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I am submitting herewith a thesis written by Abhaya Srivatsan “Can female recreational athletes alter their jump landing mechanism on verbal instructions?” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

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**CAN FEMALE RECREATIONAL ATHLETES ALTER THEIR JUMP
LANDING MECHANISM ON VERBAL INSTRUCTION?**

A Thesis Presented for
the Master of Science
Degree
The University of Tennessee, Knoxville

Abhaya Srivatsan

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CHAPTER 1: INTRODUCTION

The knee is the body part that is injured most frequently during sports participation (Jones, Louw et al. 2000; Kirialanis, Malliou et al. 2003; Agel 2007; Hootman 2007) . Surveillance of men's and women's soccer and basketball injury rates from the National Collegiate Athletic Association (NCAA) institutions showed that knee injuries contributed 16% of body injury for soccer and 19% of total injuries for basketball (Arendt and Dick 1995) . Rupture of the anterior cruciate ligament (ACL) has been shown to be the most common form of knee injury (Arendt, Agel et al. 1999) . According to the data compiled by NCAA injury surveillance system more than 60% of all athletic injuries among national collegiate women basketball players, were lower extremity injuries (Agel 2007) . Injuries to the anterior cruciate ligament accounted for 8% of the total game injuries (Agel 2007) . ACL injuries often require surgeries and extensive rehabilitation. Apart from incurring high costs, ACL injuries can be season ending and at times career ending for these athletes. Therefore, any intervention that will decrease the number of ACL injuries could benefit athletes and society greatly.

Though both men and women are equally susceptible to knee injury at a younger age (between the ages of 11 and 12), female athletes have an increased susceptibility to non contact injury as they grow older (between the ages of 14 and 15) (Jones, Louw et al. 2000) . Women soccer players exhibited twice the risk of sustaining an ACL tear when compared to their male counterparts, whereas women basketball players exhibited four times the risk of an ACL injury when compared to male players (Arendt, Agel et al. 1999) . Not only are women more susceptible to injury, but a significantly greater number of the female basketball and soccer

players who reported ACL injury required surgery when compared to their male counterparts (Arendt and Dick 1995) .

The reasons for the difference in occurrence of injury have not been fully determined. Studies have suggested that the anatomical, hormonal and neuromuscular differences between men and women contribute largely to this difference (Dugan 2005) . Additionally, female athletes appear to have a different landing technique when compared to their male counterparts (Rozzi, Lephart et al. 1999) . Females with greater knee joint laxity take greater time to detect knee joint motion when moving into extension (Rozzi, Lephart et al. 1999) . Research has indicated that incorrect landing mechanisms, pivoting and sudden deceleration are major causes of non-contact knee injury and ACL rupture (Arendt, Agel et al. 1999; Boden, Dean et al. 2000; Jones, Louw et al. 2000; Kirialanis, Malliou et al. 2003) . Approximately 80% of the injuries occur via non-contact mechanisms (Arendt, Agel et al. 1999; Boden, Dean et al. 2000) and are, therefore, potentially avoidable.

Hewett et al. (2005) showed that there is a difference in the kinematics of the knee between ACL injured and uninjured players during landing. The injured players demonstrated a significantly greater knee abduction angle and a lesser knee flexion angle when compared to the uninjured players (Hewett, Myer et al. 2005) . Another study was performed on cadaver knees to compare the anteriomedial ACL strain under sagittally symmetric impulsive axial loading with and without valgus knee movement (Withrow, Huston et al. 2006) . This simulated a jump landing or a sudden stop. Results confirmed the direct relationship between knee valgus position and the occurrence of an ACL injury. In a comparison between male and female high school basketball players, female players demonstrated a significantly greater valgus knee motion and

greater maximum knee valgus angle during a jump landing when compared to their male counterparts (Ford, Myer et al. 2003) .

Another factor contributing to an ACL injury is landing with high ground reaction force. Studies have shown that athletes who land with greater peak forces have a greater tendency to have an ACL injury (Hewett, Myer et al. 2005) . There also seemed to be a direct relationship between the seriousness of the injury and the magnitude of peak ground reaction force (i.e., the greater the ground reaction force, the worse the injury) (Louw, Grimmer et al. 2006) . A relationship between peak ground reaction force and peak knee flexion angles has also been reported. Lower ground reaction forces have been linked to increased knee flexion angles (Devita and Skelly 1992; Hewett, Myer et al. 2005; Louw, Grimmer et al. 2006) . Knee injury is associated with peak vertical ground reaction forces, which in turn is associated with the peak knee flexion angle, therefore knee flexion angle may be an important factor in ACL injury risk. It has been suggested that a greater flexion angle is associated with better impact absorption, thereby decreasing the load on the knee (Devita and Skelly 1992) . Work done by the skeletal system on the muscle is associated with eccentric contractions, which is indicated by eccentric work (Devita and Skelly 1992) . ACL injured players demonstrate less eccentric activity (negative work) when compared to injured players (Louw, Grimmer et al. 2006) . Also, the eccentric work done at the knee during softer landing was found to be 46% greater than during hard landing (Devita and Skelly 1992).

It has also been shown that there is a short delay in landing between the dominant and non-dominant foot and forces applied by the lower limbs on the ground were also asymmetrical (Oggero, Pagnacco et al. 1997). A comparison between ACL injured and uninjured players revealed that injured players exhibited a significant difference bilaterally in knee loading

whereas the uninjured players did not (Hewett, Myer et al. 2005). There has been limited research on the injuries caused due to inter-limb knee loading differences.

A study analyzing injury surveillance data reported an 80% increase in female participation in NCAA championships over the last 16 years (Hootman 2007). Therefore, there is an increasing interest in preventing ACL injuries in female athletes. Several measures have been taken to reduce the factors thought to contribute to an ACL rupture. Studies have shown that neuromuscular strengthening for female athletes can help reduce the incidence of an ACL rupture by decreasing the risk factors associated with it (Hewett, Lindenfeld et al. 1999). Other intervention strategies such as video and verbal feedback have also been employed (Onate 2005). Athletes who have watched themselves land on videotape were able to change their landing mechanics and jump with a significantly reduced ground reaction force. Since athletes at all levels cannot afford to undergo supervised training, and videotaping is not always readily available, this study proposed to see whether changes to landing mechanics can be made when verbal instructions are given to the athlete.

Traditional landing protocols involve either stepping off a box and landing onto a force plate or a vertical drop jump from a bar (Devita and Skelly 1992; Ford, Myer et al. 2003; Ford, Myer et al. 2005; Hewett, Myer et al. 2005). Although these methods are highly controlled, they do not represent what occurs during an actual game situation. They have a fixed height from which the participants jump which may not represent each individual's maximum jump height. The current study will use a technique which involves landing after a countermovement jump. This method allows a dynamic whole body movement from the ground and also represents the athlete's maximum jump height. This is closer to the jumping technique during an actual game situation, while still maintaining controlled conditions.

PURPOSE

The purpose of this study was to determine if female recreational athletes can change their landing mechanism after a countermovement jump on verbal instructions. The study aims to examine the effect of the following instructions:

(i) to land with weight equally distributed on both legs; (ii) to land with the knees directly over toes (i.e., without a valgus knee position); (iii) to land as softly as possible. A control landing condition was also included.

The following null hypotheses were tested to determine whether differences existed among the conditions. The null hypotheses for this study were:

- 1) There will be no differences in total knee valgus motion among the four conditions,
- 2) There will be no differences in the maximum knee valgus angle among the four conditions,
- 3) There will be no differences in the peak vertical ground reaction force among the four conditions,
- 4) There will be no differences in the maximum knee flexion angle among the four conditions,
- 5) There will be no differences in total eccentric work among the four conditions,
- 6) There will be no differences in symmetry index of peak vertical ground reaction force among the four conditions

LIMITATIONS:

1. Error in the motion capture system may exist. However, every effort was made to complete the process adherent to sound biomechanical principles and practices.
2. Participants may misinterpret instructions. However participants were asked to repeat instructions and to perform at least one practice jump in every condition to ensure understanding of the task.

DELIMITATIONS

1. The participants recruited were healthy and had no current lower limb injuries.
2. The participants were a convenience sample from the University of Tennessee student body.
3. The participants performed four different conditions of five trials each.

Kinematic and kinetic bilateral data were obtained. Two synchronized AMTI force plates with a sampling frequency of 1200 Hz (AMTI, Newton, MA, USA) and a seven camera motion analysis system with a sampling frequency of 240Hz (Vicon MX, Oxford. Metrics, Oxford, UK) were used.

ASSUMPTIONS:

1. Participants jumped to their maximum height.
2. Participants were motivated to put forth best effort.
3. All participants interpreted instructions similarly.

DEFINITIONS

Knee abduction/valgus angle – Knocked knee position

Maximum knee valgus angle – Angle at peak valgus position

Total knee valgus motion – Change in knee angle from initial contact to maximum knee valgus angle

Knee flexion angle – Angle at which peak flexion occurs (angle up to which the knee bends)

Peak vertical ground reaction force – The force with which the participant lands on the force plate.

CHAPTER 2: REVIEW OF LITERATURE

Incidence of Knee Injury/ ACL Rupture

The knee is one of the most frequently injured parts of the body during sports participation (Jones, Louw et al. 2000; Kirialanis, Malliou et al. 2003; Agel 2007; Hootman 2007). Rupture of the anterior cruciate ligament (ACL) is the most common form of knee injury (Arendt, Agel et al. 1999). ACL injuries often require surgeries and extensive rehabilitation. At the intercollegiate level, more than 2200 ACL tears have been predicted to occur each year for just female athletes, with the cost of recovery for each patient being approximately \$17,000 (Hewett, Lindenfeld et al. 1999). It was also observed that 76% of female athletes who have an ACL injury undergo surgery (Arendt and Dick 1995). It has been reported that ACL injuries cost an annual sum of \$100 million for high school and collegiate women athletes alone and a total of \$646 million for all female athletes (Hewett, Myer et al. 2005).

Mechanism of ACL injury

ACL injuries occur either via a contact mechanism or a non-contact mechanism. A contact injury can occur either via player contact or other contact, such as contact with the ball or floor. The non-contact mechanism of an ACL rupture occurs when injury is not associated with direct contact with an external factor; hence these types of injuries may be prevented. Non-contact injuries occur when there is deceleration and change of direction while the tibia is internally rotated (Emerson 1993); or when there is anterior tibial translation which results in the generation of anterior knee shear forces (Chappell, Yu et al. 2002). Other mechanisms include cut landing and sudden stopping during running. A much greater percentage of ACL rupture

occurs via a non-contact mechanism when compared to the contact mechanism (Arendt, Agel et al. 1999; Kirkendall and Garrett 2000). Among collegiate female basketball players, 80% of the ACL injuries occurred via non-contact mechanism and 20% via player contact (Arendt, Agel et al. 1999). A video analysis 39 anterior cruciate ligament injuries were observed to understand the mechanism of injury (Krosshaug, Nakamae et al. 2007). Of these, 23 videos were high school and college level basketball games, 5 from NBA and WNBA games and 11 from the NBA and WNBA Entertainment Inc. Eleven of these 39 injuries occurred via contact mechanism and the remaining 72% of the injuries occurred via non contact mechanism. Out of these, 10 out of 39 players were injured during a single leg landing, 13 players were injured during a double leg landing and 4 players were injured when performing a cutting maneuver. These studies show that non-contact mechanism is the most common mechanism of injury that occurs during jump-landing.

