances of suffering an injury may increase (Nordin & Dufek, 2019) especially during sports that require the athlete to perform an additional movement after landing (Dufek & Bates, 1991; Harry et al., 2019). This increased risk of injury may further increase over the course of the athlete's season due to fatigue in the lower extremities.

Decreased lower extremity strength, specifically in the quadriceps and hamstrings, has been associated with negative changes in jumping and landing performance (Rousanoglou, Barzouka, & Boudolos, 2013). Quadriceps and hamstrings have been shown as the main contributors to changes to force production, force attenuation, and lower extremity joint kinematics and kinetics (Bamac et al., 2008; Barker et al., 2018; Wulf, Dufek, Lozano, & Pettigrew, 2010). Imbalances in hamstring and quadriceps strength have be analyzed using the hamstring to quadriceps ratio (H:Q), where a decreased H:Q value has been associated with increased risk of injury, particularly to the anterior cruciate ligament, due to the hamstrings being incapable of exhibiting sufficient torque to protect against the torque created by the quadriceps (Myer, Ford, Foss, Liu, Nick & Hewett, 2009). Jumping and landing performance has also been affected by changes to lower extremity strength over an extended period of time where the individual is repeatedly performing series of jumping and landing tasks that result in fatigue (Hewett et al., 2005; Rousanoglou et al., 2013). Lower extremity strength changes have been associated with increased risk of injury in sports that require multiple jumps and landings to be performed (Dauty & Rochcongar, 2001; Rousanoglou et al., 2013). Typically, in volleyball the athletes are performing multiple jumping and landings throughout the season, which may have an effect on their performance caused by fatigue. However, it remains unclear how repeated exposure to changes in vGRF and joint kinetics and kinematics result in an increased risk of injury as a result of decreased strength and performance and needs further examination.

Therefore, the purpose of this study was to examine changes in lower extremity strength, frontal plane knee angles and moments, and performance during a countermovement and approach jump over the course of a complete Division I collegiate volleyball season in freshmen and sophomore female volleyball players. It was hypothesized that upon completion of the season there would be a decrease in quadriceps and hamstring strength, decreased sagittal and frontal plane knee angle at vGRF, increased frontal plane knee moment at vGRF and decreased maximal jump height, due to fatigue after performing repeated jumping and landing takes throughout the season.

LITERATURE REVIEW

I. JUMPING AND LANDING CHARACTERISTICS

Jumping and landing tasks are commonly performed in a variety of sports and recreational activities, one of the main sports being volleyball. During a single volleyball season these athletes are required to be constantly performing jumping and landing tasks repetitively, which requires years of experience to maximize performance. Additionally, during training and competition some situations may require the athlete to perform and addition movement immediately upon landing depending on the situation presented to them. Jumping and landing tasks are each affected by a variety of factors that can change the overall outcome of each portion of each movement. Depending on each individual characteristic, performance can be positively or negatively affected resulting in improvements or declines in addition to changes in injury risk.

a. JUMPING

i. RATE OF FORCE DEVELOPMENT

Jumping and landing tasks can be broken down into two separate movements and even further into several phases and sub phases (Harry et al., 2019). Most jumping tasks in sports require a rapid eccentric loading phases prior to take-off in order to maximize performance, which is typically seen when an athlete is performing a vertical countermovement jump (Harry et al., 2019; James, Dufek, & Bates, 2006). The purpose of this eccentric loading phase is the individual's attempt to generate as much force as possible in order to propel itself off the ground. This is achieved through a rapid eccentric rate of force development allowing the individual to take full advantage of the stretch-shortening cycle of the muscles of the lower extremities (Harry et al., 2019; James et al., 2006). During this rapid eccentric loading phase of the jump, the stretch-shortening cycle allows the muscles to build up elastic energy at an exponential rate which is then used during the concentric phase of the movement (James et al., 2006; McCaw & Cerullo, 1999). This eccentric rate of force development is identified by an initial increase of vertical GRFs prior to take-off, immediately followed by a change in magnitude of GRF indicating the individual's change in direction (Barker et al., 2018; Harry et al., 2019). Previous research has shown that a prolonged eccentric loading phase causes a significant decrease in rate of force production, therefore decreasing the amount of GRF produced during the beginning phase of a jump (Barker et al., 2018; Harry, Silvernail, Mercer, & Dufek, 2018). This decrease in force production can have a major effect on the outcome of a jump especially during sports. Additionally, depending on the eccentric rate of force development, maximal jump height, peak landing force and force attenuation may also become affected.

ii. GROUND REACTION FORCE

Increase in GRF have been identified as key contributors to overall performance during different types of jumping task (Dufek & Bates, 1991; Wulf & Dufek, 2009). Changes in GRF magnitudes have been utilized to characterize various phases and sub phases of jump tasks in addition to identifying their overall contributions to the movement as a whole (Harry et al., 2019). Prior to take-off, rapid increases in GRF magnitude during the eccentric loading phase of the countermovement jump indicates and increased reliance on eccentric force production to increase overall jump performance (Barker et al., 2018; Harry et al., 2019). This increase in eccentric force production, combined with increases in GRF magnitude could lead to greater elastic energy storage during the movement allowing the athlete to achieve a greater maximal jump height. Previous research has shown that the magnitude of the GRF during this eccentric loading phase is directly proportional to the maximum jump height of the movement (James et al., 2006). Based on the impulse-momentum relationship maximal jump height of the athlete can be determined prior to take-off based on the impulse created during the eccentric-concentric phase of the movement itself (Harry et al., 2019; James et al., 2006). Furthermore, this increase in force causes an increase in take-off velocity based off the individual's total body impulse generated prior to take-off (Barker et al., 2018; Harry et al., 2019). Maximal jump height is directly affected by these changes in GRF prior to take-off during a jumping task.

b. LANDING

i. FORCE ATTENUATION

Based on the amount of force generated at peak vertical GRF, additional changes are seen throughout the course of the landing in order to dissipate the energy (Dufek & Bates, 1991; Harry et al., 2018). Immediately upon landing, the body undergoes a negative acceleration in order to reduce excess loading on the joints of the lower extremities (Dufek & Bates, 1991; Paterno et al., 2010). Two types of landings patterns associated with force attenuation upon landing have been identified, "stiff" and "soft", each depending on the magnitude of peak vGRF as well as the individual's landing position (Harry et al., 2018; Nordin & Dufek, 2019). Landing with a "soft" landing pattern is typically characterized by a decreased peak vGRF magnitude in an attempt to decrease eccentric loading on the lower extremities (Zahradnik et al., 2017). Previous research has indicated that landing with a "stiff" landing pattern increases loading on the lower extremities which may affect overall performance throughout the course of competition or have detrimental effects on the joint structures (Dufek & Bates, 1991; Harry et al., 2018). During various sports that require constant landing patterns to be performed, such as volleyball, it has been shown that the inability to attenuate force upon landing may result from a lack of focus on the movement itself or having to quickly perform another movement immediately after landing (Harry et al., 2019).

