Modifying Spike Jump Landing Biomechanics in Female Adolescent Volleyball Athletes using Video and Verbal Feedback

By

Joanne L. Parsons

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements for the degree of

Master of Science

Faculty of Kinesiology and Recreation Management

University of Manitoba

Winnipeg

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

Modifying Spike Jump Landing Biomechanics in Female Adolescent Volleyball Athletes using Video and Verbal Feedback

BY

Joanne L. Parsons

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

MASTER OF SCIENCE

Table of Contents

Acknowledgements

First, I would like to thank the members of my thesis committee: Dr. Marion Alexander, Dr. Jane Watkinson and Dr. Catherine Casey. You were always available to share your time and knowledge with me. Special thanks go to the Manitoba Health Research Council, who provided funding to allow me to complete my degree.

Thank you also to the subjects in my study and their parents, without whom this study would not have been possible. Thanks to the coaches, Tom, Lee, and Yovana for allowing me to come into your practices. A special thanks to my friend Jen who made the school connections for me and allowed the filming to go ahead with no issues.

This two and a half year process would not have been nearly as enjoyable without the presence of the "boys" in the lab. Thanks to Mike, Brad, Adam and Brian for entertaining me when I needed a laugh and for commiserating with me when the going got rough.

Last but not least, I'd like to thank the people in my life who have supported me from the beginning. My husband Darren has encouraged me and been my number one fan from the start. You have cheered me up when I was discouraged, and been extremely understanding as my stress levels rose. I love you even more for it. My parents, Edith and Albert, have always been supportive. I value your advice and guidance. You have instilled in me the self-confidence that has allowed me to achieve my goals. I am who I am because of you. Thank you.

List of Figures

List of Tables

List of Copyrighted Material for which Permission was Obtained

1. Figure 1.2, page 4. Position of no return. Reproduced with permission from Ireland, M.L. (1999). Anterior cruciate ligament injury in female athletes; epidemiology. *Journal of Athletic Training, 34(2),* 150-154.

2. Figure 2.6, page 44. The effect of knee flexion angle on the presence of shear forces between the tibia and femur. Reproduced with permission from Daniel, D.M., Stone, M.L., Barnett ,P., Sachs, R. (1988). Use of the quadriceps active test to diagnose posterior cruciate ligament disruption and measure posterior laxity of the knee. *Journal of Bone and Joint Surgery (Am), 70(3),*386-391.) (Copyright owned by The Journal of Bone and Joint Surgery, Inc.).

3. Figure 2.7, page 50. Female vs. male squatting mechanics. Reproduced with permission from Ireland, M.L. (2002). The female ACL: why is it more prone to injury? *Orthopedic Clinics of North America, 33,* 637-651.

*see Appendix I for written permission

Abstract

The purpose of the study was to determine whether providing video and verbal feedback to female volleyball athletes completing a spike jump landing would produce an immediate improvement in landing technique and whether that change would be sustained over a four week period. A secondary purpose was to determine if volleyball spike landing technique improved after one month of volleyball participation without feedback. Nineteen subjects were filmed for the study. The nine athletes in the control group were filmed completing three spike jump landings at the beginning and again at the end of the four week study period, with no feedback provided. The ten athletes in the intervention group were filmed at the beginning of the study period, provided with feedback, and filmed again immediately. Filming was repeated at the end of weeks two and four. Twenty-four kinematic variables were measured using Dartfish analysis software, with Microsoft Excel and Statistica being used for statistical analysis. Paired t-testing demonstrated that the control group generally did not change over time. One-way repeated measures (RM) ANOVA testing showed that right knee flexion and ankle dorsiflexion within the intervention group changed over the study period. Two-way RM ANOVA analysis demonstrated that trunk flexion position was improved in the intervention group at the end of the study as compared to the control group. Female adolescent volleyball athletes can improve their jump landing biomechanics with feedback, and this technique should be employed by coaches in order to decrease the risk of injury to their athletes.

Chapter I
Introduction

GENERAL OVERVIEW

Female participation in sport has increased dramatically in the last three decades. Enactment of the Canadian Charter of Rights and Freedoms in 1982 guaranteed that females would have the right to the same opportunities that only males had received up until that point in time. Equal opportunity has improved everywhere from the business world to the sporting world, with females taking part in almost all sports that were once only the domain of males. As a result, females are sustaining the same musculoskeletal injuries as males. One injury in particular that has been found to occur more commonly in females participating in sport is injury to the anterior cruciate ligament (ACL) of the knee. A recent study suggests that females in sport suffer ACL injury 2-8 times more frequently than male athletes (Hewett et al., 2005).

Injury to this large stabilizing ligament has deleterious consequences, as complete rupture of the ligament is common and requires reconstructive surgery. After surgery, rehabilitation of nine months to a year is not unusual to return the athlete to her sport. Even if the ligament is only partially torn or overstretched, the injury usually results in loss of playing time, as well as pain and joint instability for the athlete.

Because of the extreme physical, emotional and financial toll associated with ACL injury, methods to decrease the incidence of ACL injury in the athletic population and the female athlete population specifically has been a subject of much study. Neuromuscular retraining, including jump landing training, has shown great promise as a factor in ACL injury that can be modified. Up to this point, there has been limited use of video combined with verbal feedback as a tool used by coaches to teach their athletes how to avoid potential movement patterns that put the ACL at risk. An easily accessed feedback tool, if shown to be effective, would provide a cost effective, efficient method for coaches to use to help their athletes prevent ACL injury.

ACL MECHANISM OF INJURY

The ACL is an intracapsular ligament extending from the medial tibial plateau to the lateral femoral condyle. The role of the ACL is to prevent anterior translation of the tibia on the femur (Moore, Dalley & Agur, 2010) and to stabilize the knee during high energy movements such as running, jumping and cutting. The ligament can be injured by both contact and non-contact mechanisms. A hit from behind, forcing the tibia anteriorly on the femur, can injure the ACL, as can a blow from the lateral aspect of the leg. Contact ACL injuries are much less common than non-contact, comprising approximately 30% of all ACL injuries (Withrow, Huston, Wojtys, & Ashton-Miller, 2006).

Non-contact mechanisms make up the remaining 70% of ACL injuries, and usually involve planting a foot and pivoting, a sudden change of direction, or landing from a jump. Figure 1.1 shows the anatomical location of the ACL within the knee joint. The ligament originates from the anterior intercondylar area of the tibia and extends superiorly, posteriorly and laterally to attach to the posterior part of the medial side of the lateral condyle of the femur (Moore et al., 2010).

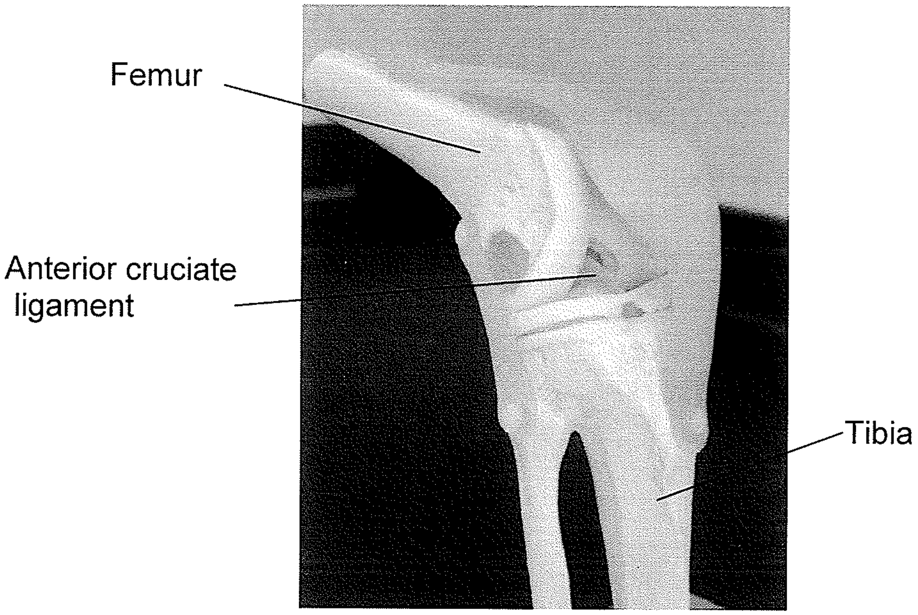


Figure 1.1: Anterior view of the knee joint, showing the position of the ACL between the femur and tibia.

Position of no return

Females are particularly at risk for ACL injury when competing in sports that involve sudden deceleration, pivoting, cutting, and jumping movements (Ireland, 2002; Silvers & Mandelbaum, 2007). These activities are risky to females because their movement patterns are such that they more commonly experience the "position of no return" (Ireland, 2002) (Figure 1.2).

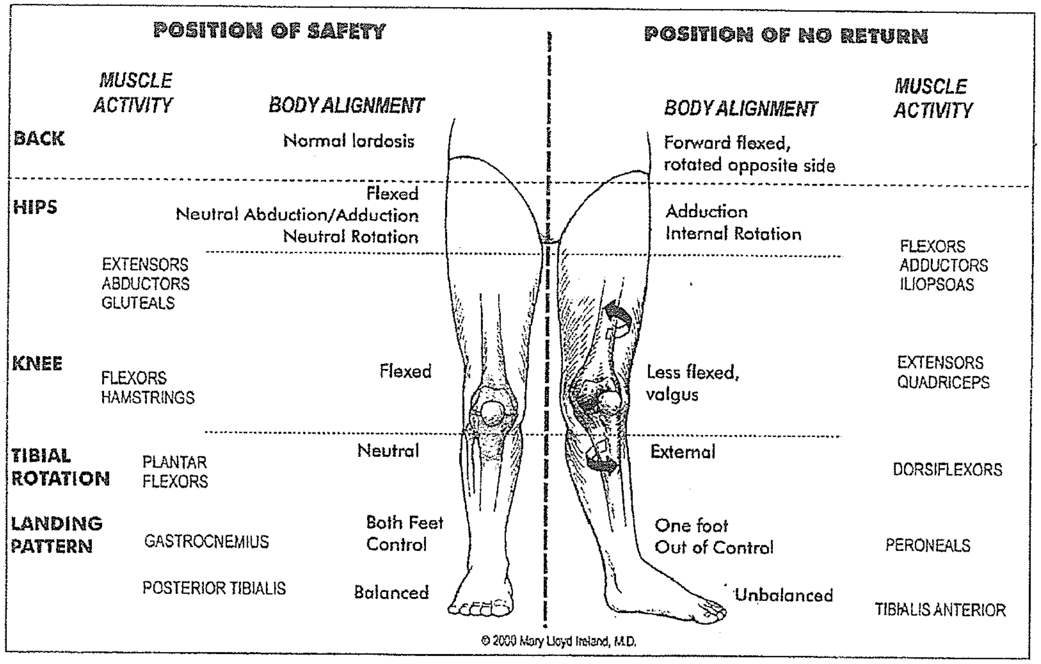


Figure 1.2: Position of no return. (Reprinted with permission from Ireland, 1999).