Relationship between ACL injury and Gender

The NCAA reported that the rate of ACL injury is higher in women when compared to men in both soccer and basketball (Agel, Arendt et al. 2005). The ACL injury rate in collegiate women is double that of collegiate men in soccer and four times that in basketball (Arendt, Agel et al. 1999). In high school basketball players it was identified that 10% of all injuries were knee injuries for boys and 20% for girls (Messina, Farney et al. 1999). Among the knee-injured participants, 33% of the boys had to undergo surgery, whereas 64% of the girls had to undergo surgery. This study indicates that at high school level more girls suffer ACL injuries when compared to boys. Also, a greater percentage of injured girls undergo surgery than injured boys.

Various different reasons have been suggested for gender differences in the incidence of ACL injury. These include differences in anatomy (Rozzi, Lephart et al. 1999; Uhorchak, Scoville et al. 2003), differences in neuromuscular factors (Moul 1998; Rozzi, Lephart et al. 1999) and differences in hormonal factors (Sarwar, Niclos et al. 1996; Wojtys, Huston et al. 1998; Hewett 2000) between the genders. The most prominent anatomical factors thought to predispose athletes to an ACL injury include a narrower femoral notch width, high body mass index (BMI) and joint laxity (Rozzi, Lephart et al. 1999; Uhorchak, Scoville et al. 2003). Increased joint laxity hinders a joint from sensing and responding to joint stress (Rozzi, Lephart et al. 1999). This may contribute to ligament injury (Rozzi, Lephart et al. 1999). The mechanism by which a reduced femoral notch and increased BMI influences the occurrence of ACL injury is still unclear, however studies have shown that these factors increase the rate of injury occurrence (Rozzi, Lephart et al. 1999; Uhorchak, Scoville et al. 2003). Femoral notch width and general joint laxity are not modifiable; body mass index is the only modifiable anatomical factor (Uhorchak, Scoville et al. 2003).

The most prominent neuromuscular factor that contributes to ACL injury is a low eccentric hamstrings to relative eccentric quadriceps strength ratio (Huston and Wojtys 1996; Moul 1998). The hamstrings act as an ACL antagonist and balance the force exerted by the quadriceps on the ACL. The quadriceps can exert 50% to 100% greater force than the hamstrings. If the hamstrings are not strong enough to oppose the force exerted by the quadriceps, it can lead to anterior translation of the tibia, thereby causing significant strains on the ACL (Huston and Wojtys 1996). Knee instability can also occur due to decreased neuromuscular strength and coordination (Hewett 2000). This can increase ligament laxity and predispose athletes to the incidence of ACL injury (Hewett 2000). Another neuromuscular factor that could potentially

predispose female athletes to ACL injuries is delayed hamstrings activation when compared to male athletes (Huston and Wojtys 1996). Activation of the hamstrings before the quadriceps maximizes the hamstring ability to protect the ACL (Steele and Brown 1999). The hamstrings co-contract with the quadriceps to lessen the force on the ACL. Therefore, a delay in hamstring activation can cause high forces exerted by the quadriceps to act on the ACL.

The presence of hormones like estrogen and progesterone in females has been identified as one of the potential risk factors predisposing them to ACL injuries (Sarwar, Niclos et al. 1996; Wojtys, Huston et al. 1998). These hormones play a role in the active and passive knee stabilization (Wojtys, Huston et al. 1998). The number of ACL injuries was found to be greater during the ovulatory phase of the menstrual cycle (Wojtys, Huston et al. 1998). The estrogen levels are very high during this phase. Another study was performed to test the changes in muscle strength with different phases of the menstrual cycle (Sarwar, Niclos et al. 1996). They found a 11% increase in quadriceps strength during the ovulatory phase when compared to the follicular and menstrual phase. This was accompanied by an increase in susceptibility to fatigue and slower relaxation in the ovulatory phase. This suggests that the hormonal fluctuation during the menstrual cycle could influence the occurrence of knee injury, though the exact relationship is still unclear (Sarwar, Niclos et al. 1996; Wojtys, Huston et al. 1998; Hewett 2000).

Occurrence of injury in the jump-landing phase

It has been reported that knee injuries frequently occur during the landing phase of jumping in any sport or exercise (Ferretti, Papandrea et al. 1992; Kirialanis, Malliou et al. 2003). Kirialanis et al., (2003) observed 162 gymnasts participating in the Greek artistic gymnastic championships. They reported that 50% of the knee injuries to female gymnasts, and 70% of the

knee injuries to the male gymnasts occurred during the landing phase of the exercise (Kirialanis, Malliou et al. 2003). These results were supported by another detailed study of the mechanism of occurrence of ACL injuries amongst 52 volleyball players injured while playing at different levels at the National Championship. Most ACL injuries (48 out of 52) occurred during the jumping phase and specifically, around 80% occurred during the landing phase (Ferretti, Papandrea et al. 1992). A video analysis by Krosshaug et al., (2007) showed that 10 of 17 male and 13 out of 22 female players obtained an ACL injury during the landing phase (Krosshaug, Nakamae et al. 2007). Another video analysis was performed on 20 videos of ACL injured female handball players from the 1998-1999 Norwegian or international competition (Olsen, Myklebust et al. 2004). They found that the landing mechanism was the second most common reason for the occurrence of ACL injury, after plant-and-cut movement. Four out of 20 injuries occurred during landing. On balance, the above mentioned studies suggest that most ACL injuries occur during the landing phase of a jump.

Knee mechanics and the occurrence of ACL injury

Studies have reported that landing with a valgus knee position is a high risk factor for the occurrence of an ACL injury (Ford, Myer et al. 2003; Olsen, Myklebust et al. 2004; Hewett, Myer et al. 2005). A study of 81 high school basketball players found gender differences in knee valgus motion (Ford, Myer et al. 2003). Female athletes demonstrated a peak knee valgus angle of $27.6 \pm 2.2^\circ$ after a vertical jump from a box of height 31 cm whereas their male counterparts demonstrated an angle of $16.1 \pm 2.1^\circ$ (Ford, Myer et al. 2003). In a video analysis of 20 ACL injured players, Olsen et al. (2004) observed that injury occurred when there was a valgus collapse with an internal or external rotation of the knee in a fully extended position

(Olsen, Myklebust et al. 2004). A prospective study measured the valgus knee position during landing in subsequently ACL injured and uninjured female athletes (Hewett, Myer et al. 2005). They prescreened 205 female soccer, basketball and volleyball players and performed a biomechanical analysis of landing before the game season. They found that female athletes who subsequently sustained an ACL rupture landed with an 8.4° greater knee abduction angle at initial contact and 7.6° (2.5 times more) greater knee peak abduction angle when compared to healthy controls (Hewett, Myer et al. 2005). Landing with a greater valgus knee position could predispose athletes to an ACL rupture (Hewett, Myer et al. 2005). Studies also suggest that female athletes tend to land with a greater valgus knee angle when compared to their male counterparts during landing (Ford, Myer et al. 2003) and during unanticipated cutting maneuvers (Ford, Myer et al. 2005).

Relationship between impact loading and occurrence of injury

A direct relationship has been demonstrated between high ground reaction forces during landing and the occurrence of injury (Hewett, Myer et al. 2005). During landing, the body segments interact to reduce the forces acting on the body. This interaction of segments is referred to as phasing. A comparison of interaction of body segments during hard and soft landing was observed (Lees 1981). Hard landing was defined as landing with a high force peak and soft landing involved landing with a low force peak. The soft landing was found to produce a phased deceleration of segments thereby reducing the total vertical force produced on the joints. During hard landings, the body is relatively rigid and all the body segments decelerate together producing higher force levels. Lower force values produced during soft landing may reduce injury risk when compared to the hard landing (Lees 1981). However, the exact

instructions provided to the participants for landing was not mentioned. Also, only two participants were used for the study, one to perform the hard landing and the other to perform the soft landing. Since the sample size was extremely small the results of the study should be interpreted with caution.

Devita and Skelly (1992) compared vertical ground reaction forces during a soft and a stiff landing among eight healthy intercollegiate basketball and volleyball players. They found that a soft landing is performed with a greater degree of knee flexion when compared to a stiff landing (Devita and Skelly 1992). The final knee position for a soft landing was found to be 117° and for the stiff landing was found to be 77° of knee flexion. The peak vertical ground reaction force exerted during the stiff landing was significantly larger than the soft landing. The eccentric work done at the knee was 46% larger in the soft landing indicating that the muscles crossing the knee were absorbing more energy in the soft when compared to the stiff landing.

Another study showed that uninjured players demonstrated greater eccentric activity when compared to ACL injured players during landing (Louw, Grimmer et al. 2006). In this study, 22 basketball players (11 previously injured and 11 uninjured) were instructed to run and simulate a basketball jump and land with one foot on each force plate (Louw, Grimmer et al. 2006). The injured players done an average eccentric work of -2.14J/N.m and the uninjured done an average eccentric work of -3.37J/N.m . Furthermore, a direct relationship was found between the magnitude of peak ground reaction force and the intensity of injury. The average peak ground reaction force between the cases and controls was not significantly different, but the participants with worse injury exhibited greater peak ground reaction force during landing. There was a positive correlation identified between the ground reaction force values and average injury score. The injured participants were asked to evaluate their knee pain by completing the

Hughston Visual Analog Knee Scale and ‘injury scores’ were calculated based on these scores with respect to gender and age. There was also an inverse relationship between the knee flexion angle and the ground reaction force. Both the controls and the cases exhibited greater values of knee flexion angles which correlated inversely with the values of peak ground reaction force. (Louw, Grimmer et al. 2006).

A relationship between peak ground reaction force during landing and injury was also found by Hewett et al (2005). Among adolescent basketball, volleyball and soccer players, those with ACL injuries had a 20% greater peak ground reaction force when compared to the healthy controls (Hewett, Myer et al. 2005). These studies indicate that landing with a greater vertical ground reaction force increases the risk of sustaining an ACL injury. Landing with greater knee flexion reduces the magnitude of vertical ground reaction force.