ii. GROUND REACTION FORCE

Upon completion of a jumping task, increase in GRF is most apparent during the landing phase of the movement (Wulf & Dufek, 2009). The landing phase of a jumping and landing task is identified at initial contact with the ground to peak vGRF until the individual has returned to a neutral standing position. Furthermore, peak vGRF can be further broken down into initial contact (F1) and maximum GRF (F2) in order to identify the type of landing being performed (Harry et al., 2019; Harry et al., 2018). Previous research has also demonstrated variations in vGRF which have been attributed to subsequent movements performed after the completion of the landing, different landing patterns by each individual and ability to attenuate the force produced (Nordin & Dufek, 2019; West et al., 2014). Variations may become more apparent in sports that are typically very fast paced, such as volleyball. Increases in vGRF upon landing changes depending on the type of movement being performed, however peak vGRF is most commonly observed when landing from a countermovement jump due to the vertical nature of the movement (Harry, Silvernail, Mercer, & Dufek, 2017; Harry et al., 2018). Due to the pure vertical nature of the movement, countermovement jumps are commonly used to analyze peak vGRF and assess and individuals overall landing mechanics (Dufek & Bates, 1991; Paterno et al., 2010). Changes in GRF occurring in both the sagittal and frontal plane have not been thoroughly examined however, some changes in both planes have been seen in movements occurring immediately after landing (Cesar, Tomasevicz, & Burnfield, 2016; Favre, Clancy, Dowling, & Andriacchi, 2016).

c. JOINT KINEMATICS

In order to accommodate for changes in GRF magnitudes throughout the course of a landing tasks, the joints of the lower extremities change in response to the amount of force generated upon landing to dissipate the amount of energy acting on the joints themselves (Nordin & Dufek, 2019). Additional variables such as landing height, surface level, task being performed and subsequent task performed after landing all have an effect on lower extremity joint kinematics (Dufek & Bates, 1991; Wulf & Dufek, 2009; Zahradnik et al., 2017). The joints of the lower extremities all respond differently during a landing task however a majority of the changes in joint kinematics occur in the sagittal plane. Typically, during sports that require the athlete to constant perform a landing task, the lower extremities will each respond to changes in vGRF according to the specific task performed (Mason-Mackay et al., 2016; West et al., 2014). However, there may be some instances where the lower extremities will experience some changes in the frontal and transverse planes of motion regardless of task being performed.

During landing, the ankle is the first joint in the lower extremity kinematic change to undergo changes, typically plantar or dorsiflexing depending on the type of landing strategy used by the individual (DiStefano et al., 2008; Harry et al., 2019; Mason-Mackay et al., 2016). Based on previous literature, an individual may land heel-to-toe or toe-to-heel, which has revealed slight differentiation when examining peak vGRF (Harry et al., 2017). Previous research has also indicated that a majority of angular displacement occurs in the sagittal plane during landing regardless of the type of movement be performed (West et al., 2014). Additionally, changes in the frontal plane have been recorded when landing, to a lesser extended. Excess changes in frontal plane range of motion about the ankle have been associated with landing on an uneven surface or performing a secondary movement upon landing resulting in additional changes to overall landing mechanics (Dufek & Bates, 1991; McCaw & Cerullo, 1999). Based on previous research it has also been revealed that significant changes in landing mechanics occurs when the ankle of an individual enters excessive inversion (Santos, McIntire, Foecking, & Liu, 2004). Ankle range of motion throughout the course of landing has shown to have additional effects on the other joints of the lower extremities.

Upon landing, the knee acts as the central source for dissipating the maximal amount of force generated upon landing for the lower extremities (Favre et al., 2016). The knee has been indicated to undergo the most angular displacement during jumping and landing tasks, more specifically from initial contact with the ground until the individual returns to a neutral standing position (Favre et al., 2016). At initial contact with the ground, a critical value of 30 degrees of knee flexion has been determined as the minimal amount of knee needed when landing in order to reduce risk of injury (Simpson et al., 2013; Sinsurin et al., 2017). After initial contact the knee goes into flexion, ranging from 45 to 120 degrees of flexion (Simpson et al., 2013; Sinsurin et al., 2017). This rapid increase in knee flexion acts as a response to the amount of force generated at peak vGRF (Harry et al., 2017; Hughes, Watkins, & Owen, 2010). Though most kinematic changes occur in the sagittal plane, it is not uncommon to see changes in frontal plane knee angle (Hughes et al., 2010). These changes in frontal plane knee angle are typically seen when the movement performed occurs after a countermovement jump, which is common in sports such as volleyball. Previous research has revealed that the knee is capable of abduction and adduction during landing, however this change has been associated with changes to internal structures of the knee joint itself (Favre et al., 2016; Wang, Gu, Chen, & Chang, 2010). The most common change identified has been knee abduction, which is common when performing an additional movement upon landing (Paterno et al., 2010; Venesky et al., 2006). This drastic change in knee joint kinematics has been attributed to sudden change in landing mechanics, however the direct cause has not been completely identified.

Compared to the knee and ankle, the hip has not been thoroughly evaluated as being majorly effected by changes in landing mechanics. However, previous research has indicated that some changes associated with the knee and ankle cause very minor alterations to overall hip joint kinematics upon landing (Pollard et al., 2010). These changes are typically seen when performing a secondary movement upon landing. Typically, during a landing task the hip joint moves into flexion in conjunction with the knee and ankle in order to assist the body in dissipating force produced upon landing as well as adjusting to maintain balance (Pollard et al., 2010). Similarly, to the knee and ankle most movement that occurs is analyzed in the sagittal plane however, there are some situations that will cause the hip to exhibit some changes in both the frontal and transverse plane (Hewett & Myer, 2011). Previous studies have shown some changes in both hip abduction/adduction and internal/external rotation during different types of landing tasks, however these differences have been shown to be insignificant (Harry et al., 2019; Pollard et al., 2010).

d. JOINT KINETICS

In combination with changes in joint kinematics and GRF, the joints of the lower extremities will experience changes in joint moments throughout the course of the landing especially if another movement is being performed in sequence (Paterno et al., 2010; Sinsurin et al., 2017). During different types of landings tasks the lower extremity joints must produce various moments in order to increase performance in addition to maintaining balance and stability during landing (Sinsurin et al., 2017). However, depending on the type of movement being performed or sport coupled with external factors the moments acting on the knee may change accordingly (Harry et al., 2018; West et al., 2014).

During landing tasks, the ankle produces flexion and extension moments according to the different phases of the movement in order to optimize landing. It has been found that during landing, more specifically during initial contact with the ground, there is a dorsiflexion moment being produced throughout that specific portion of the landing (Cordova, Takahashi, Kress, Brucker, & Finch, 2010). Additionally, as the individual returns to a neutral standing position there is a plantar flexion moment produced (Cordova et al., 2010). Previous research has found that depending on the type of landing, inversion and eversion torques are present in order to assist in landing effectively (Hughes et al., 2010). Contrarily, excessive joint moments may also cause abnormalities in landing mechanics that can have adverse effects on the overall joint structure of the lower extremities upon repeated exposure to vGRF (Dufek & Bates, 1991; McCaw & Cerullo, 1999). Joint moments have also been shown to increase in proportion to the magnitude of force produced upon landing in addition to any additional movements being performed (Harry et al., 2018; Wulf & Dufek, 2009). Previous research has also shown an increase in joint moments about the ankle in sports requiring a variety of movements being performed.