The position of no return translates into a situation with minimal knee and hip flexion and a valgus position of the knee. This position puts the ACL at risk for a number of reasons. First of all, in a situation of less knee flexion, the medial hamstring muscle group is not as effective in acting as an agonist to the ACL in preventing anterior translation of the tibia (Ireland, 2002; Moore et al., 2010). This is due to the location of the origin and insertion of the medial hamstring muscles (ischial tuberosity to posteromedial tibia, respectively). Because the lateral hamstring muscle, the biceps femoris, inserts on the head of the fibula, this muscle is unable to assist in preventing anterior translation of the tibia.

In a more flexed knee position, the hamstrings are able to produce sufficient torque to have an agonistic function along with the ACL in preventing anterior movement of the tibia on the femur (Silvers & Mandelbaum, 2007). This is due to the larger moment arm present when the knee is flexed (Figure 1.3a). The moment arm, or perpendicular distance from the line of action of the hamstrings to the knee joint upon which they act, is larger in a flexed position. Since Torque = Force x Moment Arm, the torque will increase if the moment arm increases. However, when the knee is in a more extended position, the moment arm for the hamstrings is shortened, thereby decreasing the protective torque that this muscle group can produce about the knee (Figure 1.3b).

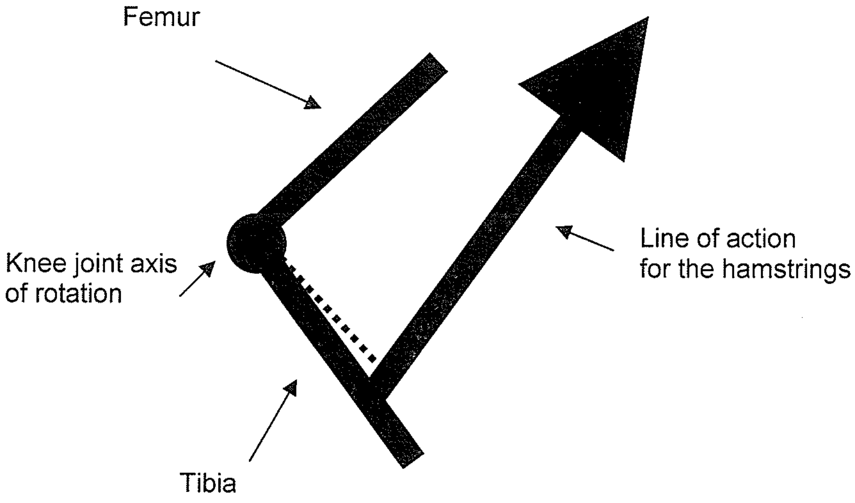


Figure 1.3a: Sagittal close-up view of the moment arm for the hamstrings in a flexed knee position (dashed line between the axis of rotation and the line of action for the hamstrings).

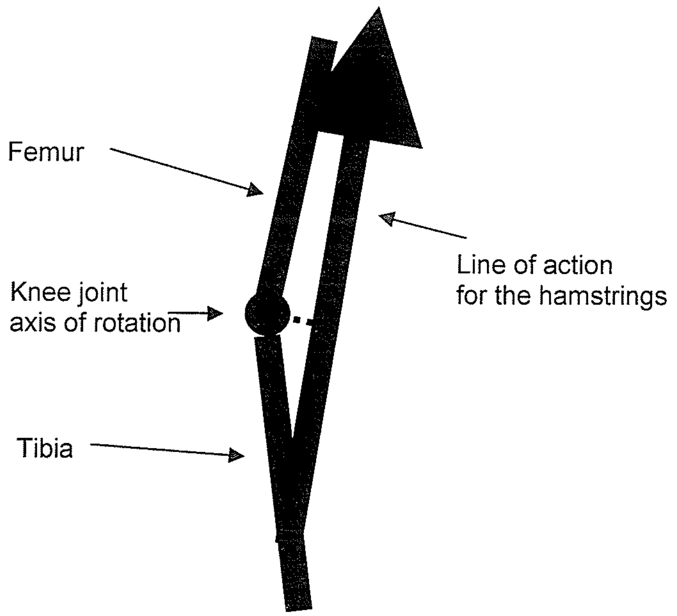


Figure 1.3b: Sagittal close-up view of the moment arm for the hamstrings in a more extended knee position. The moment arm is decreased in this situation (dashed line between axis of rotation and line of action for the hamstrings).

If the knee receives a blow to the posterior aspect of the tibia or if there is a very strong quadriceps contraction in this extended knee position, the hamstrings are unable to assist the ACL in preventing anterior translation, and the ACL can be injured.

The second reason for ACL injury risk in the position of no return is the valgus knee position. A recent study has shown that a position of knee valgus, when combined with flexion and compressive loading of the knee, increases the strain rate within the ACL, coming closer to its rupture point (Withrow et al., 2006). McLean, Su and Van Den Bogert (2004) found that sagittal plane forces only were not sufficient to rupture the ACL, which requires approximately 2000 Newtons of force to tear. Only with valgus loading did the ACL reach the breaking point of 2000 N.

INCIDENCE AND EPIDEMIOLOGY OF KNEE INJURIES IN VOLLEYBALL

A very common sports movement that may produce non-contact ACL injury is the jump landing. Volleyball is one sport where the skill of jumping is integral to the game. Every athlete must jump numerous times in a game in order to play effectively and therefore needs to be able to land successfully and safely from a jump. Ferretti, Papandrea, Conteduca, and Mariani (1992) reported that knee ligament injuries occurred more often to females in volleyball than to males, with 81% of the injuries involving women. These authors also found that nearly all injuries sustained during participation in volleyball occurred while jumping, with more injuries occurring during landing than the take-off and airborne phases combined. Agel, Palmieri-Smith, Dick, Wojtys, and Marshall (2007) found the majority of injuries occurred while the player was in the front row, where jumping for offensive spikes and defensive blocks takes place.

Agel and colleagues (2007) found that 14.1% of all knee injuries among female volleyball players in the National Collegiate Athletic Association (NCAA) involved an internal derangement. Of those, 26.3% were ACL injuries. Majewski, Habelt and Steinbruck (2006) found a higher incidence of ACL injuries in volleyball, at 60% of all internal knee injuries. Clearly, the risk for injury to the ACL in volleyball is real and preventative methods should be explored and put in place.

ACL PREVENTION STRATEGIES

There has been increased interest recently in studying ACL injury prevention strategies, as researchers aim to affect those risk factors for injury that are modifiable. Prevention program effectiveness has been demonstrated with numerous authors finding that neuromuscular retraining programs decrease the incidence of ACL injury (Mandelbaum et al., 2005; Myklebust, Engebretsen, Braekken, Skjolberg, & Olsen 2003; Petersen et al., 2005) as well as improve the biomechanics of executing a jump landing (Chappell & Limpisvasti, 2008; Myer, Ford, Palumbo, & Hewett, 2005; Pollard, Sigward, Ota, Langford, & Powers, 2006). These programs involved a variety of methods, including plyometrics, resistance training, balance exercises and specific jump landing training.

Studies have also shown that instruction regarding the proper way to land from a jump can have a significant effect on the vertical ground reaction forces of an athlete post-intervention (Cronin, Bressel & Finn, 2008; McNair, Prapavessis & Callender, 2000; Onate, Guskiewicz & Sullivan, 2001; Prapavessis & McNair, 1999). Increased vertical ground reaction forces have been correlated with a decreased knee flexion angle upon landing (Hewett et al, 2005), suggesting that lower extremity landing kinetics and kinematics are linked. However, only one of these studies examined athletes performing jump landings in a real life environment (Cronin et al., 2008). Most have been done in a laboratory setting (McNair et al., 2000; Onate et al., 2001; Prapavessis & McNair, 1999). Landing from executing a spike in volleyball is much different than stepping off a platform and landing on a force plate. The athlete must be thinking about the whole skill, including the spike approach, the jump, contacting the ball strongly and effectively and also the landing. By examining what could be altered in a practical scenario, the current study was more realistic regarding the extent to which landing biomechanics can be altered in adolescent female volleyball players.

LANDING TECHNIQUE

Little description exists in the literature specifically describing proper landing technique from a spike jump during volleyball play, probably due to the fact that the main concern for coaches and even the athletes themselves is the contact with the ball. After contact, nothing can be done to alter the accuracy or velocity of the spike. However, the landing is extremely important when considering the risk of injury, especially in females.

In ten international volleyball players, Coleman, Benham and Northcott (1993) found that each one of them landed on their left foot first and then planted their right foot. This may be due to the inherent variability within the location of the set to the hitter. It may not be desirable to always land on two feet, which prevents an off balance position in the air that may be necessary because of the timing or location of the ball from the setter (Selinger & Ackermann-Blount, 1985). However, a one foot landing may predispose athletes to injury, as the force of landing needs to be absorbed by that one leg. Adrian and Laughlin (1983) reported that landing from a spike jump on one leg produces a vertical ground reaction force equal to 4.8 to 6.0 times bodyweight. This is more than the ground reaction force experienced by each leg during a two foot landing. Blackburn & Padua (2009) looked at 40 university aged athletes landing from a jump, with one foot landing on a force plate. The authors found that the athletes in their study landed with a ground reaction force of approximately 4 times bodyweight on each leg. An additional study (Salci et al., 2004) found similar values, with their university athletes landing with ground reaction forces between three and five times bodyweight. The subjects in this study also landed from a drop jump with one foot on a force plate.