Symmetry of load distribution during landing

It has been suggested that ‘impact absorption’ of force during landing lasts only 150-200 ms and the remaining time taken for landing is concerned with restoring balance (Lees 1981). A study by Oggero et al.,(1997) investigated the difference in landing force and landing duration between limbs as a landing task was being performed by the participants (Oggero, Pagnacco et al. 1997). Four participants stepped off a box from a height of 0.39 m and landed with both feet on a force platform at the same time. Participants landed asymmetrically with respect to load and time and this asymmetry was continued to the balancing phase of the landing as well. Specifically, the participants landed with more load on the dominant limb and the ratio of the peak vertical ground reaction forces between the dominant and non-dominant forces was as high as 2: 1. The delay during landing ranged from 7 up to 15 ms, with the dominant limb

contacting the ground first. This study had an extremely low sample size of four participants therefore these results should be interpreted with caution. There was also no mention of the injury status of the participants used in the study. In a later study, it was found that ACL injured players exhibited a significant difference in the inter-limb knee loading, where as uninjured players did not exhibit any difference (Hewett, Myer et al. 2005). However, there was no mention of which leg exhibited greater load. Only a small number of studies have analyzed the relationship between asymmetrical landing and occurrence of ACL injuries.

Training interventions to reduce ACL injury risk

Several studies have found a positive effect of various types of training programs on the change in landing mechanics in athletes (Hewett, Stroupe et al. 1996; Hewett, Lindenfeld et al. 1999; Irmischer, Harris et al. 2004; Myer, Ford et al. 2005). Training has shown to stabilize the joints (Hewett, Lindenfeld et al. 1999), decrease valgus and varus knee motion (Hewett, Stroupe et al. 1996; Myer, Ford et al. 2005) and significantly reduce ground reaction forces during landing (Hewett, Stroupe et al. 1996; Irmischer, Harris et al. 2004). In a prospective jump training program, untrained female high school athletes had 3.6 times the rate of ACL injury occurrence when compared to a group of trained female athletes. They also exhibited a 4.8 times greater tendency to sustain an ACL injury when compared to a group of untrained male counterparts (Hewett, Lindenfeld et al. 1999).

Changes in lower extremity mechanics were found in a group of female high school volleyball players who participated in a six week long plyometric training program (Hewett, Stroupe et al. 1996). Jump training programs including wall jumps, squat jumps, 180° jumps

and weight lifting as a part of the exercise protocol. A 22% decrease in peak vertical ground reaction force and a 50% decrease in the peak knee abduction and adduction moments were found post training (Hewett, Stroupe et al. 1996). These results were supported by a nine week knee ligament injury prevention program for a group of female recreational athletes (Irmischer, Harris et al. 2004). Twenty-eight physically active women were recruited from a university student population, and were split equally into controls and training groups. Training included low-intensity jump-landing tasks and they were divided into four stages based on the difficulty of the exercise. Stage one included exercises like wall jumps, jump tucks; stage two included 180° jumps; stage three and stage four had several single-leg maneuvers. After training, the experimental group had a significantly decreased peak vertical impact force of close to 35% when compared to the pre-training values. The control group exhibited no difference. Another study was performed on 53 female high school basketball, volleyball and soccer players to see the effect of neuromuscular training on lower-extremity biomechanics (Myer, Ford et al. 2005). Forty-one of these participants underwent training for a period of six weeks. The training protocol included plyometric training, core strengthening, balance, resistance training, and interval speed training. Results showed increased flexion-extension range of knee motion for the trained group in both the right (7%) and left leg (8%). Trained participants also showed a decreased right knee internal valgus torque (28%) and a decreased right knee varus torque (38%) post training compared to pre-training. The controls were unchanged. Another study was performed on female soccer players between the ages of 14 and 17 (Pollard, Sigward et al. 2006). The purpose was to determine the influence of in-season injury prevention program training on lower-extremity kinematics. The training protocol included the PEP (Prevent Injury and Enhance Performance) injury prevention training as well as regular soccer practice and

competitions. At the end of the season, the athletes demonstrated less hip internal rotation and a significantly greater hip abduction but no changes in knee valgus or knee flexion angles. The results of this study differ from those of other training intervention studies with respect to change in knee kinematics. The reason could be due to the difference in training protocol. This was the only study that included training when the athletes were competing. Competition and regular soccer practice could have interfered with the training program.

Hewett et al., (1996) tracked the difference in injury rate between trained and untrained groups whereas the other studies tracked the differences in landing mechanisms pre- and post training and found positive differences post training. Though it is difficult to point to the key components which result in such a difference, it is evident that training is beneficial for reducing factors that predispose athletes to ACL injuries.

Feedback methods to alter landing technique

One group has implemented verbal and visual feedback to determine whether athletes will be able to land as instructed (Onate 2005). Four types of feedback groups were tested: expert, self, combo and a non-intervention control. The ‘expert’ group viewed a video of an expert model landing and tried imitating the landing style. The ‘self’ group viewed a video of themselves landing and tried to make changes in their landing style according to what was expected. The ‘combo’ group first watched a video of an expert performing and then watched themselves perform. The ‘non-intervention control’ group was not provided with any feedback. The participants were assessed at baseline (where no instructions were provided), performance test (performed after three sets of feedback) and the retention test (which was conducted a week after the performance test). Participants were instructed to land as softly as possible in the

performance and retention tests. Results indicated that the self and combo models showed the greatest decrease in peak vertical ground reaction forces. All feedback groups and the control group showed a significant reduction in peak ground reaction force. The self model had a 35.5% reduction in ground reaction at retention when compared to baseline. The combo model had a 30.8% reduction in peak ground reaction force values, whereas the expert group had a 24% reduction and the control group had a 23% reduction in peak ground reaction force. However, there was no discussion regarding the possible reason behind change in the control group. Post training, the self and combo models exhibited a lower value of GRF when compared to the control group whereas the expert group was comparable to the controls.

Experimental protocols used in landing studies

Studies of jump landing have used either a vertical drop jump (Ford, Myer et al. 2003; Hewett, Myer et al. 2005), stepping off a box protocol (Devita and Skelly 1992), or a 'jump shot' strategy (Louw, Grimmer et al. 2006).

Jumping off a box requires the participant to jump off a box of a specific height as determined for the study. For example, in a study of soft and stiff landings, participants were asked to step off a box 59 cm high, landing with one leg on the force platform and one on the ground (Devita and Skelly 1992). The advantage of this method is that it is highly controlled and any differences noted are likely to be landing differences. A drawback in this method is that the jump height is fixed for all participants. Therefore, a specific height could be relatively low for a tall participant or relatively high for a short participant. This protocol does not take into account the participant's jump height, hence could influence landing mechanism. This does not represent the actual game situation.

The drop vertical jump protocol was used by Ford et al.,(2003) and Hewett et al. (2005). In both studies, the athletes were asked to stand with their feet positioned 35 cm apart, on a box 31cm high. The participants were then asked to drop off the box, perform a maximum vertical jump, and land on the force platforms. The reason a specific box height of 31 cm was selected was not discussed. The drop vertical jump is a highly controlled activity, therefore it is likely to be repeatable; however as with jumping off a box, it does not replicate the game situation.

In the study by Louw et al.,(2006) the participants were asked to run forward, place one foot on the force plate and stimulate a basketball jump (Louw, Grimmer et al. 2006). This method allows the participants to jump to their maximum height and also choose their style of jumping. The advantage of this method is that it replicates the game situation more closely letting the subject run and jump like they would during a game. However, there are many uncontrolled factors, like running and style of jumping, that may influence the landing pattern. The disadvantage of this protocol is that it is relatively uncontrolled and is likely to have high inter-trial variability.

The countermovement jump requires the participant to step on the force plate, squat as much as required, and jump as high as possible and land with one foot on each force plate. The advantage of this method is that it allows the participants to jump and then land from their own maximum height. The disadvantage is that there could be variations in jump height.

SUMMARY

Previous research has shown that ACL injuries are one of the most common non-contact injuries that occur as athletes engage in sport activities. Female athletes have been shown to be four to six times more prone to these injuries when compared to their male counterparts. This is likely due to various biomechanical, hormonal, anatomical and neuromuscular differences. This is a serious issue for players at all levels, and a lot of time and money is required for surgery and extensive rehabilitation. ACL ruptures occur most commonly during the landing phase of a jump. Landing with high ground reaction forces, valgus knee angle or with unequal load distribution on limbs are common predisposing factors to ACL injury. Female athletes tend to exhibit greater peak ground reaction forces and a greater abduction angle when compared to male athletes. Participants who have undergone neuromuscular training and plyometric training have significantly reduced incidence of injury and also decreased peak ground reaction forces and a smaller valgus and varus angles. Very few studies have used verbal feedback mechanisms to try and decrease the risk factors for ACL injury associated with jumping and landing.

CHAPTER 3: METHODS

Participants

Twelve female recreational athletes who participated in at least three hours of physical activity weekly were used as participants. These athletes were recruited from the University of Tennessee student body. Each participant visited to the University of Tennessee Biomechanics/Sports Medicine Laboratory for testing purposes. Visits lasted approximately 60 minutes. The inclusion criteria were as follows: The participants were of body mass index ranging between 18.9 and 29.9 kg/m² ('normal' or 'overweight'). The 'overweight' category was included to ensure that we did not exclude athletes with large amounts of muscle mass. Participants had no current injuries, no lower limb injuries for the past 6 months and no history of an ACL injury. All participants were between the ages of 18 and 25 years. Each participant read and signed an informed consent form before their participation in the study. The informed consent form was approved by the IRB at the University of Tennessee. Participants were given the opportunity to ask questions or voice concerns regarding the study. They were also reminded that they could withdraw from the study at any point without penalty.

Instrumentation

Twenty-six retroreflective markers were placed on the lower limb joints of each participant (Figure 1a, figure 1b). Data was obtained using a 7-camera 240 Hz VICON MX motion analysis system (Vicon MX, Oxford. Metrics, Oxford, UK) and 2 synchronized AMTI force plates with a sampling frequency of 1200 Hz (AMTI, Newton, MA, USA).

Data Collection

Both anatomical and tracking markers were placed on the participant. The anatomical markers were used to define the body segments. They were placed on the following locations bilaterally: iliac crest, greater trochanter, lateral and medial epicondyles, lateral and medial malleoli, lateral, medial and proximal heel, lateral 5th metatarsal and medial 1st metatarsal. The tracking markers used for this study were four markers placed on each of five molded thermoplastic shells. One shell was placed on the pelvis over the L5-S1 region. Two shells were attached to the thighs, each on one thigh, in a proximal posterolateral location. Two shells were placed on the shanks, each on one shank, in a distal and posteromedial location.