Previous research has indicated a variety of knee joint moments during various types of landing tasks. As compared to the other joints of the lower extremities the knee has shown the most diverse and variable joint moments that are dependent on the type of movement and landing being performed (Barker et al., 2018; Favre et al., 2016; Yang et al., 2018). The knee joint experiences constant flexion and extension moments through the throughout the course of the movement more commonly during initial contact and peak vGRF (Barker et al., 2018; Wulf

& Dufek, 2009). As stated in previous literature, knee moment increases depending on the type of landing pattern performed, with significantly greater moments recorded when landing with a "stiff" landing pattern (DiStefano et al., 2008; Harry et al., 2019). This indicates that landing with reduced knee flexion results in an increased knee moment, which has been associated with changes to the overall structure of the knee over an extended period of time (Wang et al., 2010). Previous research has also found that upon landing, specifically during peak vGRF there is a possibility of the knee experiencing an abduction moment (Cesar et al., 2016; Venesky et al., 2006). This knee abduction or valgus moment has been defined as the amount of torque produced at the knee joint resulting from the distal end of the lower leg abducting while the knee adducts (Venesky et al., 2006). This type of frontal plane knee moment has been attributed to increased risk of damage to the internal structures of the knee and causes a decrease in performance over a period of time (Cesar et al., 2016; Dufek & Bates, 1991; Sinsurin et al., 2017). This indicates that this type of knee moment is common in sports that require the individual to constantly perform landing tasks in addition to other movements. Furthermore, increases in knee abduction moment have been revealed to increase depending on the type of movement being performed, typically during side-to-side movements following landing, which is common in most sports (Sinsurin et al., 2017; Venesky et al., 2006).

Hip moment has not been thoroughly examined as compared to the ankle and knee however it has still been shown to be adversely effected by different types of landing tasks (Mason-Mackay et al., 2016; Pollard et al., 2010). Similar to the other lower extremity joints, the hip exerts both a flexion and extension moment depending on the phase of the movement and type of movement. When analyzing kinetics of the hip, a hip flexor moment has typically been observed at peak vGRF (DiStefano et al., 2008; Hughes et al., 2010; Mason-Mackay et al., 2016;

Pollard et al., 2010). Depending on the type of movements this flexor moment may vary in magnitude in response to the force generated upon landing (Zahradnik et al., 2017). Furthermore, frontal plane hip joint kinetics have not been found to be significantly affected by changes to the knee and ankle. However, these changes may become more apparent when analyzed in a sport that requires constant jumping and landing. The variations in hip moment have only been identified as present as a result of sudden changes in the different types of movement being performed.

II. LOWER EXTREMITY STRENGTH

Lower extremity strength has been found to be a key component to performance during jumping and landing tasks. Though all muscles of the lower extremities contribute to these specific tasks, the muscle groups that have been shown to have the most impact on performance have been identified as the quadriceps and hamstrings. Each of these muscle groups contribute to different portions of each movement and can have a positive or negative affect on the outcome of that movement. During training, lower extremity strength is worked on throughout the course of a season however, this does not limit the possibility that additional changes may occur during a competition. These changes may also become more apparent upon completion of an entire season which may cause and increase in injury risk.

a. CONTRIBUTION TO JUMPING MECHANICS

Previous research has indicated that lower limb muscular strength is an important factor in increasing jumping performance, more specifically during competition (Rousanoglou et al., 2013). Increased jumping performance has been correlated with the extensors of the knee, quadriceps, where individuals with greater strength yielded a higher maximal jump height. This is achieved through the stretch-shortening cycle of the knee extensors (James et al., 2006;

Malfait et al., 2016). Most movements performed in sports are typically in response to changes in the individual's environment that requires them to perform said movement as quickly as possible. Additionally, in sports that require the individual to perform constant jumping tasks require that individual to have significant strength and endurance in their lower extremities. The countermovement jump has been found to be one of the best movements used for analyzing the contributions of the knee extensors during vertical jumping tasks (Wulf & Dufek, 2009; Wulf et al., 2010). Due to the nature of the countermovement jump, which allows the individual to take advantage of storing elastic energy during the eccentric loading phases of the movement (Harry et al., 2019; James et al., 2006; Wulf & Dufek, 2009). This storage of energy then allows for an increased performance outcome which is directly related with the overall strength of the individual. Previous research has also found that depending on the type of focus used by the individual, such as a response to stimuli during a competition or practicing the movement, will cause additional changes in the overall outcome of the movement (Harry et al., 2019; Wulf & Dufek, 2009; Wulf et al., 2010). Though the knee extensors are viewed as the main contributors to overall jump performance, the knee flexors, or hamstrings, provide addition support in preparation for the jump. The ratio of strength between the knee extensors and flexors are important factors in preparation for the jump as well as key determinants for injury prior to jumping.

b. CONTRIBUTION TO LANDING MECHANICS

Though overall lower limb strength is viewed as a key component in jumping performance it is argued that the muscles of the lower limbs play a more important role in landing (Malfait et al., 2016; Schaal et al., 2013). The knee extensors and flexors are both active during the eccentric deceleration phase upon landing which assist in the dissipation of GRF produced upon landing (Dufek & Bates, 1991; Harry et al., 2019). Both muscles groups have shown to have different activation patterns when landing, however the magnitude of that activation is dependent on the movement performed prior to landing in addition to any movement performed after landing (Malfait et al., 2016). Previous research has found that greater knee extensor and flexor activity when landing may be correlated with lesser knee flexion angle and may have a detrimental effect on the overall landing itself (Malfait et al., 2016; Rousanoglou et al., 2013). As state previously both the quadriceps and hamstrings undergo an eccentric contraction in order to dissipate the amount of GRF produced upon landing however, both muscle groups assist in maintaining the individuals overall balance when landing. Previous research has found that the knee extensors are responsible for increased loading within the knee as a result of transferring energy to the proximal end of the tibia though the patellar tendon (Simpson et al., 2013). Furthermore, it has also been found that the strength of the hamstrings as compared to the quadriceps will have a major impact on overall landing mechanics depending on the landing performed. Eccentric strength of both the quadriceps and hamstring as major contributors to over landing mechanics and play a major role in determining risk of injury during sports that require constant landings to be performed throughout the course of the season (Bamac et al., 2008; Malfait et al., 2016; Wulf et al., 2010).

III. KNEE INJURY

Knee injuries have been found to be one of the most devastating injuries in all sports and recreational activities, especially in those where a secondary movement is performed upon completion of another. Volleyball is a sport that requires the individual to be constantly performing different types of jumps and landings throughout the course of a season. A variety of factors have been found to contribute to knee injuries during training and competition. However, it is currently unknown how a full season of volleyball directly affects these factors especially in young collegiate athletes. Performing these types of tasks repeated may cause the knee to experience a variety of changes that may have detrimental effects on performance and joint structure.

a. FACTORS ASSOCIATED WITH INJURY

Based on previous research, multiple variables in both jumping and landing mechanics may contribute to increases in injury risk (Dufek & Bates, 1991; Mason-Mackay et al., 2016). Additionally, various factors have also been attributed to decreases in performance as a result of performing each type of movement repeatedly leading to overuse and fatigue (Paterno et al., 2010; Wang et al., 2010). Changes have been seen in both jumping and landing tasks, however significant changes have been identified during landing. These significant changes have been found due to sudden alterations in the individuals landing mechanics as a result of changes to lower extremity kinematics and kinetics in addition to reductions in overall lower limb strength (Simpson et al., 2013; Sinsurin et al., 2017).

Previous research has indicated that increased exposure to GRFs during landing tasks may have an adverse effect on knee kinematics and kinetics (DiStefano et al., 2008; Favre et al., 2016). Though most athletes that participate in sports that require them to perform constant jumping and landing tasks it is currently unknown how repeated exposure to those landing directly effects their overall mechanics and injury risk (Dufek & Bates, 1991; Hewett & Myer, 2011; Simpson et al., 2013). Upon landing, it has been found that a decrease in knee flexion angle at peak vGRF causes an increase in both sagittal and frontal plane moment about the knee. Additionally, decreases in overall sagittal plane knee angle displacement has also been observed over an extended period of time (Favre et al., 2016; Harry et al., 2017; Nordin & Dufek, 2019).