Coleman et al. (1993) suggested that increased chance of injury may occur due to landing on the left foot first, which is generally a right handed athlete's weaker leg. Biomechanically, it would be advantageous to land on both feet simultaneously, as the force required to decelerate the landing can be distributed over the musculature and joints of both lower extremities. The forces produced to absorb the landing would be doubled in the case of an athlete landing on only one foot.

Jump landing investigative methods

There have been a few different methods of investigating the biomechanics of jump landings in a controlled setting. Most studies have examined subjects executing a jump landing by dropping from a pre-determined height onto a force platform with or without subsequently performing a vertical jump (Blackburn & Padua, 2008; Chappell & Limpisvasti, 2008; Decker, Torry, Wyland, Sterett & Steadman, 2003; Devita & Skelly, 1991; Ford, Myer, Smith, Vianello, Seiwert & Hewett, 2006; Hewett, Myer, Ford & Slauterbeck, 2006; Huston, Vibert, Ashton-Miller & Wojtys, 2001; Kovacs, Tihanyi, Devita, Racz, Barrier & Hortobagyi, 1999; McNair et al., 2000; Mizner, Kawaguchi & Chmielewski, 2008; Pollard et al., 2006; Prapavessis & McNair, 1999; Salci, Kentel, Heycan, Akin & Korkusuz, 2004; Schmitz, Kulas, Perrin, Riemann & Shultz, 2007) (Figure 1.4).

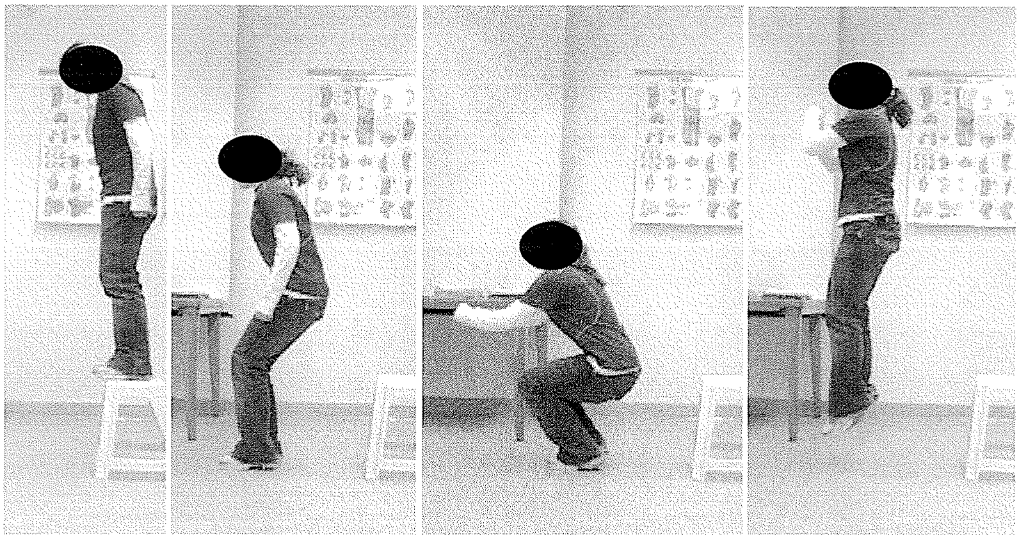


Figure 1.4: Execution of a drop jump landing with subsequent vertical jump.

Alternatively, Onate et al., (2001) and Onate, Guskiewicz, Marshall, Giuliani, Yu & Garrett (2005) employed a Vertec apparatus (http://www.vertec.co.uk) which is a jump testing implement used to evaluate the height of a jump (Figure 1.5). These investigations, as in the studies using a drop jump, utilized a force plate directly below the Vertec in order to capture the vertical ground reaction forces that were produced during the skill. Vertical ground reaction forces are particularly of interest to researchers, as increased vertical ground reaction forces have been linked to an increased risk of ACL injury (Hewett et al., 2005).

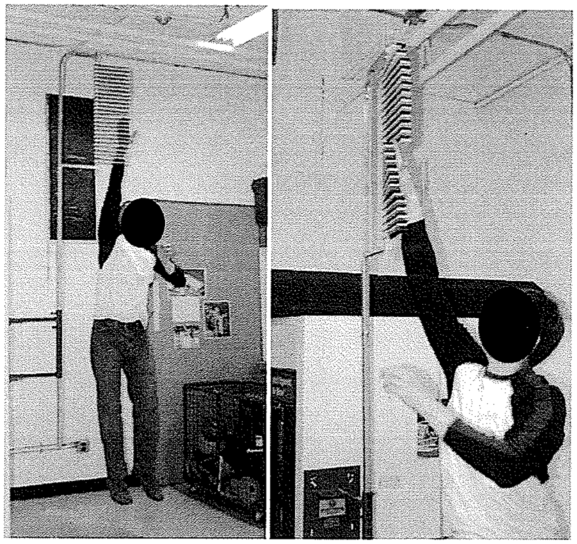


Figure 1.5: Vertec vertical jump testing implement.

The subject jumped straight up as high as possible and landed straight down in the same position from which she took off. This enabled the researchers to determine the forces required by the body to perform the landing from this jump, as well as the kinematics of the lower body during the skill.

One research group (Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005) used an adjustable hang bar suspended directly over the force plate. The subject would hang from the bar and drop onto the force plate to generate vertical ground reaction force data for the landing. These researchers felt that data collected via this method was more reliable than using the traditional drop jump technique.

The disadvantage of studying jump landings using the previously described simulations is that they have been administered in a controlled laboratory setting, in which the athlete is not undertaking any of the skills of a real life complex game situation, such as shooting a basketball or spiking a volleyball.

Only one study used a real life situation of an athlete actually completing a full volleyball spike approach, hitting a tossed volleyball, and landing on a force platform (Cronin et al., 2008). This suggests that there is a gap in the literature describing investigations involving competitive sport situations. Until ACL prevention programs are demonstrated to improve movement biomechanics in situations the athlete encounters on a daily basis in practices and games, their efficacy will be questioned.

Variables commonly measured during jump landing studies

Researchers have studied numerous variables, both kinematic and kinetic, during their investigations into jump landing biomechanics. Many researchers have used initial and peak hip, knee and ankle flexion angles to identify sagittal plane kinematics (Blackburn & Padua, 2008; Chappell & Limpisvasti, 2008; Decker et al., 2003; Mizner et al., 2008; Pollard et al., 2006; Salci et al., 2004; Schmitz et al., 2007). Some have used peak hip adduction, hip internal rotation, knee valgus and ankle eversion to investigate coronal plane movements (Blackburn & Padua, 2008; Chappell & Limpisvasti, 2008; Ford et al., 2006; Mizner et al., 2008; Pollard et al., 2006). As far as the present investigator is aware, Blackburn and Padua (2008) are the only authors to measure trunk flexion during the jump landing, while Chappell and Limpisvasti (2008) are the only authors to investigate maximum lateral and forward pelvic tilt, as well as pelvic tilt at initial ground contact.

Angular velocities of the hip, knee and ankle have been investigated by one study (Decker et al., 2003), while landing time has been described by a number of studies (Chappell & Limpisvasti, 2008; Hewett et al., 2005; Mizner et al., 2008; Schmitz et al., 2007).

Peak vertical ground reaction forces have often been used in investigative studies to describe the characteristics of the jump landing (Chappell & Limpisvasti, 2008; McNair et al., 2000; Mizner et al., 2008; Prapavessis & McNair, 1999; Schmitz et al., 2007), as increased vertical ground reaction forces have been linked to ACL injury (Hewett et al., 2005).

Kinetic variables have been used extensively to identify the forces involved in completing a jump landing. Pollard et al. (2006) studied hip external rotation, abduction and flexion moments, as well as knee external rotation, valgus and flexion moments. These variables, as well as ankle dorsiflexion and eversion moments, were also measured by Mizner and colleagues (2008). Peak hip and knee extension moments and plantarflexion moments were analyzed by Salci and colleagues (2004) to contribute to the description of the jump landing.

One aspect of the jump landing that has been largely ignored in the literature is the involvement of the arms. In terms of anterior cruciate ligament injury prevention, the arms have the potential to significantly decrease ground reaction forces (see page 62), but up to this point, this topic has not been investigated.

Gender differences in landing technique

There are many differences in regard to the technique of jump landings between female versus male athletes. Figure 1.6 demonstrates the tendency for females to land with less hip and knee flexion, less ankle dorsiflexion and more knee valgus. Females also exhibit increased hip adduction and internal rotation

(Decker et al., 2003) and less trunk flexion on average than males. This resembles the “position of no return”, as discussed earlier (Ireland, 1999) that puts the ACL at risk for injury. In a position of less knee flexion, the strain to the ACL is increased (Decker et al., 2003). As discussed in Figure 1.4, the moment arm for the hamstrings in a more extended knee position is shorter, which decreases the amount of torque the muscles can produce to prevent anterior translation of the tibia. Lacking the protective function of the hamstrings, the ACL is at an increased risk for injury in a more extended position.

Females also tend to use less hamstring recruitment and more quadriceps contraction during the jump landing (Hewett et al., 2005). As the quadriceps contract and pull the tibia anteriorly on the femur, an injury to the ACL can occur if the hamstrings have insufficient strength to assist in the prevention of this movement. Females also land with more foot pronation than males (Kernozek et al., 2005) which again leads the athlete into the position of no return.