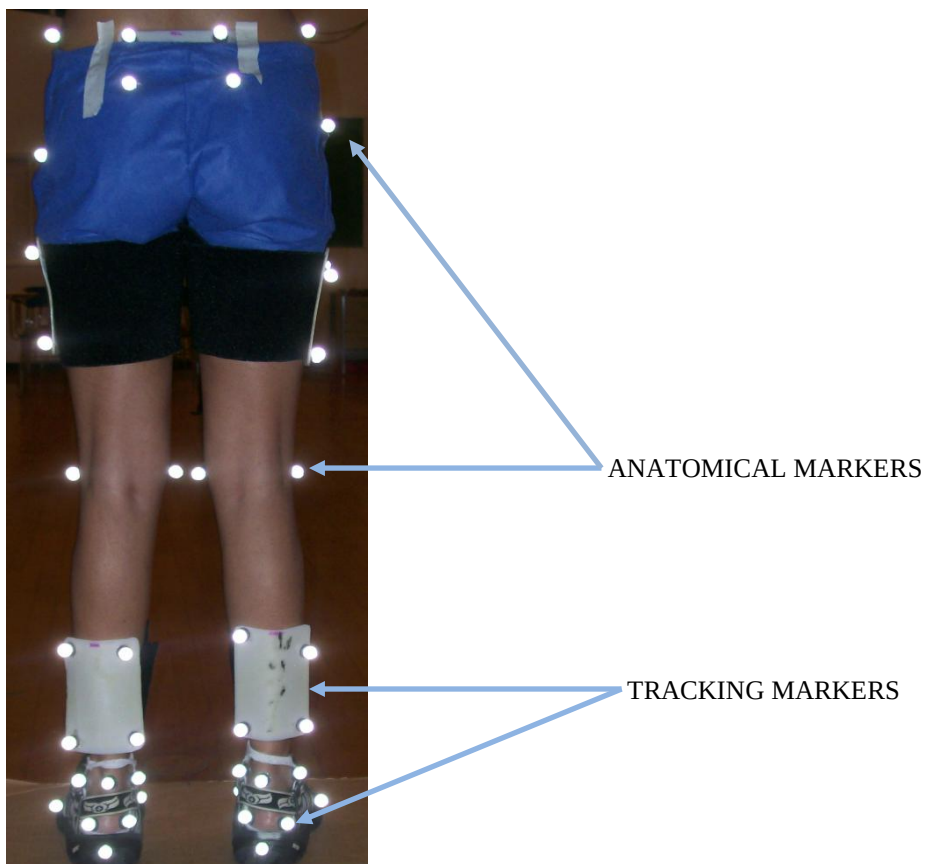


Figure 1a: Posterior view of marker locations of the lower extremity

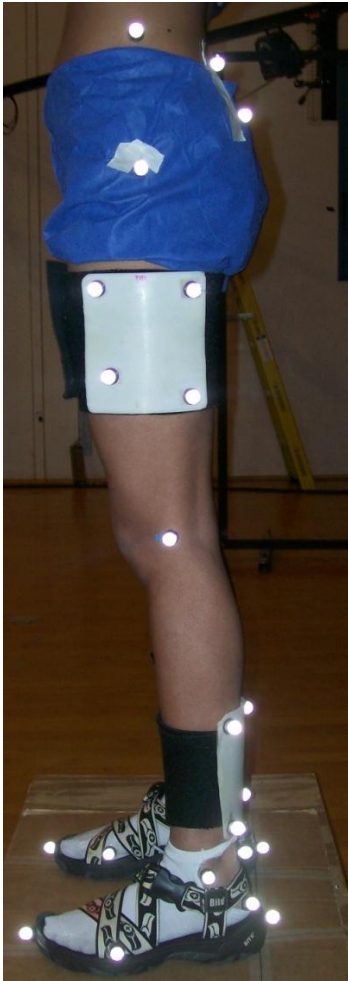


Figure 1 b : Sagittal view of marker locations of the lower extremity

Participants wore shorts and laboratory socks and sandals for easy marker placement. Leg dominance was determined based on which leg the participant steps forward with first when asked to lean forward. A static trial was taken by instructing the participants to stand on a force plate, on a standardized template (McIlroy and Maki 1997). Anatomical markers were then removed and the dynamic trials were performed with just the tracking markers. The dynamic

trials consist of jumps with four different sets of instructions, of eight successful trials each. Two force plates were used for the dynamic trials. For each set of instructions, the participants were asked to step on the force plates with one foot on each, perform a countermovement jump to their maximum height and land with one foot on each force plate. The participants practiced the countermovement jump before jumping trials were collected. Participants were given a minimum of 2 minutes rest between each condition, with the option of more if required.

Participants were first asked to perform eight control trials, where they jumped naturally. The set of instructions for this condition was to step on the force plate and perform their 'natural' countermovement jump and land on the force plate, with one leg on each plate. The instruction for the control countermovement jump was "step on the force plate with one foot on each plate, squat as low as you require, jump up as high as possible, and land on the force plate with one leg on each plate". Following the control condition, the order of occurrence of the three intervention conditions was counterbalanced. The three intervention conditions were as follows: 'knees over toes', 'equal weight', and 'soft landing'.

Landing with 'knees over toes' involved performing the countermovement jump and landing with the knees moving forward in line with toes, thereby landing with a neutral frontal plane angle and avoiding a valgus knee position. The set of instructions given for this condition was "step on the force plate with one foot on each plate, squat as low as you require, jump up as high as possible, and land on the force plate with one foot on each plate with your knees over your toes".

Landing with 'equal weight' was defined as performing the countermovement jump and landing with equal weight distribution on both feet. The set of instructions for this condition was "step on the force plate with one foot on each plate, squat as low as you require, jump up as

high as possible, and land on the force plate with one foot on each plate with equal weight distributed on both your feet”.

‘Soft landing’ was defined as performing the countermovement jump and landing as soft as possible on the force plates. The instructions for this condition was “step on the force plate with one foot on each plate, squat as low as you require, jump up as high as possible, and land on the force plate with one foot on each plate as soft as possible”. Each condition was explained as described here and then was referred as “knees over toes”, “equal weight” or “soft landing” at the start of each jump.

Data Processing

Five good trials out of eight were used for data processing. The criteria for choosing the trials included visibility of all the markers through the landing phase of the jump. Variables were calculated for the dominant limb. The landing phase during the countermovement jump was used for analysis. The landing phase was defined as the point of foot contact on the force plate up to the point of maximum knee flexion during landing. Visual3D (C-motion Inc, Rockville, MD) was used for rigid body analysis to obtain three-dimensional kinematics and kinetics. Total knee valgus motion (TKVM) was calculated as the change in angle from initial contact to maximum valgus position during the landing phase. Maximum knee valgus angle (MKFA) was the angle at the peak valgus position. Peak vertical ground reaction force (PvGRF) was the maximum vertical ground reaction force during the landing phase. Maximum knee flexion angle (MKFA) was the peak knee flexion angle during the landing phase. The total eccentric work (NEGWORK) done by the knee in the sagittal plane was calculated by integrating the negative phase of the sagittal plane power curve. Power was calculated as the

product of joint moment and angular velocity to enable the calculation of eccentric work. Custom MATLAB and LABView programs were used for data processing. LABView was used to obtain peak ground reaction forces and MATLAB was used for the calculation of other variables. Ground reaction force data for both dominant and non-dominant limbs were used to determine inter-limb symmetry. The symmetry index (SI) was calculated by the formula determined by Robinson et al. (Robinson, Herzog et al. 1987)

$$S.I = \frac{2(xd - xn)}{xd + xn} * 100$$

Where,

xd - value of the peak vertical GRF (PvGRF) obtained from the dominant leg

xn - value of the peak vertical GRF (PvGRF) obtained from the non dominant leg.

A high positive value in the symmetry index indicates landing with greater PvGRF on the dominant leg, a high negative value indicates landing with greater PvGRF in the non dominant leg. A value close to zero indicated equal landing forces exerted by both legs.

Statistical Analysis

All statistical analysis was conducted using SPSS (SPSS 15.0 for Windows, SPSS Inc. Chicago, Illinois). The mean value for each variable of interest was calculated for each of five trials for each participant in each condition. These values were then averaged to obtain a mean value per participant per condition. The mean value per participant was then averaged across all participants for each experimental condition to obtain a group mean and standard deviation. Mean jump height was calculated used a pelvis marker to confirm that maximum jump height was similar across conditions. Data was visually inspected for any order effects in the three

counterbalanced groups. A repeated measures MANOVA was performed to identify differences between the four conditions for the five variables calculated for the dominant limb. Where significant differences at the $p \leq 0.05$ level were noted in the MANOVA, post-hoc paired t-tests were used to determine between which pairs of conditions the differences lay. SI was a composite measure of the dominant and non dominant limb and hence was treated separately. A repeated measures ANOVA was performed to identify differences between the experimental conditions on the absolute value of the symmetry index. Post-hoc paired t-tests were performed where differences at $p \leq 0.05$ level were noted.

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CHAPTER 4

Can Female Recreational Athletes Alter Their Jump Landing Mechanism On Verbal Instruction?

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ABSTRACT

Background: Female athletes may be at increased risk of anterior cruciate ligament injury due to their mechanics when landing from a jump. In particular, high peak ground reaction force and frontal plane knee biomechanics may be altered.

Hypothesis/Purpose: The purpose of this study was to determine if female recreational athletes can change their landing performance after a countermovement jump following a single session of verbal instruction.

Study Design: Crossover Study

Methods: Twelve female recreational athletes were recruited. Participants performed countermovement jumps under each of four conditions: control, knees over toes, equal weight distribution and soft landing. Three-dimensional lower extremity biomechanical data were collected.

Results: Participants were able to land with lower peak vertical ground reaction force in the soft condition compared to the control ($1.590 \pm 0.2\text{BW}$; $1.989 \pm 0.7\text{BW}$; $p = 0.014$). There was a corresponding increase in peak knee flexion angle in the soft condition compared to the control ($94.6 \pm 17.2^\circ$; $87.1 \pm 19.9^\circ$; $p = 0.023$). The knees over toes instruction resulted in an increased maximum knee flexion angle compared to the control ($101.4 \pm 18.9^\circ$; $87.1 \pm 19.9^\circ$; $p = 0.003$). This corresponded to an increase in eccentric work done in the knees over toes condition when compared to the control ($-1.3 \pm 0.5\text{N/kg}$; $-1.1 \pm 0.4\text{N/kg}$, $p = 0.044$). The equal weight distribution condition improved symmetry by almost half when compared to the control condition (21.089 ± 18.4 ; 10.562 ± 7.8 ; $p = 0.024$), indicating better distribution of load on both limbs following instruction.