Changes in frontal plane knee angle at peak vGRF has also been shown to increase when performing various jumping tasks over an extended period of time (Cesar et al., 2016). Previous research has shown that the knee entering increased abduction upon landing increase knee abduction moment at the time of peak vGRF (Cesar et al., 2016; Paterno et al., 2010). This increase in knee abduction moment has also been shown to couple with additional rotational force upon landing, especially when the individual has performed repeated landings. Increases in peak vGRF have also been associated with increases in injury risk (Nordin & Dufek, 2019). This increase in peak vGRF coupled with increases knee abduction angle and decrease in knee flexion may further increase risk of injury about the knee joint, more specifically the anterior cruciate ligament (Venesky et al., 2006; Wang et al., 2010). This increased risk of injury has typically been associated with increases in vGRF and knee abduction moment upon landing, however overall lower limb strength has been found to contribute to increased injury as well (Hewett & Myer, 2011; Rousanoglou et al., 2013). Muscular imbalance has been shown to cause decreases in performance as well as altering landing mechanics in sports that require the individual to constantly perform these jumping and landing tasks (Wulf et al., 2010). Previous research has found that decreases in muscular strength, specifically in the quadriceps and hamstrings, may contribute to additional increases in overall injury risk (Malfait et al., 2016; Nordin & Dufek, 2019; Schaal et al., 2013). Though it is currently unclear what the effects of a full season of a sport such as volleyball effects overall landing mechanics an injury risk, it is certain that some changes occur as a result of performing repeated landings over an extended period of time.

METHODS

PARTICIPANTS

A stratified sample of eight freshman/sophomore collegiate-level female volleyball players (18.63 ± 0.52 years, 1.75 ± 0.08 m, 71.25 ± 11.31 kg) were recruited to examine the effects of a volleyball season on jump and landing performance. Juniors/seniors were omitted as they are more likely to be accustom to the rigor of the season. The frequency of position included: one setter, three outside hitters, two middle blockers, and two defensive specialists. To be included in the study, participants were required to be on the university's volleyball team and have two-years of experience prior to entering college. Additionally, all participants were required to be at least eighteen years old, physically able to perform a vertical countermovement jump and an approach vertical jump and be free of lower limb injuries for at least 6 months that would hinder their ability to complete each movement. The Division I collegiate season took place over a four-month period and all athletes took part in team workouts throughout the season. Prior to completing any laboratory activities, written consent was obtained in accordance with the local Institutional Review Board and the Declaration of Helsinki (General Assembly of the World Medical Association (2014).

EXPERIMENTAL PROCEDURE

Data collection took place on two separate days, once prior to the start of the season (pre-season) and once after the season (post-season). Procedures for each day were controlled such that both sessions were as identical as possible. Upon arrival to the laboratory, participants were informed of the study procedures and were instructed to fill out a questionnaire regarding history of sports participation, injury history and physical activity. Once all forms were completed, participants' height and mass were measured and recorded. Participants were instructed to wear tight-fitting clothing to accurately represent segment movement and assist in the placement of motion capture markers.

Prior to all testing, participants performed a standardized warm-up consisting of jogging or running on a treadmill at a self-selected pace followed by dynamic stretching replicating the warm-up performed during team workouts. After completing the warm-up, participants' strength was assessed bilaterally on a motor-driven isokinetic dynamometer (Systems 3, Byiodex Medical Systems, Inc., Shirley, NY, USA) with isokinetic knee extensions and flexions at $60°s^{-1}$. Participants were seated in the dynamometer chair and the thigh, waist, and shoulders were secured with safety belts. The rotational axis of the dynamometer was aligned with the medial-lateral knee-joint axis and connected to the distal end of the tibia using a length-adjustable rigid lever arm. The three-dimensional positions of the rotational axis, the position of the chair, and the length of the lever arm were identical for both sessions. Participants performed a series of five consecutive, extension-flexion movements against the lever arm of the dynamometer. The angular velocity of the dynamometer was selected due to its high reproducibility (Dauty & Rochcongar, 2001). Average isokinetic strength for the quadriceps and hamstrings were determined as the average peak torque of all extension and flexion trials. Torque values were recorded for each limb and normalized to the individual's body mass (Nm/kg) for comparison (Rousanoglou et al., 2013). The H:Q ratio was calculated by dividing the average peak flexion torque value by the average peak extension value and used for further comparison.

Upon completion of the strength assessment, participants were given a five-minute rest before completing the jumping tasks. Following the rest period, retro-reflective spherical markers were adhered bilaterally to the following anatomical landmarks of the lower extremities and trunk with hypoallergenic double-sided adhesive tape: anterior superior iliac spine, posterior superior iliac spine, iliac crests, greater trochanters, lateral and medial epicondyles, lateral and medial malleolus, base of the second toe and acromion processes. In addition, singular markers were adhered to the following landmarks of the trunk: manubrium, sternal process, seventh cervical vertebrae, tenth thoracic vertebrae, inferior angle of the right scapula and sacrum. Three non-collinear markers were placed bilaterally on the heel counter of the shoe. Thermo-plastic shells with four non-collinear markers were placed bilaterally, mid-segment, on the thighs and legs using elastic wraps.

Once all markers were adhered, participants were instructed to stand within the capture volume for static calibration. Additionally, five familiarization trials of all study related-jumps were completed to ensure familiarity with each of the jumping tasks (Harry et al., 2018). The jumping tasks used in the current study included countermovement vertical jumps and approach vertical jumps; both jump types were for maximal height. Participants were given eight attempts to complete five successful trials of each jump task. A successful trial was defined as the participant landing with a foot on each force plate without losing their balance and returning to a standing position. If participants completed the five successful trials they did not perform the remaining attempts. No participant required more than the eight attempts they were given to perform five successful trials. Up to 30-seconds of rest was allotted between each trial.

During all jumping tasks, markers trajectories and kinetic data were collected and time synchronized using a 10-camera three-dimensional motion capture system (200 Hz, Vicon Motion Systems, Ltd., Oxford, UK) and two in ground force platforms (1,000 Hz, Advanced Mechanical Technology Inc., MA, USA), mounted flush with the floor, respectively. Kinematic and kinetic data were interfaced to a computer running Vicon Nexus software (version 2.9.1).