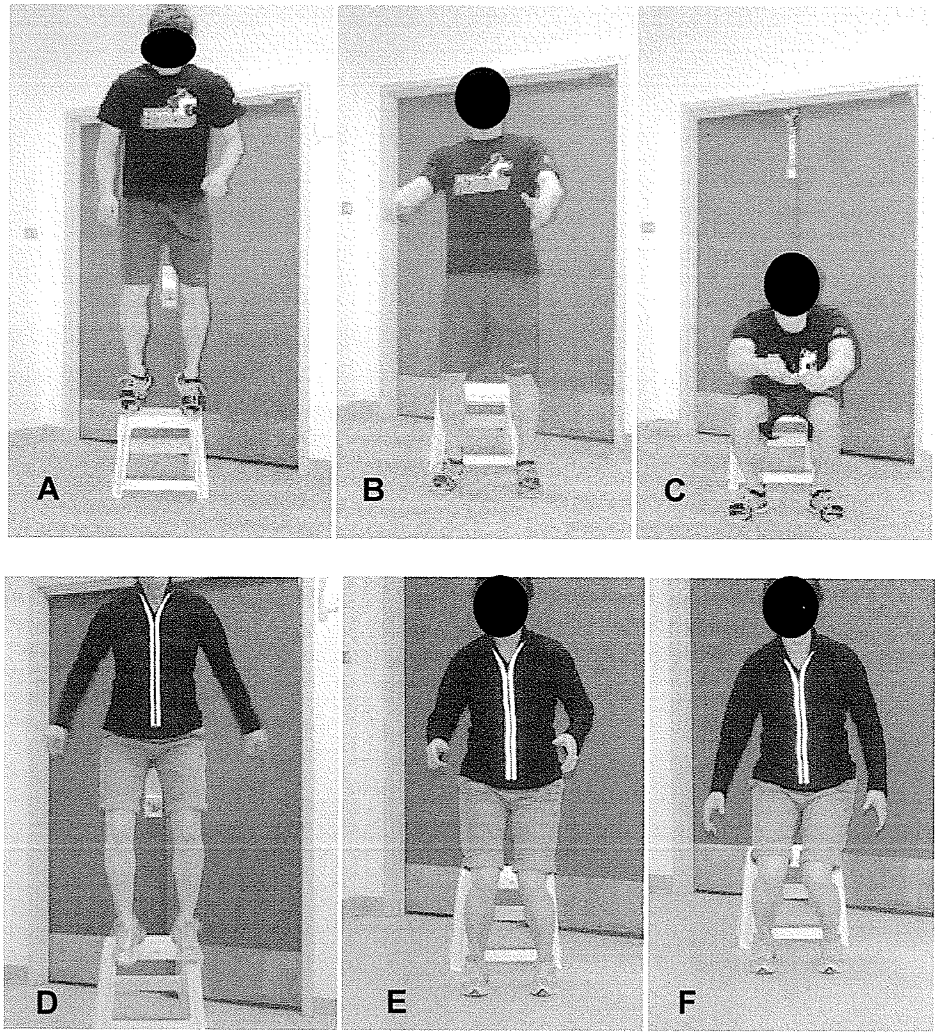


Figure 1.6: Gender differences in movement patterns when landing from a drop jump (top-male; bottom-female).

Safer landing technique

Clearly a difference exists between males and females in terms of how they land from a jump. Considering that this is an extremely important part of the game of volleyball, exploring ways to change this movement strategy to a safer technique is valuable. Ireland (1999) suggests that a safer landing strategy would incorporate increased knee flexion at initial ground contact of the landing, and keeping the leg in a neutral position, with hips over knees and knees over toes (Figure 1.6 A-C). Athletes should avoid hip internal rotation and adduction which contributes to knee valgus as well as tibial external rotation and foot pronation (Figure 1.6 D-F). Silvers and Mandelbaum (2007) agreed with these recommendations, but also suggested landing initially on the forefoot and rolling back to the rearfoot as an important component of safe landing technique.

PURPOSE OF THE STUDY

The purpose of the present study was to examine whether spike jump landing mechanics in adolescent female volleyball players could be improved during a single practice session using video and verbal feedback and whether that change could be sustained over a four week period. A secondary purpose was to determine if volleyball spike landing technique improved during the course of regular team practices, without jump landing training intervention.

HYPOTHESES

1) Verbal and video feedback regarding landing biomechanics from a volleyball spike jump would cause an improvement in landing biomechanics during a single practice session.
2) Verbal and video feedback regarding landing biomechanics from a volleyball spike jump would cause a sustained change in landing biomechanics after a four week time period. However, this change would be less significant than the immediate changes.

RATIONALE FOR THE STUDY

Increased incidence of ACL injuries in female athletes

ACL injuries in females have reached epidemic proportions, with the associated financial, emotional and physical costs to the athletes involved. Since the adoption of Title IX in 1972, male participation in high school level sports in the United States has increased by about 3%, while female participation has doubled every ten years (Hewett et al., 2005). This huge growth in women's sport has led to an increased incidence of musculoskeletal injury in females, and in ACL injuries in particular. Approximately 38 000 ACL injuries to female participants occur in the United States annually (Hewett et al., 2005).

The overall incidence of ACL reconstruction surgery has been found to be between 34 and 81 per 100 000 people (Renstrom, Ljungqvist, Arendt, Beynnon, Fukubayashi, Garrett et al., 2008). However, this incidence drastically increases when only the physically active population is considered (Renstrom et al., 2008). These numbers underestimate the occurrence of ACL injury, as only those injuries that are severe enough to warrant reconstructive surgery are included. When first and second degree sprains to the ligament are considered along with third degree ruptures, the overall incidence of ACL injury in female athletes is much higher.

Financial costs of ACL injury

The monetary costs associated with ACL injury, especially third degree rupture, are considerable. Surgical costs are very high, including physician and nursing wages, operating room time, and anesthesia and other drugs. Hewett and colleagues (2005) report that the average cost of an ACL injury in the United States is $17 000. Rehabilitation for ACL reconstruction surgery is intensive and can last from nine months to one year before the athlete can return to her usual sport. As well, expensive knee braces, costing as much as $1000 may be required, both immediately after surgery for stability as well as when the athlete returns to the field of play.

Physical health costs of ACL injury

The physical health costs to the athlete are significant as well. An ACL injury is truly debilitating, with most athletes experiencing periods of “giving way” when weightbearing, even after reconstructive surgery. Initially the injury may not be very painful with a complete rupture of the ligament, as all the nociceptors have been interrupted along with the ligamentous tissue, preventing pain signals from reaching the brain. However, when inflammation and swelling start to occur, the pain can be intense. The swelling is usually quite significant, preventing full flexion or extension of the knee joint. This severely limits the mobility of the athlete, which has detrimental side effects including decreased fitness levels and well-being.

Muscle atrophy commences within twenty-four hours, not only in the muscles immediately surrounding the knee, but also in any other muscle groups in the body that are not being utilized. Cardiovascular deconditioning also occurs, as the athlete is unable to move enough to elevate her heart rate to a training level. All the associated benefits of being active and involved in sport come to a halt, as the athlete waits for surgery and subsequent rehabilitation to begin.

Emotional health costs of ACL injury

Besides the physical toll on the athlete, an ACL injury can be a devastating emotional blow to an athlete. It is most often a season ending injury, and leads to early retirement from sport (Myklebust & Bahr, 2005). For an athlete in the prime of her competition cycle, or for an athlete on a full scholarship to a university because of her athletic ability, the emotional consequences of being unable to participate and truly be a part of the team are significant. This is an often overlooked result of severe athletic injury, but it should not be considered unimportant.

A need for preventative programs at an early age

If a conditioning program or specific coaching advice can help prevent ACL injuries in female adolescent athletes, it is clear that this would be beneficial to the athlete, the coach and team, and the health care system. Modifying neuromuscular movement patterns is evolving as one of the most promising means of decreasing the chance of ACL injuries in all athletes (Renstrom et al., 2008). By educating athletes on how they move and how they can alter those movements to decrease injury while not sacrificing performance, athletes can be prepared for a lifetime of injury free participation.

It has been found that boys and girls land from a jump in a similar pattern until age 12, after which females begin to land with progressively less knee flexion up until age 16 (Renstrom et al., 2008). The observable difference in ACL injury rates between genders begins at about age 12, around the time females begin puberty (Shea, Pfeiffer, Wang, Curtin & Apel, 2004). If these young athletes can be trained and educated from the beginning of their athletic careers, before they start establishing poor neuromuscular control patterns, the majority of ACL injuries might well be avoided.

A need for effective, efficient ACL injury prevention techniques

A decrease in the incidence of ACL injury has been found with the implementation of neuromuscular retraining programs among athletes (Mandelbaum et al., 2005; Myklebust et al., 2003; Petersen et al., 2005). A key component of the programs was the inclusion of jump landing technique education. The education stressed landing with deeper knee and hip flexion as well as trying to land softly as opposed to landing with flat feet. These programs caused change in the athletes via long term neuromuscular adaptation, over the course of at least one competitive season, which is not always convenient or realistic for middle school aged teams with limited budgets and schedules.

Many studies have also been conducted looking at the immediate effect of jump landing technique education (Cronin et al., 2008; McNair et al., 2000; Onate et al., 2001; Prapavessis & McNair, 1999). These studies involved re-evaluating the landing biomechanics of athletes during the same session, after some type of feedback describing how to improve their landing technique. Obviously the changes observed by the researchers were not a result of long term neuromuscular adaptation, but rather short term changes in the neuromuscular patterning of the movements.

No studies were located that have looked at the longer term effects of instructing volleyball athletes on proper landing technique using video and verbal feedback. The longest study done to date re-evaluated recreational athletes from many sports one week after the initial feedback session and found that the athletes maintained the biomechanics they learned during the initial intervention session (Onate et al., 2001). The current study attempted to determine whether the skills learned during one session of verbal and video feedback were evident immediately, as well as four weeks post-intervention. In terms of the existing literature this constitutes a long term study, however it does not endeavor to measure a permanent change in performance.

LIMITATIONS

1) The subjects for this study were female volleyball athletes from two private schools. This limited the ability to generalize the findings of the study to other populations, including athletes competing in sports other than volleyball.
2) Subjects were 12 to 14 years of age. Results may not be extrapolated to female volleyball players of other ages.
3) This study included only female volleyball players. Results may not be generalized to male volleyball players.
4) Sample size in this study was small, increasing the chance that differences between subjects were a result of intersubject variability rather than actual change due to visual or verbal feedback

DEFINITION OF TERMS

Afferent Input: Sensory nerve information traveling from the periphery of the body to the central nervous system (Moore et al., 2010).

Agonist: A role played by a muscle, tendon or ligament acting to cause a movement of a body segment at a joint; the structure is acting as a mover (Hall, 2007).

Antagonist: A role played by a muscle, tendon or ligament acting to slow or stop a movement of a body segment at a joint; the structure is acting as an opposer (Hall, 2007).

Femoral Torsion: The angle as measured between the long axis of the femoral neck and a line through the femoral condyles, when the femur is viewed from above. See Figure 1.7.