Conclusions: Participants were able to lower peak ground reaction force, increase maximum knee flexion angle, increase eccentric work done and reduce asymmetry according to specific verbal instructions during a single performance bout. However, there were no differences in total knee valgus motion and maximum knee valgus angle on instruction.

Clinical Relevance: Simple verbal instructions regarding landing performance after a countermovement jump resulted in immediate improvements in biomechanical variables associated with increased risk of anterior cruciate ligament injury. If simple verbal instructions can be shown to also result in long term learning of these changes, they may be incorporated into injury prevention and rehabilitation programs to reduce the risk of further injury.

Key Terms: Verbal instructions, ACL injury, symmetry landing, soft landing.

INTRODUCTION

The frequency of knee injury during sports participation is extremely high (Jones, Louw et al. 2000; Kirialanis, Malliou et al. 2003; Agel 2007; Hootman 2007). The rupture of the anterior cruciate ligament (ACL) has been shown to account for 8% of total game injuries (Agel 2007). In the United States, at the intercollegiate level, more than 2200 ACL tears have been predicted to occur each year in female athletes alone, with 76% of those leading to surgery (Arendt and Dick 1995). The cost of recovery has been estimated to be \$17,000 for each patient (Hewett, Lindenfeld et al. 1999), which yields a total of \$646 million for all female athletes (Hewett, Myer et al. 2005). ACL injuries often are often season-ending and at times career-ending for these athletes. Therefore, any intervention that might decrease the number of ACL injuries would have great personal and economic benefits for the athlete and society. Eighty percent of ACL injuries occur via non-contact mechanisms (Arendt, Agel et al. 1999; Boden, Dean et al. 2000).

Women soccer players exhibit twice the risk and basketball players four times the risk of ACL injuries when compared to their male counterparts (Arendt, Agel et al. 1999). Several factors have been associated with ACL injuries. For example, ACL injured players demonstrate a significantly larger knee abduction angle and a smaller knee flexion angle when compared to uninjured players (Hewett, Myer et al. 2005). In addition, athletes who land with greater peak forces have a greater tendency to have an ACL injury (Hewett, Myer et al. 2005). Knee injury has been associated with greater peak vertical ground reaction forces, which in turn is associated with reduced peak knee flexion angle (Devita and Skelly 1992; Hewett, Myer et al. 2005; Louw, Grimmer et al. 2006). There is a short delay from the time the dominant foot lands until the non dominant foot land, which results in different forces applied to the lower limbs, with the

dominant limb landing earlier and with greater peak force when compared to the non dominant limb (Oggero, Pagnacco et al. 1997). Injured players exhibited greater differences in bilateral knee loading when compared to uninjured players (Hewett, Myer et al. 2005). Therefore, injured players exhibited a greater amount of asymmetry when compared to uninjured players (Hewett, Myer et al. 2005).

Several intervention strategies have been employed to reduce the risk of ACL injuries. Some of these included multiple sessions of training (Hewett, Lindenfeld et al. 1999; Pollard, Sigward et al. 2006; Mizner, Kawaguchi et al. 2008), and others looked at changes in a single session (Onate 2005; Mizner, Kawaguchi et al. 2008).

Video and verbal feedback (Onate 2005) and verbal feedback couple with live demonstration (Mizner, Kawaguchi et al. 2008) have successfully reduced peak ground reaction forces (Onate 2005; Mizner, Kawaguchi et al. 2008) and peak knee valgus angles (Mizner, Kawaguchi et al. 2008) post instructions. The video analysis (Onate 2005) involved one session with the feedback instructions followed by a session of retention tests which were implemented a week after the instructions. The study by Mizner et al., (Mizner, Kawaguchi et al. 2008) involved just one session of verbal instruction and live demonstration. It might be advantageous to have a simple type of feedback with verbal instructions only and avoid additional equipment like video tapes etc.

The purpose of this study was to determine whether female recreational athletes can change their landing pattern after a countermovement jump by following specific verbal instructions during a single visit. In particular, the hypothesis is that there will be no change in total valgus knee motion, maximum knee valgus angle, peak vertical ground reaction force, maximum knee

flexion angle, total eccentric work and the symmetry index of the peak vertical ground reaction force following verbal instruction.

METHODS

Participants

Twelve female recreational athletes between the ages of 18 and 35 years who participated in at least three hours of physical activity weekly were recruited from the institution's student body (age 25.27 ± 1.95 years; height 1.62 ± 0.05 m, weight 57.33 ± 9.5 kg). These details were orally confirmed by the recruiter. The body weight and height were measured after the athletes agreed to participate in the study. The inclusion criteria were as follows: body mass index between 18.5 and 29.9 kg/m² (normal and overweight categories) (CDC) ; no current injuries, no lower limb injuries for the past 6 months, and no history of an ACL injury. The study protocol and informed consent form was approved by the Institutional Review Board. Before the commencement of the study and all participants read and signed an informed consent form before participating.

Power Analysis

For all the variables sample size was based on predicted power to detect differences between groups. For all variables an α of 0.05 and 80% power was used. A moderate effect size (0.50) was input into the analysis for all variables. Power was calculated using regression equations from Park and Schutz (Park and Schutz 1999). Correlation between repeated measures was set at 0.9 based on data from Ford et al. (2007). Data from the following previous studies indicated

that an effect size of 0.5 represented a change of around 15% for the variables of interest. The power analysis indicated that a minimum of nine participants were required. Ford et.al., (Ford, Myer et al. 2003) reported a peak knee valgus angles of $-8.1^{\circ} \pm 2.2^{\circ}$ for the dominant side in female athletes who participated in jumping and pivoting sports. Hewett et al., (Hewett, Myer et al. 2005) reported a peak knee flexion angle of $82.4 \pm 8^{\circ}$ as well as a peak vertical ground reaction force of $1057.8 \pm 289.9\text{N}$ for uninjured female athletes who participated in high risk sports (Hewett, Myer et al. 2005). For calculating eccentric work, data was obtained from Devita et al., (Devita and Skelly 1992). They reported a eccentric work of $-8.9 \pm 0.17 \text{ J/kg}$ done during soft landing.

Data Collection

Participants wore shorts and standard laboratory sandals with an athletic sole midsole (BITE shoes, Redmond, WA). Leg dominance was determined based on which leg the participant stepped forward with first when asked to lean forward. Twenty-six retroreflective markers were placed on the lower limb joints of each participant (Figure 1a). Anatomical markers were used to define the body segments. They were placed on the following locations bilaterally: iliac crests, greater trochanter, lateral and medial epicondyles, lateral and medial malleoli, lateral, medial and proximal heel, lateral fifth metatarsal and medial first metatarsal. Four tracking markers were mounted on molded thermoplastic shells. A shell was placed on the pelvis over the L5-S1 region. Two shells were attached to the thighs, in a proximal posterolateral location. Two shells were placed on the shanks, in a distal and posteromedial location. In addition three tracking markers were placed on the heel. Neoprene wraps were secured with hook and loop

tape around the shanks and thighs. The shells were also secured to the wraps using hook and loop tape.

Three-dimensional marker position data were obtained using a 7-camera 240 Hz VICON MX motion analysis system (Vicon MX, Oxford. Metrics, Oxford, UK) and 2 synchronized AMTI force plates with a sampling frequency of 1200 Hz (AMTI, Newton, MA, USA). A static trial was recorded with the participant in a standard foot position (McIlroy and Maki 1997), the anatomical markers were then removed. The dynamic trials consist of countermovement jumps with each of four different sets of instruction conditions.

The first set of instructions was to step on the force plate and perform a control countermovement jump. The participant was instructed as follows: “step on the force plate with one leg on each plate, squat as low as you require, jump up as high as possible, and land on the force plate with one leg on each plate”. The order of occurrence of the three intervention conditions was counterbalanced. The three intervention conditions were as follows: ‘knees over toes’, ‘equal weight’, and ‘soft landing’. Participants were given the same instructions as the control condition with the following modifications to the landing: (a) land with knees over their toes, (b) land with equal weight distributed on both their feet and (c) land as softly as possible. Five good trials were recorded in each condition.

Data Processing

Variables were calculated for the dominant limb. The landing phase during the countermovement jump was used for analysis. The landing phase was defined as the point of foot contact on the force plate until the point of maximum knee flexion during landing.

Visual3D (C-motion Inc, Rockville, MD) was used for rigid body analysis to obtain three-

dimensional kinematics and kinetics. For the purpose of data processing, the 3D conventions used are as follows: X axis represented the medial-lateral axes, Y axis represented the anterior-posterior axes and the Z axis represented the vertical axis. Internal moments were computed. Total knee valgus motion was calculated as the change in angle from initial contact to maximum valgus position during the landing phase. Maximum knee valgus angle was the angle at the peak valgus position. Peak ground reaction force was the maximum vertical ground reaction force during the landing phase. Maximum knee flexion angle was the peak knee flexion angle during the landing phase. Sagittal plane knee power was calculated as the product of joint moment and angular velocity. The total eccentric work done by the knee in the sagittal plane was calculated by integrating the negative part of the sagittal plane power curve. Both peak vertical ground reaction force and eccentric work done was normalized by body mass. Custom MATLAB (The Mathworks Inc., Natick MA) and LABView (National Instruments, Austin, TX) programs were used to calculate specific variables of interest. Peak vertical ground reaction force for both dominant and non-dominant limbs was used to determine inter-limb symmetry. Lower value of symmetry index is associated with a greater value of symmetry. The symmetry index was calculated by the formula developed by Robinson et al (Robinson, Herzog et al. 1987),.

$$S.I. = \frac{2(xd - xn)}{xd + xn} * 100$$

Where,

xd - value of the peak vertical GRF obtained from the dominant leg

xn - value of the peak vertical GRF obtained from the non dominant leg

Statistical Analysis

All statistical analyses were conducted using SPSS (SPSS 15.0 for Windows, SPSS Inc. Chicago, Illinois). The mean and standard deviation for each variable of interest were calculated for each of five trials for each participant. These values were then averaged across all participants for each condition. A repeated measures multivariate analysis of variance (MANOVA) was performed to identify differences between conditions for the five variables calculated for the dominant limb. Where significant differences at the $p \leq 0.05$ level were found, post-hoc paired t-tests were used to determine between which pairs of conditions the differences lay. The symmetry index variable was a composite measure of the dominant and non dominant limb and hence was treated separately. A repeated measures analysis of variance (ANOVA) was performed on the absolute value of the symmetry index to identify differences between conditions. Post-hoc paired t-tests were performed where difference at $p \leq 0.05$ level was noted, to identify differences between each pairs of conditions.

RESULTS

Total knee valgus motion was similar across conditions ($p = 0.346$; $F = 1.104$, Table 1; Figure 2). There was also no difference in the maximum knee valgus angle across conditions ($p = 0.724$; $F = 0.219$, Table 1).