DATA PROCESSING

Raw data were exported to Visual3D Biomechanical Software (C-Motion Inc., Germantown, MD, USA) for processing. Raw data were filtered with a low-pass Butterworth digital filter using cutoff frequencies of 12 and 50 Hz for the marker and force data, respectively. From the smoothed marker trajectories, sagittal and frontal plane knee joint angular positions were computed using a Cardan (X-Y-Z) rotation sequence, where X represents the meidal-lateral axis, Y represents the anterior-posterior axis, and Z represents the longitudinal axis. Frontal plane joint moments were calculated using Newtonian inverse dynamic procedures and the right-hand rule was used for three-dimensional net internal joint moment calculation, with moments resolved in the coordinates of the proximal segment. The following variables were measured pre-season (PRE) and post-season (POST) for each landing task: peak vGRF, sagittal and frontal plane knee angle displacement, sagittal and frontal plane knee moment, landing momentum, rate of force attenuation, loading and attenuation phase impulse contribution, maximal jump height and average peak torque during extension and flexion. Vertical position of the pelvis center of mass (COM) was used to obtain a representation of the COM and to track COM motion during each movement, and vertical COM velocity was calculated as the first derivative of the vertical COM position data with respect to time. Take-off and ground contact were identified as the times when summed vGRF data decreased below and subsequently increased above 20 N respectively. At the onset of the jump, it was ensured that no participant unloaded to less than 20 N prior to applying force or take-off (Harry et al., 2019). Landing height was calculated as the square of COM vertical velocity at ground contact divided by two times gravitational acceleration. Peak vGRF was determined as the second peak GRF magnitude, sometimes called ‘F2’, observed during the loading phase (Harry, Barker, Eggleston & Dufek, 2018). The end of the landing was defined as the time when the vertical COM velocity crossed zero after ground contact, while the time between the end of the loading phase and the end of the landing was defined as the attenuation phase (Harry et al., 2018). Rate of force attenuation was calculated by dividing the difference between the peak vGRF and the vGRF at the end of the attenuation phase by the time of the attenuation phase (Harry et al., 2018). Loading and attenuation impulse contributions were calculated by dividing each phase's net impulse by the net impulse produced from both phases (Harry et al., 2018). Maximal jump height was determined by square of COM vertical velocity at takeoff divided by two times gravitational acceleration. Maximal jump height was used in conjunction with landing height because jump height was considered to be the performance measure. Landing momentum was calculated by multiplying the athlete's mass by their COM velocity at ground contact. All joint angle displacements were determined from initial contact to peak vGRF. All kinetic variables were normalized to body weight.

Statistical Analysis

Statistical Analyses were conducted using SPSS version 24 (IBM, Corp., Armonk, NY). Mean and standard deviation values were computed for each variable of interest for PRE and POST sessions. Two (limb: right and left) by two (time: pre and post) factorial analyses of variance (ANOVA; $\alpha=0.05$) were used to test for significant differences for each variable of interest as appropriate. If an interaction was detected, dependent *t*-tests ($\alpha=0.05$) were used for both unilateral comparisons between conditions and between-condition comparisons. If no interaction was detected, limb and time main effects were examined after applying the Sidak adjustment. Dependent *t*-tests ($\alpha=0.05$) were used to test for statistical significance for participants' height, body mass, peak vGRF, maximal jump height, landing momentum, rate of force attenuation, and loading and attenuation impulse contribution between pre and post season. Effect sizes (ES) were also computed as partial eta squared (η^2) and were evaluated with Cohen's scale with trivial ES <0.2, small ES = 0.2-0.49, moderate ES = 0.5-0.79, and large ES ≥ 0.8.

RESULTS

One participant was excluded from the analysis due to suffering an injury during the season, resulting in a final sample of seven female collegiate-level volleyball players (18.71 ± 0.49 years, 1.73 ± 0.05 m, 67.50 ± 4.23 kg). No significant changes between PRE and POST season height and weight (Table 1).

Table 1: PRE and POST Height and Weight

	PRE		POST		
	Mean (SD)		Mean (SD)		p-value
Height (m)	1.73	(0.06)	1.73	(0.05)	0.77
Weight (kg)	67.67	(4.02)	67.50	(4.23)	0.71

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$)

Approach Jump

Landing Characteristics

No significant differences were detected between PRE and POST season values for peak vGRF, landing momentum, rate of force attenuation, loading impulse contribution and attenuation impulse contribution (Table 2).

Jumping Performance

A significant difference between PRE and POST maximal jump height was detected ($p = 0.03$; Table 2) with POST maximal jump height being significantly higher than PRE maximal jump height.

Table 2: PRE and POST Jump Height and vGRF Data for Approach Jump

	Approach Jump				
	PRE		POST		
	Mean (SD)		Mean (SD)		p-value
Peak vGRF (N/BW)	3.31	(0.20)	3.50	(0.36)	0.09
Jump Height (m)	0.37	(0.05)	0.40	(0.07)	0.03*
Landing Momentum (kg*m/s)	-177.44	(17.47)	-181.72	(23.03)	0.15
Rate of Force Attenuation (N/s)	6.86	(2.52)	8.53	(2.45)	0.10

Loading Impulse Contribution (%)	35.23	(12.21)	38.97	(16.17)	0.64
Attenuation Impulse Contribution (%)	64.77	(12.21)	61.03	(16.17)	0.64

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$)

Joint Kinematics and Kinetics

No significant time by limb interactions were detected for all knee joint kinematic and kinetic variables during landing sagittal plane knee displacement ($F(1,24) = 0.01$, $p = 0.93$, $\eta^2 = 0.00$), frontal plane knee displacement ($F(1,24) = 0.53$, $p = 0.47$, $\eta^2 = 0.02$), sagittal plane knee moment ($F(1,24) = 0.37$, $p = 0.55$, $\eta^2 = 0.02$), and frontal plane knee moment ($F(1,24) = 2.58$, $p = 0.12$, $\eta^2 = 0.10$). A significant time main effect was detected for sagittal plane knee displacement ($p = 0.02$). POST sagittal knee displacement from initial contact to peak vGRF was significantly decreased compared to PRE values. No additional time main effects were detected for the remaining kinematic and kinetic variables: frontal plane knee displacement ($p = 0.26$), sagittal plane knee moment ($p = 0.53$), and frontal plane knee moment ($p = 0.99$). A significant limb main effect was detected for frontal plane knee moment at peak vGRF ($p = 0.02$). No additional limb main effects were detected for the remaining kinematic and kinetic variables from initial contact to peak vGRF: sagittal plane knee displacement ($p = 0.93$) frontal plane knee displacement ($p = 0.34$) and sagittal plane knee moment ($p = 0.25$). All η^2 were trivial in magnitude.

Table 3: PRE and POST Knee Kinematics and Kinetics for the Approach Jump

	Approach Jump								
	PRE				POST				
	Left		Right		Left		Right		
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		p-value
Sagittal Plane Displacement (deg)[a]	33.12	(4.01)	33.12	(4.01)	28.14	(5.87)	28.47	(5.27)	0.93
Frontal Plane Displacement (deg)	-0.68	(4.42)	-3.08	(2.78)	-0.07	(4.53)	-0.41	(2.92)	0.47
Sagittal Plane Moment (Nm/kg)	1.09	(0.38)	1.39	(0.42)	1.19	(0.54)	1.28	(0.43)	0.55
Frontal Plane Moment (Nm/kg)[b]	-0.41	(0.15)	0.05	(0.36)	-0.23	(0.24)	-0.12	(0.36)	0.12

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$). P-value represents interaction between time and limb. [a] indicates time main effect between pre- and post-season. [b] indicates limb main effect between left and right limb.

Countermovement Jump

Landing Characteristics

No significant differences were detected between PRE and POST values for peak vGRF, landing momentum, rate of force attenuation, loading impulse contribution and attenuation impulse contribution (Table 4).

Jumping Performance

No significant differences between PRE and POST maximal jump height were detected for the countermovement jump ($p = 0.38$; Table 4).