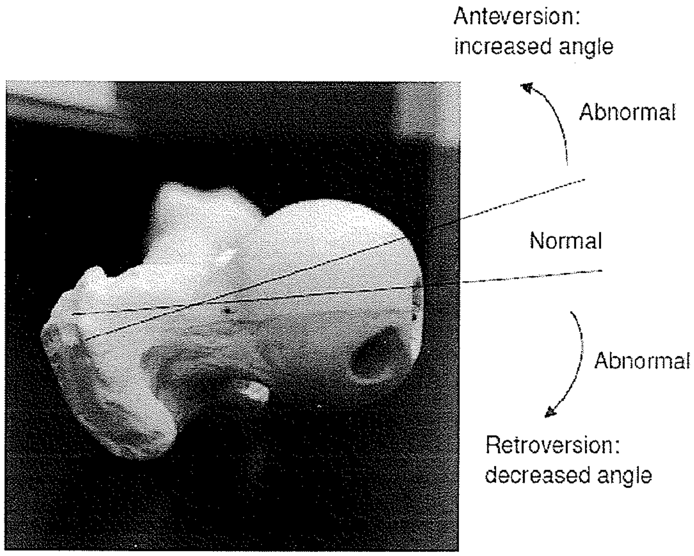


Figure 1.7: Superior view of the left femur illustrating femoral torsion.

Ground Reaction Force: The force exerted upwards by the ground in response to a force applied down upon it. The ground reaction force is of equal magnitude but in the opposite direction to the applied force (Hall, 2007).

Internal Derangement: Disorder of the knee due to a torn meniscus, or a partial or complete cruciate rupture, with or without injury to the capsular ligament of the knee (Veteran's Affairs, Canada, retrieved on July 21, 2008 from www.vac-acc.gc.ca/clients/sub.cfm?source=dispen/elguide/internald).

Kinematics: The description of motion, including the form, pattern or sequencing of movement with respect to time (Hall, 2007).

Kinetics: The study of the action of forces associated with motion (Hall, 2007).

Long Term: For the purposes of this study, refers to a timeframe of more than one week.

Mechanism of Injury: The source of forces that produce mechanical deformations and physiologic responses that causes an anatomic lesion or functional change in humans (Retrieved on August 6, 2008 from www.nhtsa.dot.gov/PEOPLE/injury/ems/emstraumasystem03/glossary.htm).

Moment: The rotary effect caused by an application of force; also known as torque (Hall, 2007).

Moment Arm: The perpendicular distance between the line of force and the axis of rotation (Hall, 2007). In the human body, it is the distance between the line of muscle pull and the axis through the joint.

Nociceptors: Nerve receptors whose stimulation gives rise to pain (Vander, Sherman & Luciano, 2003).

Position of No Return: A pathological anatomical position proposed by Mary Lloyd Ireland (1999), related to an increase in frequency of ACL injury in females. It consists of a pronated foot, valgus knee, externally rotated tibia, internally rotated and adducted femur, and extended knee. She also suggested that a flexed trunk contributes to this potentially dangerous position, but another study disagreed (Blackburn & Padua, 2008). See Figure 1.8.

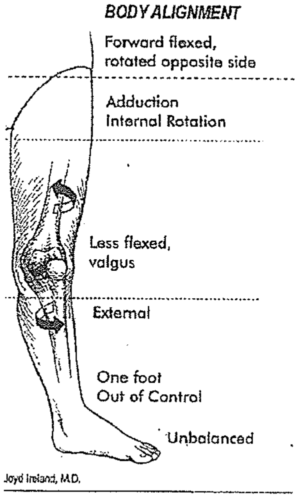


Figure 1.8: Position of no return as suggested by Ireland (1999).

Q-angle: The angle as measured between a line joining the anterior superior iliac spine with the midpoint of the patella and a line joining the midpoint of the patella and the tibial tuberosity. (Magee, 1997) (Figure 1.9).

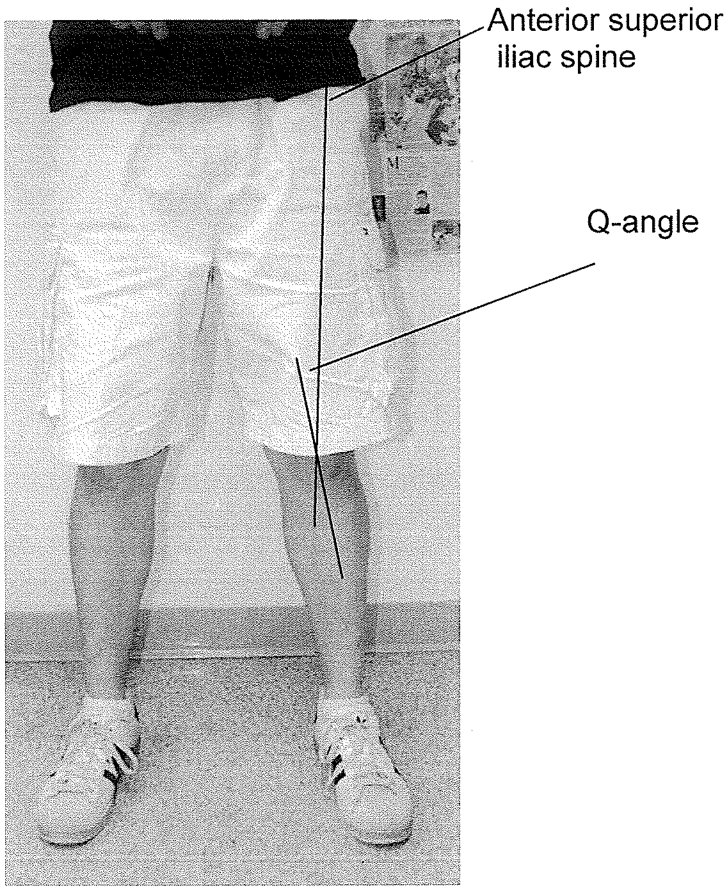


Figure 1.9: Q-angle of the lower extremity.

Sagittal Plane: One of three planes of the body, dividing the body vertically into left and right halves, in which forward and backward movements of body segments occur (Hall, 2007).

Short Term: For the purposes of this study, refers to a timeframe of less than or equal to one week.

Spike Approach: A three or four step sequence taken by a volleyball athlete as she approaches the net in preparation for a spike. Usually a left-right-left pattern for a right handed hitter (Retrieved August 7, 2008 from www.strength-and-power-for-volleyball.com/volleyball-spike.html).

Sprain: Stretching and/or tearing of ligamentous tissue. Sprains are generally classified into three grades. Grade I consists of an overstretching of the ligament. Grade II involves some ligament fibers tearing. Grade III denotes a complete tear of the structure (Arnheim & Prentice, 2002).

Valgus Knee: Deviation of the tibia away from the midline in the anatomical position. Thus, a valgus knee occurs when the lower leg is angled away from the midline (also known as "knock-kneed" or "genu valgum). By convention any deformity, or deviation, is described in terms of the movement of the distal part. See Figure 1.10.

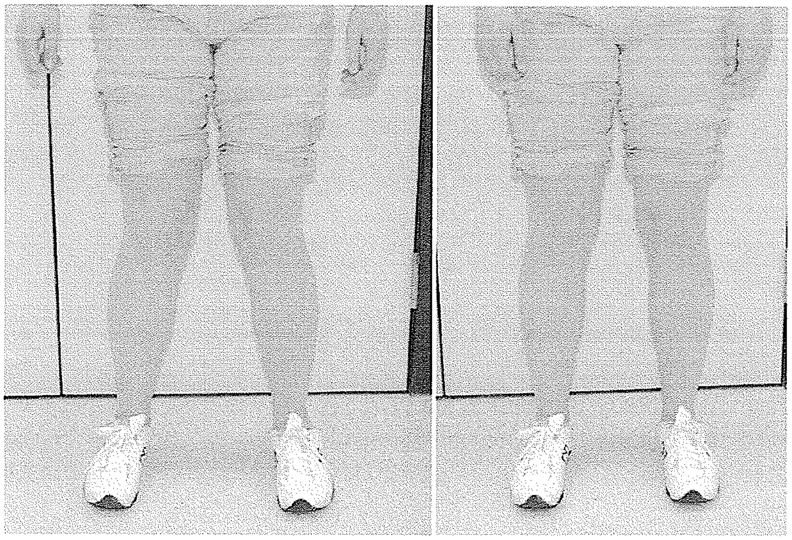


Figure 1.10: Comparison of a valgus knee position (left) versus normal alignment.

Chapter II
Literature Review

To establish a background for this study, a comprehensive review of literature on ACL injuries, specifically looking at non-contact mechanisms and biomechanical factors that may contribute to injury, was completed. The components and effectiveness of ACL injury prevention programs was also reviewed. Some background information describing the prevalence of ACL injury in the sport of volleyball has also been included to demonstrate the relevance of this study. The review of literature also includes the effect of video and verbal feedback on skill development and skill learning

INCIDENCE OF INJURY IN VOLLEYBALL

Overall injury rates

Volleyball is a hugely popular sport worldwide, with estimates of about 150 million participants in more than 200 countries taking part in the sport (Bahr & Bahr, 1997). Due to the nature of the game, with the net dividing the two teams, the majority of injuries are non-contact in nature. Different authors have found varying injury rates in volleyball. Schafle, Requa, Patton, & Garrick (1990) found an overall injury rate of 2.3 injuries per 1000 player hours during competition. Bahr & Bahr (1997) found a slightly increased rate, at 3.5 injuries per 1000 player hours in competition. One Danish study found an incidence of 5.7 per 1000 player hours during games (Yde & Nielsen, 1988). Injury rates during practice have been found to be about 2 injuries per 1000 hours of participation (Schmidt-Olsen & Jorgensen, 1987; Yde & Nielsen, 1988). Bahr & Bahr (1997) found a slightly lower probability of injury at 1.5 per 1000 hours of participation. To compare these numbers to other common sports, basketball has been found to have an average injury rate of 2.7 per 1000 hours of participation, team handball has recorded a rate of 8.3, and ice hockey a rate of 1.4 during practice and 78.4 during games (Colliander, Eriksson, Heckel & Skoeld, 1986; Jorgenson, 1984; Lorentzon, Wedren, & Pietela, 1988). Volleyball, therefore, can be considered about equal to basketball in terms of injury and of lesser risk than either hockey or handball.