Table 1: Group average mean (standard deviation) for the variables of interest in each of the four¹ conditions

	CONTROL	SOFT	EQUALWEIGHT	KNEESOVER
TKVM	7.7(3.4)	8.5(3.2)	8.7(3.5)	9.0(4.1)
MKVA	-10.5(4.1)	-9.9(3.9)	-10.7(4.2)	-10.4(6.2)
PvGRF	1.9 (0.6)	1.5(0.2) ^{c,e,k}	1.8(0.5) ^s	1.7(0.4) ^s
MKFA	87.1(19.9)	94.6(17.2) ^c	91.7(22.3)	101.4(18.9) ^{c,s,e}
NEGWORK	-1.082(0.493)	-1.11(0.427)	-1.11(0.432)	-1.2(0.5) ^{c,s}
S.I	21.0(18.4)	16.4(10.5)	10.5(7.7) ^{c,s,k}	19.8(13.5)

TKVM = total knee valgus motion (°); MKVA = maximum knee valgus angle (°), PvGRF = peak vertical ground reaction force (BW), MKFA = maximum knee flexion angle (°), NEGWORK = eccentric work done by the knee (J/Kg), S.I = symmetry index.

¹ The significant differences among conditions were denoted by the alphabets c (control), k (knees over toes), s (soft) and e (equal weight).

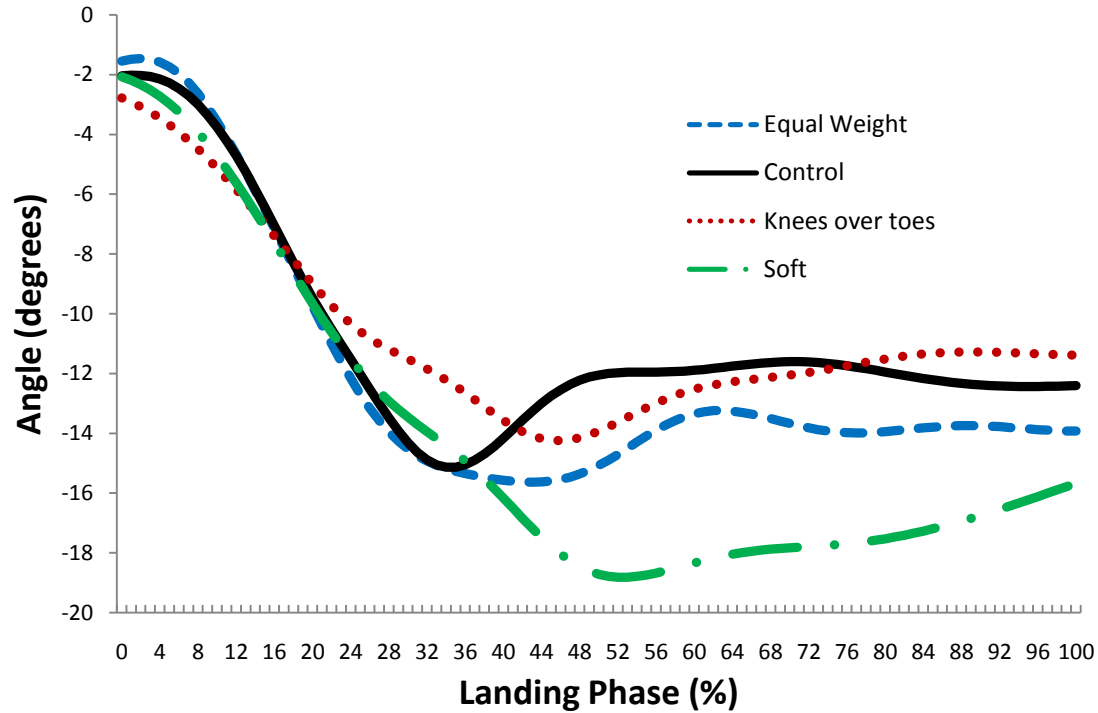


Figure 2: Individual participant representation of the frontal plane knee angle during landing under each condition. Valgus (abduction) angles are negative, varus (adduction) angles are positive.

There were differences in PvGRF across conditions ($p = 0.003$; $F = 5.665$; Table 1, Figure 3). Peak ground reaction force was lower in the soft condition compared to the control condition ($p = 0.014$). Peak ground reaction force in the soft condition was also lower than in the knees over toes ($p = 0.013$) and equal weight conditions ($p = 0.027$). Other conditions were similar to each other.

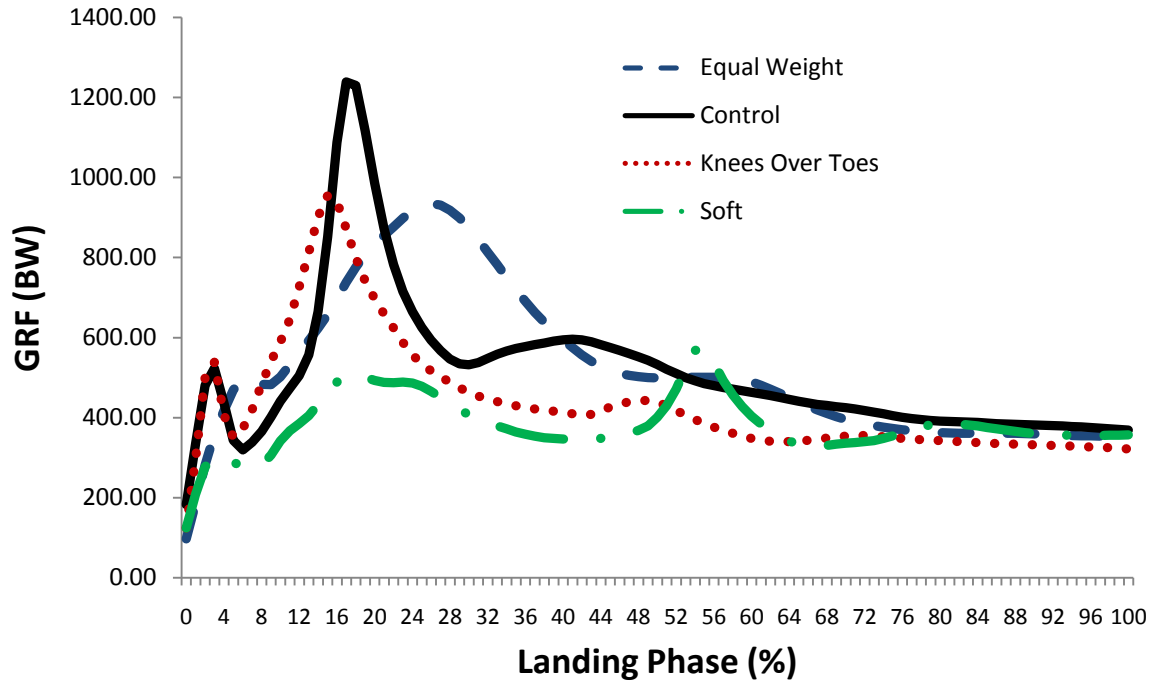


Figure 3 : Individual participant representation of vertical ground reaction force during landing under each condition

Differences were found in maximum knee flexion angle across conditions ($p = 0.001$; $F = 6.910$; Table 1, Figure 4). Higher peak knee flexion was observed in the soft condition when compared to the control condition ($p = 0.023$) as well as knees over toes condition when compared to the control condition ($p = 0.003$). A larger amount of knee flexion was demonstrated in the knees over toes condition when compared to the soft ($p = 0.024$) and equal weight conditions ($p = 0.021$). However, the knee flexion angle in the equal weight condition was similar to that of the control and soft conditions.

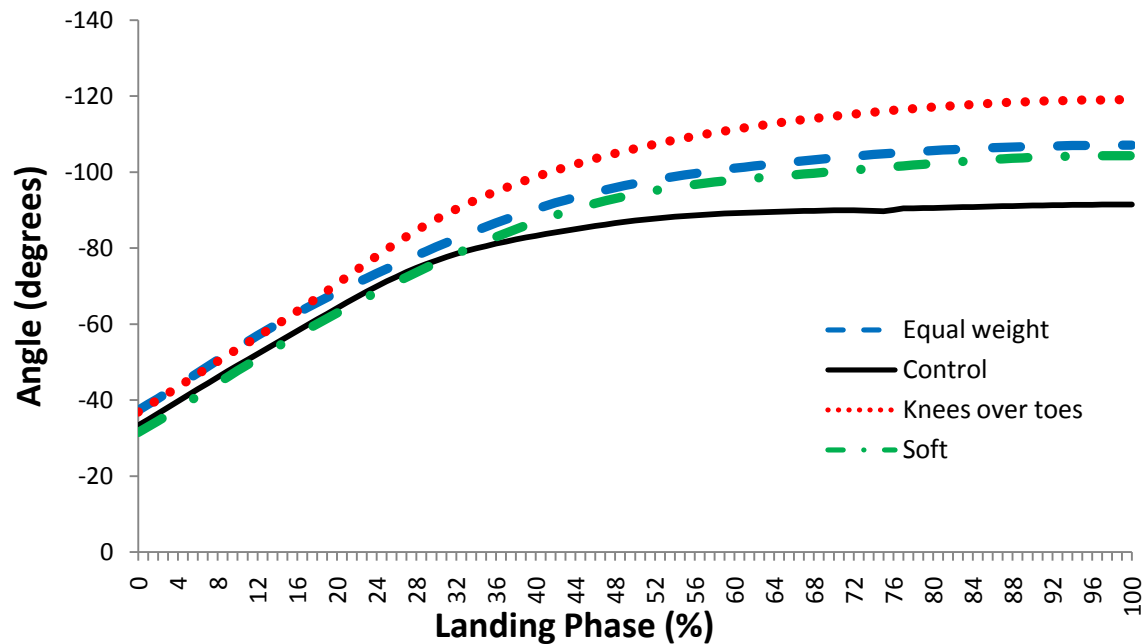


Figure 4: Individual participant representation of the sagittal plane knee angle during landing under each condition. Flexion angles are positive and extension angles are negative.

Differences were also found in the total eccentric work done across conditions ($p = 0.039$, $F = 3.133$; Table 1, Figure 5). The eccentric work done during the control condition was smaller than the knees over toes condition ($p = 0.044$) but similar to that of the soft, equal weight conditions. A larger amount of eccentric work was done in the knees over toes condition compared to the soft condition ($p = 0.04$). Eccentric work was similar in the other conditions.