Table 4: PRE and POST Jump Height and vGRF Data for Countermovement Jump

	Countermovement Jump				
	PRE		POST		
	Mean (SD)		Mean (SD)		p-value
Peak vGRF (N/BW)	3.33	(0.46)	3.47	(0.49)	0.34
Jump Height (m)	0.33	(0.06)	0.35	(0.05)	0.28
Landing Momentum (kg*m/s)	-165.38	(16.91)	-172.32	(20.14)	0.06
Rate of Force Attenuation (N/s)	10.48	(5.99)	8.68	(2.78)	0.25
Loading Impulse Contribution (%)	49.20	(17.97)	36.78	(12.56)	0.07
Attenuation Impulse Contribution (%)	50.80	(17.97)	63.22	(12.56)	0.07

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$)

Joint Kinematics and Kinetics

No significant time by limb interactions were detected for all knee joint kinematic and kinetic variables during landing: sagittal plane knee displacement ($F(1,24) = 0.05$, $p = 0.82$, $\eta^2 = 0.00$), frontal plane knee displacement ($F(1,24) = 1.01$, $p = 0.33$, $\eta^2 = 0.04$), sagittal plane knee moment ($F(1,24) = 0.04$, $p = 0.85$, $\eta^2 = 0.00$), and frontal plane knee moment ($F(1,24) = 1.74$, p

= 0.20, η^2 = 0.07). A significant time main effect was detected for sagittal plane knee displacement ($p = 0.02$; Table 4). POST sagittal knee displacement from initial contact to peak vGRF was significantly lower from PRE values. No additional time main effects were detected for the remaining kinematic and kinetic variables: frontal plane knee displacement ($p = 0.61$), sagittal plane knee moment ($p = 0.85$), and frontal plane knee moment ($p = 0.56$). No limb main effects were detected for all knee joint kinematic and kinetic variables: sagittal plane knee displacement ($p = 0.92$), frontal plane knee displacement ($p = 0.47$), sagittal plane knee moment ($p = 0.20$) and frontal plane knee moment ($p = 0.06$). All η^2 were trivial in magnitude.

Table 5: PRE and POST Knee Kinematics and Kinetics for the Countermovement Jump

	Countermovement Jump								
	PRE				POST				
	Left		Right		Left		Right		
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		p-value
Sagittal Plane Displacement (degree) [a]	32.75	(3.51)	32.25	(1.57)	27.69	(5.76)	28.01	(6.52)	0.82
Frontal Plane Displacement (degree)	0.32	(4.33)	-2.32	(4.05)	-0.42	(3.72)	-0.02	(3.91)	0.33
Sagittal Plane Moment (Nm/kg)	1.10	(0.34)	1.28	(0.32)	1.02	(0.30)	1.16	(0.31)	0.85
Frontal Plane Moment (Nm/kg)	-0.35	(0.23)	-0.04	(0.26)	-0.28	(0.25)	-0.22	(0.27)	0.20

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$). P-value represents interaction between time and limb. [a] indicates time main effect between pre- and post-season. [b] indicates limb main effect between left and right limb.

Lower Extremity Strength

No significant time by limb interactions were detected for PRE and POST average peak extension and flexion torque values ($F(1,24) = 0.02$, $p = 0.89$, $\eta^2 = 0.00$ and $F(1,24) = 0.15$, $p = 0.70$, $\eta^2 = 0.01$, respectively), or H:Q Ratio ($F(1,24) = 0.79$, $p = 0.38$, $\eta^2 = 0.03$). No significant time nor limb main effects were detected for PRE and POST season average peak extension ($p = 0.61$ and $p = 0.81$, respectively) and flexion ($p = 0.91$ and $p = 0.36$, respectively) torque values or H:Q Ratio ($p = 0.38$ and 0.37, respectively). All η^2 were trivial in magnitude.

Table 6: PRE and POST Lower Extremity Strength Values

	PRE				POST				
	Left		Right		Left		Right		
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	p-value
Average Peak Extension (Nm/kg)	1.80	(0.56)	1.82	(0.60)	1.87	(0.44)	1.95	(0.39)	0.89
Average Peak Flexion (Nm/kg)	0.91	(0.29)	1.03	(0.28)	0.93	(0.18)	0.98	(0.18)	0.70
H:Q Ratio	51.01	(10.12)	58.57	(15.77)	50.95	(8.71)	51.05	(8.11)	0.38

Note: Asterisk (*) indicates a statistically significant difference between pre- and post-season ($p < 0.05$). P-value represents interaction between time and limb. [a] indicates time main effect between pre- and post-season. [b] indicates limb main effect between left and right limb.

DISCUSSION

The purpose of this study was to examine changes in lower extremity strength, frontal plane knee angles and moments, and performance during a countermovement and approach jump over the course of a complete Division I collegiate volleyball season in freshmen and sophomore female volleyball players. It was hypothesized that upon completion of the season, there would be a decrease in quadriceps and hamstring strength, decreased sagittal and frontal plane knee angle at vGRF, increased frontal plane knee moment at vGRF and decreased maximal jump height. The findings of this study did not support the hypothesis.

Previous studies have indicated that decreases in quadriceps and hamstring strength coupled with increased peak vGRF, changes in both sagittal and frontal plane knee angle and increases in frontal plane knee moment result from repeatedly performing jumping and landing tasks (Dufek & Bates, 1991; Hughes, Watkins, & Owen, 2010; Paterno et al., 2010; Rousanoglou, Barzouka, & Boudolos, 2013). Repeatedly performing jumping and landing tasks, especially in a sport that may require a secondary movement to be performed immediately upon landing, may lead to increased risk of injury or have a negative effect on overall performance (Hewett & Myer, 2011; Nordin & Dufek, 2019). Additional factors including rate of force attenuation, loading and attenuation impulse contribution and landing moment have been identified as contributors to overall landing mechanics, therefore may be affected by repeated jumping and landing tasks (Barker, Harry, & Mercer, 2018; Harry, Barker, & Paquette, 2019).

Jumping Performance

As displayed in Table 2, approach maximal jump height significantly increased from PRE to POST. The increase in maximal jump height may have resulted from continued training throughout the course of the season, however, this cannot be confirmed as analyzing the strength and conditioning programs of the athletes was beyond the scope of this study. This finding also indicates that the athletes may have increased their take-off velocity when performing the approach jump which would then translate to this increase in performance, based on take-off velocity being directly proportional to overall jump height (Harry et al., 2019; James, Dufek, & Bates, 2006; Wulf & Dufek, 2009). Previous research has confirmed this increase in jump height resulting from an increase in take-off velocity, due to jump height being proportional to velocity, therefore an increased jump height will coincide with an increased takeoff velocity and jump impulse (Harry et al., 2019; Harry, Lanier, Nunley, & Blinch, 2019; Wulf & Dufek, 2009). Overall, there was an improvement in approach jump performance, indicating these athletes improved their jumping abilities regardless of whether there were season-related fatigue effects.

Landing Characteristics

Contrary to this study's hypothesis, there was no significant increase in peak vGRF, which has been identified as a factor contributing to overuse injury (Dufek & Bates, 1991), upon landing for both countermovement and approach jump. Upon analysis of additional landing variables, such as rate of force attenuation, loading and attenuation impulse contribution and landing momentum, no changes in landing mechanics were observed between PRE and POST values. Loading and attenuation impulse contribution have been previously used to determine whether an individual has improved their overall landing mechanics (Harry et al., 2019; Paterno et al., 2010). It has been suggested that increased loading impulse contribution during landing may increase risk of injury while increase in attenuation impulse contribution may reduce this risk of injury (Harry et al., 2019; Harry et al., 2019; Paterno et al., 2010). Increases in attenuation impulse can be further analyzed alongside rate of force attenuation during the landing to determine how well the athlete is attenuating the force generated at peak vGRF until the movement is completed. Landing momentum was not significantly different from PRE and POST for either movement, suggesting the athletes would not produce increased GRF upon landing. However, due to an increase in maximal vertical jump height when preforming the approach jump an increase in landing momentum should have occurred due to the relationship between jump height and landing momentum. Upon further analysis, no differences in body mass between PRE and POST may suggest that these individuals have adopted a new landing strategy to account for than increase in jumping height when landing. Lack of significant differences in landing momentum indicated that the athletes were not at an increased risk of injury or changes in performance resulting from increased vGRF upon landing.