Incidence of knee injury in volleyball

Bahr & Bahr's study (1997) found a relatively low incidence of knee injury in volleyball, at only 0.1 per 1000 hours, or 8% of all injuries. Agel et al., (2007) reported higher injury incidence, with knee internal derangements comprising 14.1% of all game injuries and 7.8% of all practice injuries in women's volleyball in the NCAA from 1988-2004. Of those, 26.3% were found to be ACL injuries. Majewski et al., (2006) found in their study that the highest risk for ACL injury occurred in volleyball and team handball.

Similar to other sports, women are found to have a much increased chance of knee injury and specifically ACL injury in volleyball than males. Ferretti et al., (1992) found that 81% of the volleyball players that underwent ACL reconstructive surgery at a particular hospital in Rome were female. They state that volleyball should be considered a high risk sport in terms of knee injury, as the preponderance of jumping puts athletes at risk and this activity has been shown to cause the majority of ACL injuries. Sixteen percent of knee injuries in female volleyball players in the Swiss National Youth and Sports Organization were found to be ACL injuries as opposed to eleven percent of knee injuries in males (de Loes, Dahlstedt, & Thomee, 2000). This was the second highest female to male ratio found in the study, behind gymnastics. Many other sports in the study had higher absolute numbers of ACL injuries, but the ratio between men and women was not as high. This suggests that females are at a significantly increased risk of ACL injury compared to males if they engage in the sport of volleyball. Rauh, Macera & Wiksten (2007) suggested that not only are new ACL injuries in volleyball a risk, but that female volleyball athletes are at a significantly increased risk of subsequent ACL injuries as compared to other sports.

EPIDEMIOLOGY OF INJURY IN VOLLEYBALL

Game versus practice and court position affects the risk of ACL injury

Sprains are the most common injury in volleyball, with approximately 65% of all injuries being recorded of this type (Bahr & Bahr, 1997). Bahr and Bahr (1997) found that more of these sprains occurred during a game situation than during practice. This was only true for male players, however, and not females. An increased chance of injury during games versus practice was found for females and males alike by Ferretti and colleagues (1992). Playing in an offensive position (front row) versus a defensive position (back row) on the court also seems to increase the chance of injury (Ferretti et al., 1992). Agel et al., (2007) agreed that the majority (67.3%) of injuries to volleyball players occurred to athletes playing in the front row.

Type of volleyball skill attempted affects the risk of ACL injury

Bahr & Bahr (1997) found that most of the injuries sustained during participation in volleyball occurred during take-off or landing from a jump or during the actual spiking motion. Gerberich, Luhmann, Finke, Priest and Beard (1987) determined that 63% of all injuries including 61% of all knee injuries in volleyball occurred during jumping, landing and twisting on impact. In a study by Ferretti et al., (1992), 48 of 52 volleyball athletes who suffered an ACL rupture identified the injury as occurring during a phase of jumping. Thirty-eight of these injuries occurred during the landing phase, and seven during the takeoff. The three others believed their injury had occurred during the airborne phase.

NON-CONTACT MECHANISM OF INJURY TO THE ACL

Injury to the ACL has been subdivided into contact and non-contact etiologies. Non-contact causes are by far more common, with approximately 70% of all ACL injuries falling in that category (Silvers & Mandelbaum, 2007). The mechanisms that cause the non-contact ACL injury most often involve a sudden deceleration, a rapid change of direction, cutting maneuvers, or landing from a jump (Silvers & Mandelbaum, 2007). During these movements, particularly in females, the lower extremity enters the “position of no return” (Ireland, 1999). The foot is planted and pronated, the tibia is externally rotated and the knee is in minimal flexion. The hip is internally rotated and adducted. If the athlete then attempts to change direction, the result is increased tension on the ACL and risk of injury.

Anatomical factors contributing to non-contact ACL injury

Many factors have been suggested as reasons why females are more susceptible than males to the position of no return, including differences in anatomy. Females are thought to have increased femoral anteversion, an increased Q-angle and more tibial torsion compared to males (Silvers &

Mandelbaum, 2007). Femoral torsion is the angle between the long axis of the femoral neck and a line through the femoral condyles, when the femur is viewed from above. When this angle is increased by the femoral neck being situated in a more forward position, it is termed femoral anteversion (Figure 2.1). Femoral anteversion causes the hip joint to sit in an internally rotated position as its "neutral" position. To compensate for this internally rotated femur, the tibia must be externally rotated in order for the female's foot to point in a forward direction for locomotion.

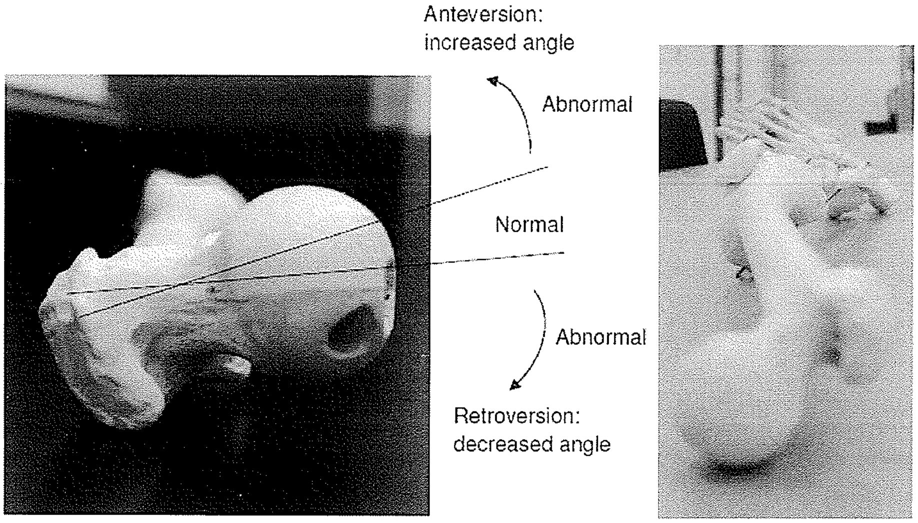


Figure 2.1: Femoral torsion of the left femur (left); and the effects of right femoral anteversion on the right lower extremity (right).

The Q-angle, or Quadriceps angle, is the angle between a line joining the anterior superior iliac spine of the pelvis with the midpoint of the patella and a line joining the center of the patella with the tibial tuberosity (Figure 2.2).

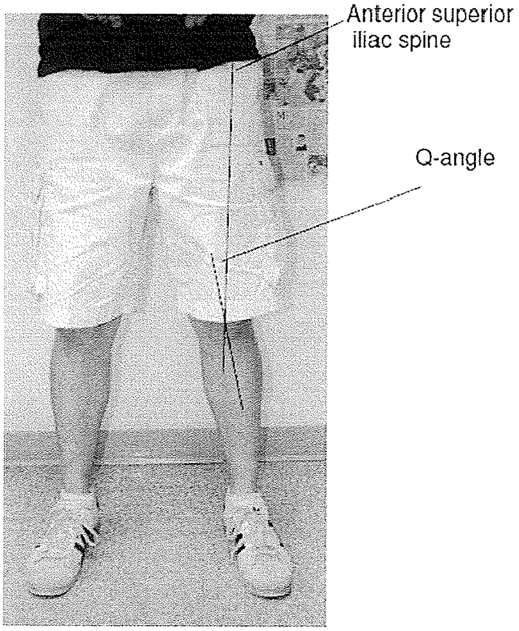


Figure 2.2: Diagram of the Q-angle.

An increased Q-angle in females is related to an increased valgus angle at the knee, which is generally thought to put the ACL at risk. However, researchers have not found a definitive link between any anatomical factors and increased ACL injury as of yet (Schultz, Nguyen & Beynnon, 2007). It is agreed, however, that anatomical factors are part of the equation, and must be considered in a dynamic context.

Neuromuscular control issues contributing to non-contact ACL injury

Recently, much attention has been given to the neuromuscular factors that contribute to ACL injury in females. This is the one area of ACL research that has offered some concrete proof that the risk of ACL injury can be decreased by intervention. Neuromuscular control of the knee involves the unconscious ability of the body to sense knee position and movement, and react accordingly in response to an external or internal perturbation to maintain stability of the structure. This reaction comes through the muscular attachments surrounding the knee.

The signals that travel from the knee to the central nervous system to elicit a coordinated response can be of two types; feedback or feedforward. Feedback mechanisms work in a reflexive manner. They work in response to afferent input from the various proprioceptors about the knee, and are therefore slower to respond (Silvers & Mandelbaum, 2007). Feedforward mechanisms "are a result of preactivated preparatory activation of muscle" (Silvers & Mandelbaum, p. i55). This mechanism senses the body's position before the force is applied, preparing the joints to best receive the perturbation. It is a preventative strategy that uses proper biomechanics and positioning prior to a potentially injurious situation. This feedforward mechanism is being manipulated during neuromuscular training programs undertaken by teams and athletes to decease their injury risk.

Hip abduction strength

Not only is muscular control important around the knee, but recent studies have begun to uncover the essential role of more proximal muscles as well. The muscles of the hip, and specifically the hip abductors, are crucial in determining the position of the lower extremity during activity (Leetun, Ireland, Willson, Ballantyne & McClay Davis, 2004; Myer, Brent, Ford & Hewett, 2008; Myer, Chu, Brent & Hewett, 2008; Willson, Ireland & Davis, 2006). The hip abductors include gluteus minimus and gluteus medius (Moore et al., 2010). These muscles act to stabilize the pelvis and prevent the lower extremity from moving into hip adduction when it is in single leg support (Leetun et al., 2004). Hip adduction has been suggested by Ireland (1999) to be part of the "position of no return" mechanism of injury to the ACL. It follows that strong hip abductor muscles would be of benefit in the avoidance of ACL injury.

Decreased hip abductor muscle strength has previously been identified in females as compared to males (Cahalan, Johnson, Liu & Chao, 1989; Leetun et al., 2004; Willson et al., 2006). Other authors (Brent, Myer, Ford & Hewett, 2008) found that male athletes increased their relative hip abduction strength at a significantly greater rate than female athletes as they progressed through puberty. This decrease in strength in females can have a number of negative consequences. Willson et al., (2006) found that a lack of hip abduction strength was directly correlated to an increase in knee valgus angle in a group of 46 male and female university athletes performing a single leg squat. Increased knee valgus angle is another factor suggested by Ireland (1999) as being part of the "position of no return" which puts the athlete at risk for ACL injury. Knee valgus and its influence on ACL injury risk is discussed in more detail on page 43.