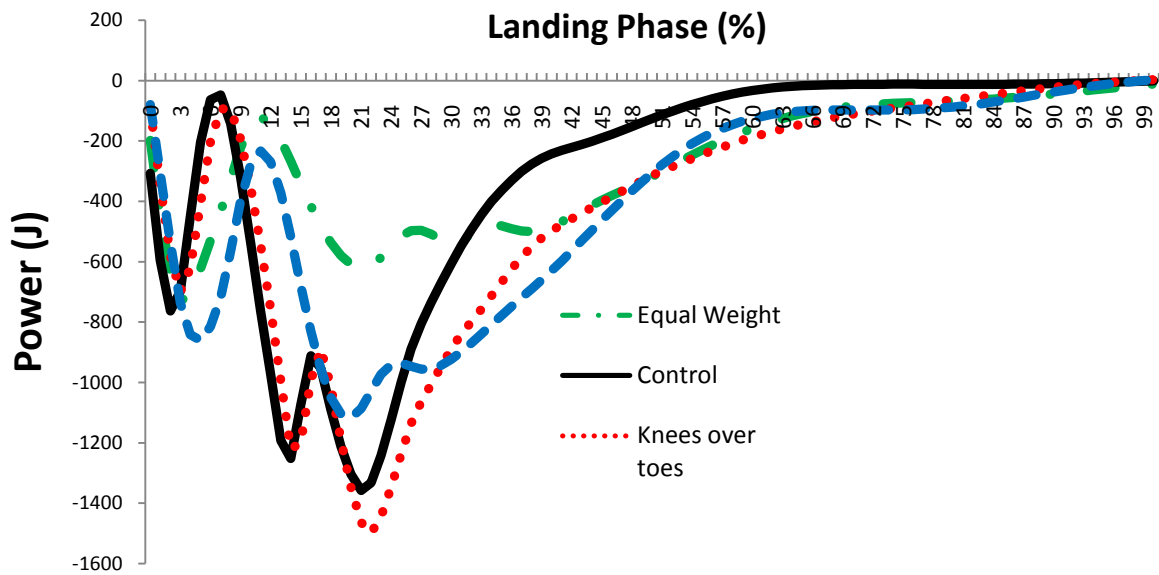


Figure 5 : Individual participant representation of the sagittal plane power at the knee during landing under each condition. Note that eccentric work is equal to the area under the negative part of the power curve.

Differences were found in the symmetry index across conditions ($p = 0.045$, $F = 2.993$; table 1, figure 5). Symmetry index was lower in the equal weight condition when compared to the control ($p = 0.024$), soft ($p = 0.042$) and knees over toes ($p = 0.010$) conditions, indicating that the participants landed with greater symmetry in the equal weight condition. The symmetry index in the control condition was similar to the soft and knees over toes conditions.

DISCUSSION

The purpose of this study was to determine whether female recreational athletes could change their landing pattern after a countermovement jump with simple verbal instructions.

Although there have been various different intervention studies, this study employed only simple verbal instructions to alter landing biomechanics in female recreational athletes during a single bout. Three different instructions were employed. The ‘soft’ landing instruction has been employed in other studies (Devita and Skelly 1992; Hewett, Myer et al. 2005; Louw, Grimmer et al. 2006), however, to the authors’ knowledge the ‘knees over toes’ and the ‘equal weight’ instructions have not been explicitly given in previous studies.

There were no differences in the total valgus knee motion or maximum knee valgus angle across conditions. This was not surprising because the athletes were healthy and free of injury. Since they had no prior ACL injury, it was less likely that they would exhibit knee valgus motion, a risk factor for ACL injury, in the control. This is contrary to a recent study by Mizner et al., reported a decrease in knee valgus angle post instruction (Mizner, Kawaguchi et al. 2008). The athletes used for the study by Mizner et al., (Mizner, Kawaguchi et al. 2008) were also normal, healthy participants, free of injury. However, they were able to decrease their peak knee valgus angle after instruction. The difference in protocol between the two studies may have contributed to this difference. Mizner et al., (Mizner, Kawaguchi et al. 2008) provided a live demonstration of both correct and incorrect landing technique to the study participants in addition to verbal instructions. This may have contributed to their understanding of the task and ability to initiate changes in their jump landing performance.

There were differences in peak vertical ground reaction forces between conditions. As expected, the ‘soft’ condition resulted in lower peak ground reaction force compared to the other conditions. Previous studies have also found decreased peak ground reaction force after landing instruction or training (Hewett, Stroupe et al. 1996; Irmischer, Harris et al. 2004; Onate 2005; Mizner, Kawaguchi et al. 2008). Plyometric training programs helped decrease peak

vertical forces by 14% (Irmischer, Harris et al. 2004) and by 22% (Hewett, Stroupe et al. 1996) . There was a 24% decrease in PvGRF in the soft condition when compared to the control condition in the present study. Athletes who were shown a video combination of an expert landing as well as feedback of their landing technique were seen to reduce their peak ground reaction force, by 28% when compared to baseline. . Another study reported a 20% decrease decrease in peak ground reaction forces after both verbal instructions and demonstration (Mizner, Kawaguchi et al. 2008) . Decreases in PvGRF were also seen in the soft condition compared to the equal weight and kneesover toes condition. This decrease shows that the participants responded to the soft landing instruction and showed no such decrease in the other two intervention conditions.

In combination with the decrease in peak vertical ground reaction force, maximum knee flexion angle was also increased in soft landing compared to the control condition. The study by Onate et al., (Onate 2005) which used video feedback, also instructed their participants to land softly. They found a 70 % increase in knee flexion angles in the combo model compared to the control group (Onate 2005). In the study by Mizner et al., (Mizner, Kawaguchi et al. 2008) which coupled verbal instruction and demonstration, an increase in knee flexion by 13% was found post- instruction. This increase is comparable to the 8.6% increase in knee flexion angle post soft landing instructions. The study by Onate et al., (Onate 2005) showed such a large difference because the participants in their study showed a much small knee flexion angle of 57 in the baseline test compared to an angle of 87 in the control condition in the present study. It should be noted that the decreases in peak ground reaction force and knee flexion angle found in the present study were achieved during a single session and with verbal instruction only. Several studies have reported an inverse relationship between the knee flexion angle and peak vertical

ground reaction force with greater knee flexion being associated with lower peak vertical ground reaction force (Devita and Skelly 1992; Hewett, Myer et al. 2005; Louw, Grimmer et al. 2006). In the present study, the ‘soft’ condition exhibited a smaller peak ground reaction force when compared to the ‘control’ condition and also exhibited a corresponding increase in knee flexion angle.

Soft jump landings have been associated with larger values of eccentric work done when compared to hard or stiff landings. Greater values of eccentric work indicate that the muscles crossing the joint absorb more energy (Devita and Skelly 1992; Louw, Grimmer et al. 2006). This indicates that the rest of the system will be exposed to lower forces when compared to a stiff landing, which is beneficial in terms of injury risk. In the study by Devita and Skelly (Devita and Skelly 1992) greater amount of eccentric work was done by the knee joint when a soft landing technique was compared to a stiff landing. This finding was not supported by the results of the present study. Eccentric work in the control condition was similar to the soft and equal weight conditions. This did not correspond to a decrease in peak vertical ground reaction force in the soft condition when compared to the control. It is possible that Devita et al., (Devita and Skelly 1992) found differences in eccentric work because they tested hard and soft landing patterns specifically. It may be that the eccentric work done across all conditions in the present study was similar because there was no ‘hard’ landing condition, and ‘soft’ landing was compared to normal landing. The healthy recreational athletes in the present study may have naturally developed a landing strategy that protects them from excessively high forces, as would be found in a ‘hard’ landing. A specific ‘stiff’ landing was not included in the present protocol. We cannot expect as much of a difference in eccentric work between soft and control conditions as we can between soft and hard landing conditions.

The eccentric work done in the knees over toes condition was greater than the control condition. This corresponds to a greater peak knee flexion angle in the knees over toes condition when compared to the control condition. Although Louw et al., compared injured and uninjured athlete, a relationship between the knee flexion angle and eccentric work done was also demonstrated (Louw, Grimmer et al. 2006). They found uninjured basketball players exhibited deeper knee flexion angles and did greater eccentric work in the knee when compared to their injured counterparts. This is similar to the knees over toes condition. However, in the current study, peak vertical ground reaction force was similar in the control and knees over toes conditions. This similarity was also observed in the study by Louw et al (Louw, Grimmer et al. 2006). Though there was a difference in the eccentric work done by the injured and uninjured players, the peak ground reaction force was similar between the groups (Louw et al). This case is similar to the present study where the peak ground reaction force is similar in the control and knees over toes condition but less eccentric work was done in the control condition when compared to knees over toes.

As expected, there was a greater amount of symmetry exhibited in the equal weight condition when compared to the other three conditions. It should be noted that normal and healthy individuals are not completely symmetrical when they land (Robinson, Herzog et al. 1987). However, Hewett et al., found that injured athletes tend to show a greater asymmetry while loading when compared to uninjured athletes (Hewett, Myer et al. 2005). We found that asymmetry was reduced even in the healthy cohort included in this study. Asymmetry was reduced by almost half following the equal weight instruction compared to the control condition.

The participants were able to land with a lower peak vertical ground reaction force and greater amount of knee flexion when asked to land as soft as possible when compared to control condition. Participants were also successfully able to successfully land with a greater amount of symmetry when asked to land with equal weight distributed over both feet. Landing with greater symmetry is important in reducing asymmetrical limb loading which may increase the risk of injury (Hewett, Myer et al. 2005). Asking participants to land with their knees over their toes did not create a significant change in landing mechanics. This may be due, at least in part, to using normal healthy participants with no history of ACL injury who naturally avoid extremes of knee valgus. Of the three instructions, landing softly and the equal weight distribution while landing were the most successful in making a change in frontal plane knee landing mechanics of these recreational female athletes.

The intervention strategy used in this study was simply to provide verbal instructions on how to land. The advantage of this intervention is that other equipment, for example a video camera for feedback or recreational facilities for strength training, are not required. Hence this intervention is simple and cost-effective. Participants were able to perform a lower risk landing strategy within a single session of verbal instruction.

Only short term performance changes in landing mechanics were measured in the present study, hence it is not known if these changes can be learned and retained over time. This is a limitation of the study. Additionally, all participants recruited were healthy recreational athletes who have been active in sports without sustaining an ACL injury. Therefore, potentially greater changes can be seen in athletes who have previously had an ACL injury.

No change in frontal plane knee kinematics was found in the present study. This is likely due to the normal healthy participants recruited. Future studies should screen potential

participants to identify those who show increased frontal plane motion, who may be at risk for ACL injury. The current study determined whether changes in landing mechanics can be made with verbal instructions. To reduce the risk of injury, changes need to be learned by the athlete and become permanent. Future studies should incorporate a retention test after a number of weeks to determine whether positive changes are retained several weeks after instruction. Additionally, a live demonstration along with verbal instructions had a greater impact on the changes in frontal plane motion in the study by Mizner et al., (Mizner, Kawaguchi et al. 2008). Since the utility of simple verbal instruction has been established in the present study, a next step is to determine whether female athletes who are at a high risk for injury show similar changes on verbal instructions.