Joint Kinematics and Kinetics

As displayed in Tables 3 and 5, no significant time by limb interactions were detected for sagittal and frontal plane knee displacement in addition to sagittal and frontal plane knee moment for either movement. However, upon further analysis there was a significant decrease in sagittal plane knee displacement between PRE and POST for both the approach and countermovement jump. Previous research has found that a decrease in knee flexion throughout the course of a landing may increase likelihood of injury when performing repeated jumping task or jumping tasks followed by a secondary movement (DiStefano, Padua, Brown, & Guskiewicz, 2008; Dufek & Bates, 1991; Favre, Clancy, Dowling, & Andriacchi, 2016). Decrease in sagittal plane range of motion coupled with increasing in peak vGRF has also been found to further increase risk of injury due to the athlete not being able to dissipate the force created upon landing, specifically during the loading phase (Cesar, Tomasevicz, & Burnfield, 2016; Harry, Silvernail, Mercer, & Dufek, 2017; Hewett & Myer, 2011). However, this decrease in sagittal plane range of motion at the knee is not a determinant of injury risk alone, additional research has shown that increases in frontal plane knee moment occur alongside this change (Dufek & Bates, 1991; Paterno et al., 2010). Differences in frontal plane knee moment between limbs were also observed upon landing from the approach jump. Previous research has shown that upon landing, individuals may favor their dominant limb slightly in order to stabilize the landing, and prepare themselves for a secondary movement that they may need to perform immediately upon landing (Harry, Silvernail, Mercer, & Dufek, 2018; Nordin & Dufek, 2019; Sinsurin, Srisangboriboon, & Vachalathiti, 2017). Limb dominance becomes more apparent as significant differences in frontal plane knee moments at peak vGRF between limbs occurred when landing from an approach jump which simulates a movement constantly performed during competition. Increases in knee moment have been identified as a component linked to increased injury risk between limbs, however lack of increased knee moment specifically at peak vGRF suggest that these athletes are not at an increased risk of injury upon completing a full season of competition.

Lower Extremity Strength

No decreases in lower extremity strength were found between PRE and POST based peak average torque values during extension or flexion. This finding did not support this study's hypothesis that upon completion of a volleyball season, there would be a decrease in quadriceps and hamstring strength or a change in H:Q ratio as a result of repeatedly performing jumping and landing tasks throughout the season. Previous research has shown that a decrease in muscular strength in the quadriceps and hamstring muscle groups may have detrimental effects on overall performance and landing mechanics (Bamac et al., 2008; Dufek & Bates, 1991; Schaal, Ransdell, Simonson, & Gao, 2013). Muscular balance has been determined as a possible factor for increasing injury risk, typically when the hamstrings are incapable of producing a torque value that increases with the quadriceps as indicated by the H:Q ratio (Rousanoglou et al., 2013;

Schaal et al., 2013). This muscular imbalance affects the overall structure of the knee when landing and may lead to increase frontal plane knee moment and decreases in sagittal and frontal plane knee displacement. However, no significant differences in H:Q ratio suggested that these athletes were not at an increased risk of injury nor did they suffer from fatigue throughout the course of the season.

Limitations

Possible limitations to this study included a small sample size, inability to simulate movements performed during competition, and lack of control over exercise routine. Because this study's sample size was small (only eight participants were tested which then became seven total athletes due to injury), the results should be considered preliminary. This study recognizes that additional significance may have been found in variables such as frontal plane knee moment, vGRF and strength values if there was an increased sample size. The individuals that were recruited for this study were the only ones from the team that met the qualification criteria, therefore this was the largest sample size possible from the team. However, future research may follow these individuals throughout their collegiate careers and expand on overall sample size as additional player are added to the team. Movements that were analyzed for this study were instructed to each participant in order to control each individual's movement, however during "in-game" situations these movements may change drastically according to a number of variables include the position of each athlete. Not all athletes will be constantly performing an approach jump or countermovement jump as each position has their own specific responsibility. Finally, all athletes participated in team practices and had similar workout routines, however, it was impossible to control for additional training by each individual athlete outside of team practices. This additional training may have had an effect on overall outcome measures.

CONCLUSION

The current study revealed that a complete Division I colligate volleyball season has no effects on lower extremity strength, sagittal and frontal plane knee angle and moments, nor compromises performance. Lack of significant changes in variables associated with increased injury risk indicated that despite participation in a full colligate volleyball season, this group of freshmen and sophomore players were not at an increased risk of injury or negative performance outcomes. No decreases in lower extremity strength or muscular imbalance indicated that these athletes were not at an increased risk of injury, which may result from fatigue throughout the course of the season. Though some differences were present between PRE and POST sagittal plane knee displacement it cannot be concluded that increased risk of injury will result from this change alone. Furthermore, some differences in frontal plane knee moment between limbs may indicate limb dominance when landing; however, this can only be determined through additional research. Finally, an increase in approach jump performance was found upon completion of the volleyball season; however, this increase in jumping performance cannot be expanded upon by the outcomes measures of the current study. Based on these outcomes it is possible that changes may occur in performance however, no changes in landing mechanics or increased risk of injury are present.

REFERENCES

Bamac, B., Colak, T., Ozbek, A., Colak, S., Cinel, Y., & Yenigun, Ã. (2008). Isokinetic performance in elite volleyball and basketball players. *Kinesiology: International Journal of Fundamental and Applied Kinesiology, 40*(2), 183-189.

Barker, L. A., Harry, J. R., & Mercer, J. A. (2018). Relationships between countermovement jump ground reaction forces and jump height, reactive strength index, and jump time. *Journal of Strength and Conditioning Research, 32*(1), 248-254. doi:10.1519/JSC.0000000000002160 [doi]

Cesar, G. M., Tomasevicz, C. L., & Burnfield, J. M. (2016). Frontal plane comparison between drop jump and vertical jump: Implications for the assessment of ACL risk of injury. *Sports Biomechanics, 15*(4), 440-449.

Cohen, J, 1988. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Erlbaum, Hillsdale, New Jersey

Cordova, M. L., Takahashi, Y., Kress, G. M., Brucker, J. B., & Finch, A. E. (2010). Influence of external ankle support on lower extremity joint mechanics during drop landings. *Journal of Sport Rehabilitation, 19*(2), 136-148.

Dauty, M., & Rochcongar, P. (2001). Reproducibility of concentric and eccentric isokinetic strength of the knee flexors in elite volleyball players. *Isokinetics and exercise science*, *9*(2 3), 129-132.

DiStefano, L. J., Padua, D. A., Brown, C. N., & Guskiewicz, K. M. (2008). Lower extremity kinematics and ground reaction forces after prophylactic lace-up ankle bracing. *Journal of Athletic Training, 43*(3), 234-241.

Dufek, J. S., & Bates, B. T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine, 12*(5), 326-337.

Favre, J., Clancy, C., Dowling, A. V., & Andriacchi, T. P. (2016). Modification of knee flexion angle has patient-specific effects on anterior cruciate ligament injury risk factors during jump landing. *The American Journal of Sports Medicine, 44*(6), 1540-1546.