As well, Leetun et al., (2004) found that injury was more likely to occur in athletes who displayed weak hip abduction in pre-season testing. The study involved 139 university aged male and female athletes. Their hip abduction strength was measured isometrically within the first two weeks of the competitive athletic season and their injury history was followed over one competitive season. Females suffered more than double the number of injuries in this study as compared to the male subjects. There was one ACL injury during the course of this study, and it involved a female athlete. She displayed a significant deficiency in hip abduction strength (23% of bodyweight) compared to both the injured (28.9% of bodyweight) and uninjured female athletes (29.4% of bodyweight).

Testing for hip abduction strength can be done relatively easily, with little training. A common test used in the clinical setting is the Trendelenburg test (Prentice, 2009). The test is conducted by asking the athlete to stand on one leg. The person conducting the test stands directly behind the athlete. If the non-stance hip drops downward, this indicates a weak gluteus medius muscle on the stance leg (Figure 2.3).

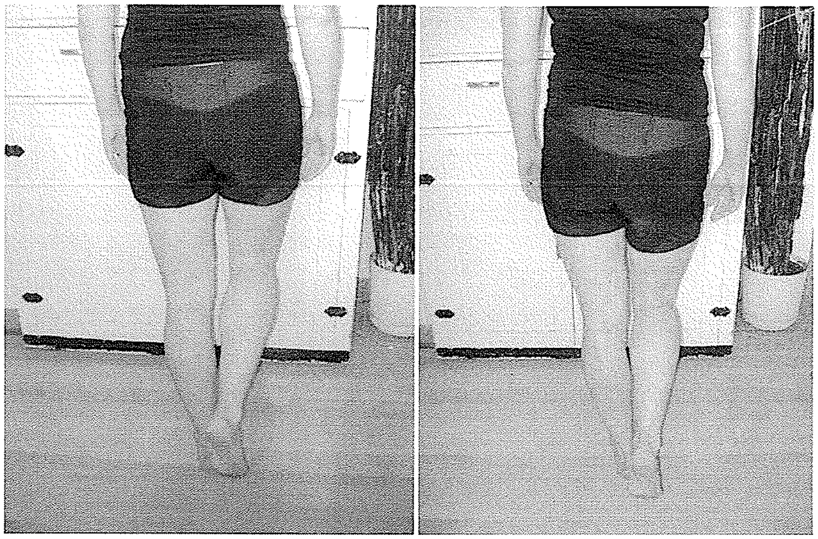


Figure 2.3: Negative Trendelenburg test on the left; positive Trendelenburg test on the right, indicating weak hip abductor muscles on the left leg.

Muscle activation patterns

The hamstring and quadriceps are the main muscle groups that exert influence over the knee joint. The three hamstring muscles cross the knee posteriorly. Two insert on the medial tibia and one inserts on the fibula. The four quadriceps muscles cross the knee joint anteriorly via the patellar tendon, which inserts on the tibial tuberosity on the anterior aspect of the tibia (Moore et al., 2010). Simultaneous contraction of the hamstring and quadriceps muscle groups serves to increase knee joint stiffness and stability by increasing tibiofemoral joint compression (Markolf et al., 1978). This guards the knee joint against excessive anterior translation. The ACL is stressed with abnormal anterior movement of the tibia on the femur, and therefore co-contraction of the thigh muscles is desirable.

A number of studies have demonstrated that females have a quadriceps dominant muscle activation pattern as compared to males (Hewett, Zazulak, Myer & Ford, 2005; Malinzak et al., 2001; Myer, Ford & Hewett, 2005) during physical activity. The studies used electromyographical data to track the activity of the quadriceps and the hamstrings during various tasks such as a plant and side-cut maneuver. They all found that in females, the quadriceps activity far exceeded the activity in the hamstrings. The decreased hamstring recruitment is detrimental in two ways. First, it decreases the level of muscular co-contraction occurring about the knee during movement. As discussed above, this decreases the stiffness and stability of the knee joint, making it more susceptible to anterior shear forces (Huston, 2007).

Secondly, it decreases the counterforce that the hamstrings can apply to the knee joint to prevent the quadriceps from exerting an anterior shear force on the tibia. Because of the attachment of the patellar tendon onto the tibial tuberosity, when the quadriceps contract, part of the force created causes an anterior shear of the tibia on the femur (Figure 2.4).

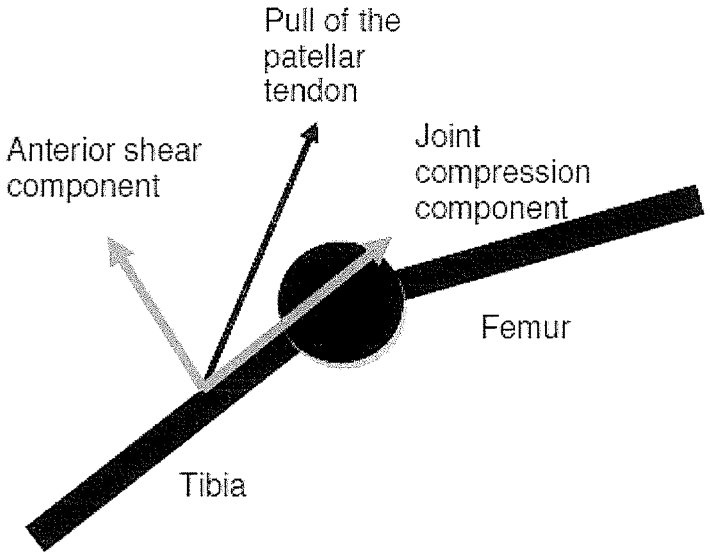


Figure 2.4: Lateral view of the knee joint, showing the component vectors of the line of pull of the patellar tendon.

The ACL is one of the main structures that prevents excessive anterior shear in the absence of hamstring muscle contraction (Moore et al., 2010). If the shear caused by the quadriceps exceeds the load capacity of the ACL, it will be injured. However, if the hamstring muscles contract simultaneously with the quadriceps, they can counteract some of the shear force, taking the load off the ACL (Huston, 2007). The hamstrings are capable of this because of their insertion on the posteromedial tibia (Figure 2.5).

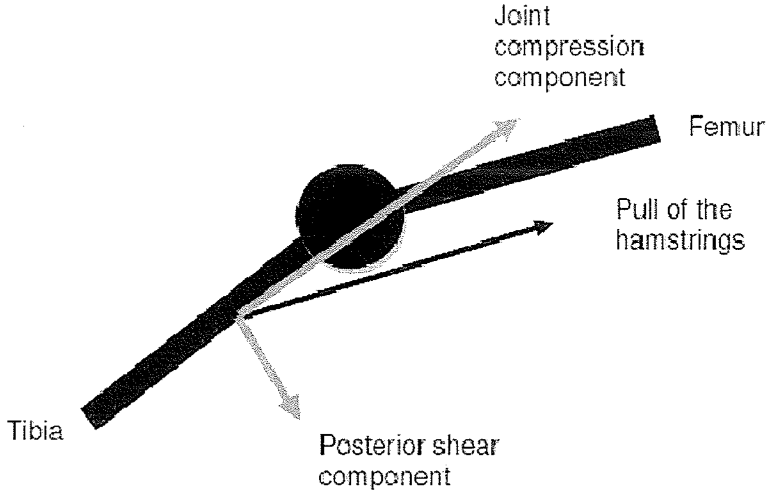


Figure 2.5: Lateral view of the knee joint, showing the component vectors of the line of pull of the hamstring muscle group.

Muscle length

As previously discussed, the hamstring muscle group can play a large role in preventing ACL injury. However, in order for the hamstrings to make a contribution, they must be able to produce sufficient force. Regular strength training can increase the capabilities of the muscle group by increasing muscle mass (Ripptoe & Kilgore, 2005). However, unless the muscle group is at an optimum length, it will not be able to use its entire force producing capacity.

Muscles generate optimum muscle contractions at slightly above the resting length of the muscle (Hall, 2007). If it is shortened or lengthened significantly beyond the resting length, the muscle is not able to produce as much force because of a lack of actin/myosin crossbridging within the sarcomeres of the muscle. When landing from a jump, the hamstring muscles change in length. They are biarticular muscles, meaning they cross both the hip and the knee joints. Movement at either joint causes a change in the length of the hamstring muscles. Knee flexion and hip extension shorten the hamstrings, while knee extension and hip flexion lengthen that muscle group. If both knee flexion and hip flexion occur at the same time, the hamstrings tend to stay at the same length, and therefore contract isometrically (Milne, n.d.). However, if the hips flex more than the knees, the hamstrings lengthen and therefore contract eccentrically (Withrow, Huston, Wojtys, & Ashton-Miller, 2006). A muscle is able to produce more force during an eccentric contraction than during a concentric or isometric contraction (Hall, 2007).

A study on the kinematics of the hamstrings during running found that the muscle group had maximal length when the hip was flexed 55-65 degrees and the knee was flexed 30-45 degrees (Thelen et al., 2005). The muscles were stretched 7-9% on average beyond resting length. However this study only looked at hamstring length in sprinters and the maximal hamstring length actually occurred during the swing phase. The relationship to a jump landing task may be limited, but it does illustrate the fact that a moderate amount of hip and knee flexion could help create the optimum conditions for the hamstrings to produce maximal force. The more force they can produce, the better chance they have of preventing ACL injury.

A recent study (Withrow et al., 2006) suggests that this strategy could be used by athletes when landing from a jump in order to decrease ACL injury risk. This study looked at the effect of different types of hamstring contractions on the strain rate in the ACL. Using 10 cadaver models, the knee was axially loaded, similar to when landing from a jump. During different trials, ACL strain rate was recorded with the hamstrings contracted concentrically, eccentrically or isometrically. The ACL showed significantly less strain when the hamstrings contracted eccentrically as compared to the concentric or isometric conditions. The authors suggested that landing with more hip flexion than knee flexion would put the hamstrings in a lengthened state, thereby decreasing the strain on the ACL.