In conclusion, this study employed three different simple verbal instruction strategies to alter jump landing mechanisms in female athletes. The soft landing instruction resulted in a decreased peak vertical ground reaction force and increased knee flexion angle compared to the natural landing. The ‘equal weight distribution’ condition resulted in a greater landing symmetry. In the ‘knees over toes’ instruction condition, frontal knee landing mechanics were similar to the control condition. The advantage of this verbal instruction strategy is that it does not require any additional equipment, making it simple and cost effective.

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APPENDICES

APPENDIX A

INFORMED CONSENT FORM

IRB APPROVAL # 7563B

INFORMED CONSENT FORM

Can athletes change their jump-landing pattern on verbal instructions?

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Purpose

You are invited to take part in a research study entitled “Can athletes change their jump-landing mechanism on verbal instructions?” The purpose of this study is to see if you can change the way you land when given verbal instructions. To take part in this study, you should be a female recreational athlete who participates in physical activity at least three hours a week. You should have no history of an ACL tear and no lower limb injuries for the past six months. You should have no injuries at the moment and be able to perform repeated jumps. You will be given as much rest as you require between each jump condition.

If you meet these criteria and agree to participate, we will measure your body mass index (a combination of height and weight) to make sure that it is below our limit 30 kg/m^2 . If you do not meet all of these criteria or choose not to participate in the study, your visit will end.

Data Collection

If you are eligible to participate, you will stay at the lab for around an hour for data collection. You will need to wear a tight fitting t-shirt. We will have a pair of laboratory shorts, shoes and socks for you to wear.

You will have small silver balls attached to your waist, hips, legs and feet using medical tape and plastic shells. These will not interfere with the way you jump. The cameras in our lab record the position of these balls as you perform the jumping activities. You will land on two metal plates that are embedded in the floor. These plates record the way you make contact with the ground.

You will perform eight successful jump landing trials for four different instructions. At the end of each set of trials, you will be given a rest period of two minutes, or longer if you require. After every jump, we will review the data before asking you to continue to the next trial.

Potential Risks

The potential risks associated with this study include trips and falls as you jump. We will do our best to minimize these risks by explaining what will happen in the session and letting you practice the jumps before data collection. The risks associated with the study are no more than you encounter in your regular sports activity. You will be able to ask questions at any time during the data collection if you are unsure about anything.

If you become injured during the data collection, standard first aid procedures will be carried out as needed. In the event of physical injury as a result of taking part in this study, the University of Tennessee does not automatically provide reimbursement for medical care or other compensation.

Benefits of Participation

While there are no direct benefits to you following participation in the study, the results of the study will provide information about landing patterns in female athletes. The results of the study will also indicate whether athletes can change their landing pattern based on instruction. This is a first step in developing a rehabilitation tool that focuses on adjusting landing technique to reduce injury risk.

Confidentiality

Your identity will be kept confidential by using code numbers to identify your information after data collection. These numbers will be used during all processing and analysis of the data and reports of the study and its results.

Contact Information

If you have any questions at any time about the study you can contact Abhaya Srivatsan or Dr. Clare Milner. Questions about your rights as a participant can be addressed to Research Compliance Services in the Office of Research at (865) 974-3466.

Questions and/ or Withdrawal

You may ask questions and/ or withdraw your consent and discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Consent

By signing, I am indicating that I understand the potential risks and benefits of participation in this study and that I am agreeing to participate in this study.

Participant's Signature

Date

Participant #

Investigator's Signature

Date

APPENDIX B

INDIVIDUAL PARTICIPANT ANTHROPOMETRIC AND DEMOGRAPHIC DATA

Individual participant anthropometric and demographic data

Participant #	Weight	Height	BMI	Age	Leg Dominance
1	55.45	1.70	19.18	24	Left
4	49.09	1.53	20.97	23	Right
5	71.36	1.68	25.28	25	Right
8	47.04	1.56	19.32	24	Right
9	58.18	1.66	21.11	27	Left
10	43.63	1.58	17.47	25	Right
11	70.45	1.66	25.56	26	Right
12	65.45	1.61	25.24	-	Right
13	52.16	1.61	20.12	26	Right
15	50.22	1.61	19.37	28	Right
16	56.81	1.61	21.91	28	Left
17	68.18	1.68	24.15	22	Right
MEAN	57.34	1.62	21.65	25.65	
STDEV	9.52	0.05	2.78	1.95	

APPENDIX C

INDIVIDUAL PARTICIPANT DATA

Individual participant data for total knee valgus motion (°) by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	10.9	14.5	13.3	11.8
4	4.0	8.6	4.9	6.0
5	8.0	8.0	11.5	17.6
8	2.9	3.9	5.2	4.4
9	9.1	6.0	5.7	4.1
10	3.4	3.4	4.0	3.8
11	4.6	4.8	5.6	6.6
12	6.1	10.0	8.9	10.7
13	8.5	11.6	10.6	9.2
15	11.3	11.1	11.1	11.8
16	12.1	11.0	10.6	10.0
17	11.3	11.1	11.1	11.8
MEAN	7.7	8.7	8.5	8.7
STDEV	3.3	3.4	3.2	4.2

Individual participant data for maximum knee valgus angle (°) by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	-13.60 (2.08)	-17.58 (2.61)	-15.92 (3.83)	-14.25 (1.36)
4	-8.78 (0.66)	-7.45 (1.49)	-6.45 (0.91)	-7.06 (1.68)
5	-10.79 (0.78)	-12.49 (0.82)	-12.81 (1.45)	-26.01 (8.41)
8	-4.17 (0.99)	-5.05 (1.03)	-4.99 (1.85)	-2.88 (1.15)
9	-15.09 (2.16)	-10.76 (1.44)	-9.70 (1.46)	-8.30 (0.74)
10	-5.54 (2.48)	-5.46 (0.38)	-5.56 (1.90)	-3.45 (1.14)
11	-7.01 (0.84)	-5.64 (0.97)	-5.39 (1.76)	-5.67 (1.62)
12	-5.59 (2.81)	-8.35 (4.04)	-6.49 (2.30)	-8.34 (2.55)
13	-11.48 (0.75)	-14.62 (1.83)	-12.94 (1.05)	-11.47 (1.73)
15	-14.23 (0.57)	-14.11 (3.24)	-12.71 (2.02)	-13.05 (1.89)
16	-15.13 (0.89)	-12.74 (0.51)	-12.87 (1.50)	-11.00 (1.19)
17	-14.23 (0.57)	-14.11 (3.24)	-12.71 (2.02)	-13.05 (1.89)
MEAN	-10.4	-10.69	-9.87	-10.37
ST DEV	4.0	4.20	3.87	6.18

Individual participant data for peak vertical ground reaction force (BW) by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	2.48	1.74	1.77	2.15
4	2.17	2.04	1.72	2.09
5	1.00	1.30	1.12	1.10
8	2.57	2.83	1.64	1.75
9	2.36	2.13	1.57	2.01
10	2.62	2.12	1.23	1.84
11	2.98	3.01	1.60	2.70
12	1.54	1.40	1.63	1.73
13	1.94	1.78	1.65	1.76
15	1.27	1.27	1.42	1.67
16	1.09	1.21	1.21	1.13
17	1.86	1.95	1.57	1.59
MEAN	1.99	1.89	1.51	1.79
STDEV	0.65	0.58	0.21	0.43

Individual participant data for maximum knee flexion angle (°) by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	-107.02 (9.62)	-109.38 (7.09)	-109.77 (3.98)	-117.76 (4.04)
4	-63.72 (8.35)	-90.59 (4.43)	-69.80 (6.64)	-83.79 (7.65)
5	-86.97 (11.78)	-90.06 (4.24)	-96.49 (7.23)	-89.88 (10.22)
8	-65.09 (17.51)	-67.63 (3.84)	-73.64 (11.08)	-99.13 (5.12)
9	-76.10 (5.29)	-75.73 (5.25)	-85.97 (5.66)	-85.32 (3.23)
10	-50.20 (9.55)	-51.24 (3.53)	-79.61 (2.74)	-80.17 (1.72)
11	-80.10 (1.64)	-72.51 (10.72)	-80.41 (3.39)	-84.85 (6.05)
12	-92.66 (3.25)	-96.32 (5.37)	-103.71 (2.80)	-102.06 (5.33)
13	-104.27 (7.73)	-104.82 (2.07)	-108.25 (10.57)	-123.27 (4.15)
15	-107.45 (6.13)	-124.18 (7.60)	-118.84 (8.16)	-129.99 (4.09)
16	-103.58 (3.15)	-96.91 (7.17)	-89.63 (5.43)	-90.29 (17.55)
17	-107.45 (6.13)	-124.18 (7.60)	-118.84 (8.16)	-129.99 (4.09)
MEAN	-87.0	-91.9	-94.5	-101.3
STDEV	19.9	22.3	17.2	18.9

Individual participant data for eccentric work (J/Kg) done by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	-2.06	-1.92	-1.83	-2.05
4	-0.62	-1.05	-0.61	-0.84
5	-0.61	-0.66	-0.69	-0.58
8	-0.52	-0.86	-0.66	-1.27
9	-0.66	-0.74	-0.86	-0.85
10	-0.62	-0.50	-0.86	-1.16
11	-1.23	-1.07	-0.86	-1.16
12	-1.29	-1.07	-1.38	-1.55
13	-1.61	-1.70	-1.68	-2.11
15	-1.57	-1.58	-1.65	-1.81
16	-1.09	-1.09	-1.01	-0.79
17	-1.11	-1.19	-1.27	-1.15
MEAN	-1.08	-1.11	-1.11	-1.27
STDEV	0.49	0.42	0.43	0.50

Individual participant data for symmetry index by condition:

PARTICIPANT	CONTROL	EQUAL WEIGHT	SOFT	KNEES OVER TOES
1	18.38	0.28	6.35	0.28
4	12.16	11.91	16.17	13.42
5	59.15	26.45	17.92	30.14
8	1.37	10.48	15.61	39.31
9	31.17	13.95	25.27	15.02
10	14.98	4.51	0.41	13.33
11	11.61	12.89	11.63	6.82
12	7.12	6.90	24.03	25.11
13	16.51	15.54	21.86	33.02
15	55.25	19.32	37.52	41.48
16	18.06	1.39	19.51	12.80
17	7.31	3.12	1.58	7.87
MEAN	21.08	10.56	16.48	19.88
STDEV	18.42	7.79	10.55	13.50

VITA

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