General Assembly of the World Medical Association. (2014). World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *The Journal of the American College of Dentists*, *81*(3), 14.

Harry, J. R., Barker, L. A., Eggleston, J. D., & Dufek, J. S. (2018). Evaluating performance during maximum effort vertical jump landings. *Journal of applied biomechanics*, *34*(5), 403-409.

Harry, J. R., Barker, L. A., & Paquette, M. R. (2019). A joint power approach to define countermovement jump phases using force platforms. *Medicine and Science in Sports and Exercise,* doi:10.1249/MSS.0000000000002197 [doi]

Harry, J. R., Lanier, R., Nunley, B., & Blinch, J. (2019). Focus of attention effects on lower extremity biomechanics during vertical jump landings. *Human Movement Science, 68*, 102521.

Harry, J. R., Silvernail, J. F., Mercer, J. A., & Dufek, J. S. (2017). Comparison of pre-contact joint kinematics and vertical impulse between vertical jump landings and step-off landings from equal heights. *Human Movement Science, 56*, 88-97.

Harry, J. R., Silvernail, J. F., Mercer, J. A., & Dufek, J. S. (2018). Bilateral comparison of vertical jump landings and step-off landings from equal heights. *The Journal of Strength & Conditioning Research, 32*(7), 1937-1947.

Hewett, T. E., & Myer, G. D. (2011). The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury. *Exercise and Sport Sciences Reviews, 39*(4), 161-166. doi:10.1097/JES.0b013e3182297439 [doi]

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt Jr, R. S., Colosimo, A. J., McLean, S. G., Van den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *The American journal of sports medicine*, *33*(4), 492-501.

Hughes, G., Watkins, J., & Owen, N. (2010). Differences between the sexes in knee kinetics during landing from volleyball block jumps. *European Journal of Sport Science, 10*(1), 1-11.

James, R. C., Dufek, J. S., & Bates, B. T. (2006). Effects of stretch shortening cycle exercise fatigue on stress fracture injury risk during landing. *Research Quarterly for Exercise and Sport, 77*(1), 1-13.

Laffaye, G., & Wagner, P. (2013). Eccentric rate of force development determines jumping performance. *Comput Methods Biomech Biomed Engin*, *16*(1), 82-83.

Malfait, B., Dingenen, B., Smeets, A., Staes, F., Pataky, T., Robinson, M. A., et al. (2016). Knee and hip joint kinematics predict quadriceps and hamstrings neuromuscular activation patterns in drop jump landings. *PloS One, 11*(4), e0153737.

Mason-Mackay, A. R., Whatman, C., Reid, D., & Lorimer, A. (2016). The effect of ankle bracing on landing biomechanics in female netballers. *Physical Therapy in Sport, 20*, 13-18.

McCaw, S. T., & Cerullo, J. F. (1999). Prophylactic ankle stabilizers affect ankle joint kinematics during drop landings. *Medicine and Science in Sports and Exercise, 31*, 702-707.

McHugh, M. P., Hickok, M., Cohen, J. A., Virgile, A., & Connolly, D. A. (2020) Is there a biomechanically efficient vertical ground reaction force profile for countermovement jumps?. *Translational Sports Medicine*.

Myer, G. D., Ford, K. R., Foss, K. D. B., Liu, C., Nick, T. G., & Hewett, T. E. (2009). The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clinical journal of sport medicine*, *19*(1), 3-8.

Nordin, A. D., & Dufek, J. S. (2019). Reviewing the variability-overuse injury hypothesis: Does movement variability relate to landing injuries? *Research Quarterly for Exercise and Sport, 90*(2), 190-205.

Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Huang, B., et al. (2010). Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *The American Journal of Sports Medicine, 38*(10), 1968-1978.

Pollard, C. D., Sigward, S. M., & Powers, C. M. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clinical Biomechanics, 25*(2), 142-146.

Rousanoglou, E. N., Barzouka, K. G., & Boudolos, K. D. (2013). Seasonal changes of jumping performance and knee muscle strength in under-19 women volleyball players. *The Journal of Strength & Conditioning Research, 27*(4), 1108-1117.

Santos, M. J., McIntire, K., Foecking, J., & Liu, W. (2004). The effects of ankle bracing on motion of the knee and the hip joint during trunk rotation tasks. *Clinical Biomechanics, 19*(9), 964-971.

Schaal, M., Ransdell, L. B., Simonson, S. R., & Gao, Y. (2013). Physiologic performance test differences in female volleyball athletes by competition level and player position. *The Journal of Strength & Conditioning Research, 27*(7), 1841-1850.

Simpson, K. J., Yom, J. P., Fu, Y., Arnett, S. W., O'Rourke, S., & Brown, C. N. (2013). Does wearing a prophylactic ankle brace during drop landings affect lower extremity kinematics and ground reaction forces? *Journal of Applied Biomechanics, 29*(2), 205-213.

Sinsurin, K., Srisangboriboon, S., & Vachalathiti, R. (2017). Side-to-side differences in lower extremity biomechanics during multi-directional jump landing in volleyball athletes. *European Journal of Sport Science, 17*(6), 699-709.

Venesky, K., Docherty, C. L., Dapena, J., & Schrader, J. (2006). Prophylactic ankle braces and knee varus-valgus and internal-external rotation torque. *Journal of Athletic Training, 41*(3), 239-244.

Wang, L. I., Gu, C. Y., Chen, W. L., & Chang, M. S. (2010). Potential for non-contact ACL injury between step-close-jump and hop-jump tasks. *Journal of Sports Science & Medicine, 9*(1), 134-139.

West, T., Ng, L., & Campbell, A. (2014). The effect of ankle bracing on knee kinetics and kinematics during volleyball-specific tasks. *Scandinavian Journal of Medicine & Science in Sports, 24*(6), 958-963.

Wulf, G., & Dufek, J. S. (2009). Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *Journal of Motor Behavior, 41*(5), 401-409.

Wulf, G., Dufek, J. S., Lozano, L., & Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus. *Human Movement Science, 29*(3), 440-448.

Yang, C., Yao, W., Garrett, W. E., Givens, D. L., Hacke, J., Liu, H., et al. (2018). Effects of an intervention program on lower extremity biomechanics in stop-jump and side-cutting tasks. *The American Journal of Sports Medicine, 46*(12), 3014-3022.

Zahradnik, D., Jandacka, D., Farana, R., Uchytil, J., & Hamill, J. (2017). Identification of types of landings after blocking in volleyball associated with risk of ACL injury. *European Journal of Sport Science, 17*(2), 241-248.

VITA

Christian Noel Sanchez graduated from the University of Texas at El Paso in 2018, with a Bachelor of Science (B.S) in Kinesiology. Upon graduating, he enrolled in the University of Texas at El Paso's Masters in Kinesiology program and was employed as a graduate teaching assistant under Dr. Jeffrey D. Eggleston. As a graduate teaching assistant, he assisted in the instruction of various undergraduate labs including biomechanics, exercise prescription and coronary intervention. During his studies he attended and presented original research at the International Society of Biomechanics and American Society of Biomechanics Annual Conferences. As a graduate student Christian received the Dodson Research Grant through the University of Texas at El Paso's Graduate school, which assisted him in funding additional research. Christian will pursue his doctoral degree in the Fall of 2021, continuing his interest in lower extremity mechanics in athletes and recreationally active individuals while performing various movements in practice and competition. Specifically, examining lower extremity mechanics associated with injury.