Measurement of movement patterns in exploratory studies

A common method of kinematic measurement in a laboratory setting is via the use of multi-camera, computer generated 3-D motion analysis software such as Vicon motion measurement systems (http://www.vicon.com). This type of instrumentation is extremely expensive and not conducive to use outside a laboratory setting. All studies found in the course of this literature review used these complex motion analysis systems in a laboratory setting to examine the biomechanics of the jump landing. Measurement of joint angles is done automatically from the videotape by the software system.

Dartfish computer software (http://www.dartfish.com) is a 2-D motion analysis system designed for use in the field in practical situations. As such, it is not often used in research studies. Since the purpose of the current study was to examine a practical situation, Dartfish software was a realistic alternative to the complex 3-D methods. Rather than using joint markers that are automatically converted into angular quantities in the 3-D software, angular variables in the extremities in the present study were measured using relative angles. This entails measuring the angle between the long axis of one body segment and the long axis of the adjacent body segment at the joint of interest. The trunk angle was measured as an absolute angle, between the long axis of the trunk and the vertical axis. Both measurements were taken using the 180 degrees scale. In anatomical position, according to the 180 degree system, all joints are in a position of zero degrees. Any deviation from anatomical position is measured and designated the joint angle (Hall, 2007). Dartfish has a built in angle measurement tool and a vertical line tool to aid in the calculation of each angular variable.

The measurement of knee valgus using Dartfish was undertaken by Glass, Priest and Hayward (n.d). They measured knee valgus in terms of the angle between a vertical line passing through the ankle joint and a line through the long axis of the lower leg in the frontal plane. Using this method, they were able to distinguish between trials of subjects using good squat biomechanics and those that demonstrated knee valgus mechanics. However, this method was used in a laboratory setting where athlete movement could be highly controlled. As a result, it is not a method that is conducive to use in a real life sport situation if valid knee valgus measurement is desired.

“The accuracy and reliability of Dartfish is highly dependent upon camera positioning, camera resolution, the distances of the objects from the cameras, the angles of objects and movements with respect to the cameras, and the precision with which the operator can visually identify and mark the positions” of the joints in question (Abercromby, Thaxton, Onady & Rajulu, 2006). Therefore, data was collected by the principal investigator only, in order to be as consistent as possible with camera settings and placement.

Dartfish software has been used successfully in the Biomechanics Laboratory at The University of Manitoba by previous investigators. Taylor (2007) and Shackel (2008) both found Dartfish to be a reliable method of measuring joint angles and distances when analyzing athletic skills.

Gender differences in movement patterns contributing to ACL injury

Knee flexion and knee valgus

Females have different movement patterns than males when participating in sports and activities (Decker et al., 2003). During maneuvers that put the ACL at risk, such as pivoting, cutting and landing from a jump, females exhibited eight degrees less knee flexion and eleven degrees greater knee valgus than males (Malinzak, Kirkendall & Yu, 2001). In a small study of active adults landing from a 60 cm height, Decker and colleagues (2003) found that females had seven degrees less knee flexion at initial impact than males. The females landed with 22.8 degrees of knee flexion, compared with 30 degrees in the male subjects. Decreased knee flexion and increased knee valgus during physical activity have both been suggested as factors that are related to an increased risk of ACL injury for female athletes.

Firstly, landing with decreased knee flexion increases the load across the knee and increases the anterior shear force of the tibia on the femur, thus stressing the ACL (Silvers & Mandelbaum, 2007). This is directly related to the angle of pull of the patellar tendon on the tibia. As the quadriceps muscle contracts, the force is transferred through the quadriceps tendon, over the patella, and into the patellar tendon. As seen in Figure 2.6(A), when the knee is flexed between 60 and 75 degrees, the line of pull of the patellar tendon is perpendicular to the tibial plateau, and therefore there is no shear force present. There is only a stabilizing force (blue arrow) occurring. However, when knee flexion angle drops below 60 degrees, the vector representing the pull of the patellar tendon now has both a stabilizing component (blue arrow) and an anterior shear (red arrow) component (Figure 2.6, B). Conversely, when the knee is flexed in excess of 75 degrees, the pull of the patellar tendon causes a posterior shear component (red arrow) along with a stabilizing (blue arrow) component (Figure 2.6, C). Therefore, landing from a jump with less than 60 degrees of knee flexion will increase the strain on the ACL because of the presence of an anterior shear force.

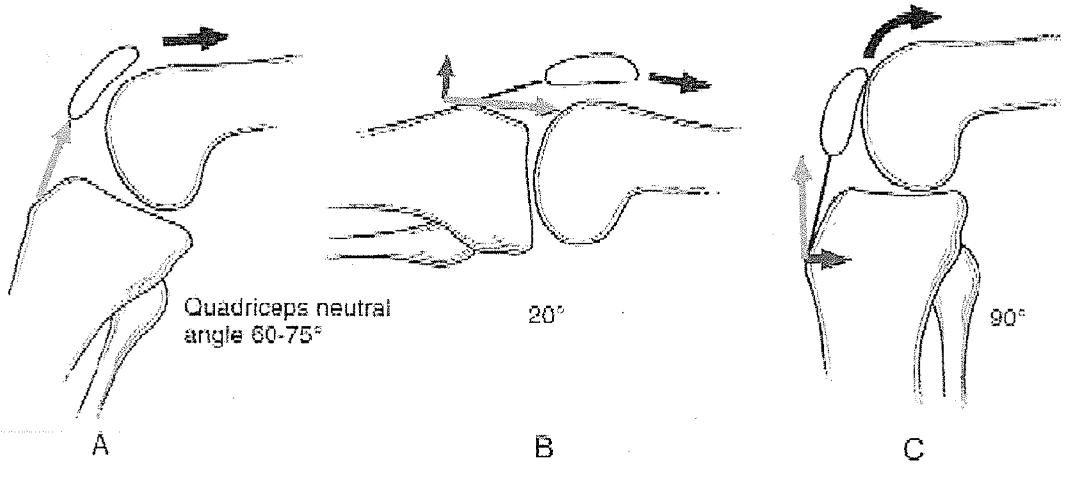


Figure 2.6: The effect of knee flexion angle on the presence of shear forces between the tibia and femur (Reproduced with permission from Daniel, D.M., Stone, M.L., Barnett ,P., Sachs, R. (1988). Use of the quadriceps active test to diagnose posterior cruciate ligament disruption and measure posterior laxity of the knee. *Journal of Bone and Joint Surgery (Am), 70(3),*386-391.) (Copyright owned by The Journal of Bone and Joint Surgery, Inc.)

Huston et al., (2001) also found decreased knee flexion angles when testing a small sample of adults during a drop from a platform. Females landed with significantly less knee flexion at initial impact than the male participants. A force platform was used during this study to capture the magnitude of the ground reaction forces upon landing. The authors found that vertical ground reaction forces increased by about one percent for every degree of difference in knee extension when landing between females and males. The role of ground reaction forces in ACL injury is discussed in detail on page 57. In general, landing with less knee flexion is detrimental to athletes because it increases the stress on the ACL, as well as the landing forces that must be dissipated up through the body.

In a recent study (Hewett et al., 2005), the knee kinematics of over 200 adolescent female athletes were tested using a drop jump before their competitive season began. A valgus knee position was found in nine athletes who subsequently suffered an ACL injury during their competitive season. The knee kinematics of the nine athletes who were injured were compared to those of the 196 subjects that did not sustain an ACL injury. The authors found that the group who did sustain an injury had an average of eight degrees more knee valgus than the non-injured group. They suggest that knee motion in the frontal plane can be predictive of ACL injury.

Another group of researchers (Withrow et al., 2006) found that knee valgus can contribute to ACL injury. In a laboratory setting, they loaded 10 cadaveric knees to simulate landing from a jump. When the knees were loaded with a valgus force, the strain in the ACL increased by 15% compared to when the knees were loaded in a neutral frontal plane position. These findings help to explain the previous findings of Hewett and colleagues regarding why a valgus knee position can lead to ACL injury.

Silvers, Giza and Mandelbaum (2005) described a "pathokinetic chain" that leads to a valgus knee. The sequence of events included an increased hip adduction moment and a decrease in hip abduction control causing an increase in hip adduction angles. This contributed to the knee assuming a valgus position. Ireland (1999) has also reported extensively on the tendency of the female athlete to demonstrate poor lower extremity biomechanics. She identified the "position of no return", similar to the pathokinetic chain discussed by Silvers et al., by viewing numerous videotapes showing actual ACL injuries occurring.

Kernozek et al. (2005) conducted a study using 30 university aged recreational athletes. The authors found that at the instant of peak knee valgus during a drop landing, the female athletes had a lower varus moment than the male athletes. A varus moment is a torque that produces movement in the varus direction. A varus moment is considered a protective mechanism that prevents the leg from collapsing into a dangerous valgus position. The result of this study underscores the importance of maintaining good alignment during landing. The fact that the female knee is already in an increased valgus position upon landing (Hewett et al., 2005; Malinzak et al., 2001), coupled with a low varus moment (Kernozek et al., 2005), means that the athlete is unable to produce the torque required to remove her from that potentially dangerous position.

Athletes who exhibit excessive valgus at the knee during landing have been described as ligament dominant as opposed to muscle dominant (Andrews & Axe, 1985). Contraction of the gluteus medius, gluteus minimus and tensor fascia latae muscles can prevent the thigh from adducting and the knee from collapsing into a valgus position. In a ligament dominant athlete, these leg muscles are unable to control the excessive valgus occurring, and therefore the ligaments and specifically the ACL must take on that task if injury is to be avoided.

Many reasons for the disparity between male and female athletes in terms of knee valgus have been postulated. It has been suggested by previous studies (Hewett et al., 2004; Markolf et al., 1978) that males demonstrate an increase in muscular power, strength and coordination during puberty, whereas females do not demonstrate the same increases. A large study was conducted by Hewett and colleagues (2004) to investigate the effects of maturation level on knee kinematics and muscular strength. They had 181 subjects between the ages of 11 and 15 undergo testing, which included a drop jump and isokinetic dynamometer strength testing. One significant outcome from the study was that females had significantly decreased hamstring and quadriceps peak torques compared to males with increasing maturation. As they grew, the males demonstrated a relative increase in strength, whereas the females did not show that same improvement. In an older study, Markolf and colleagues (1978) found that contraction of the muscles surrounding the knee joint can decrease the frontal plane laxity of the knee threefold. Decreasing the laxity of a joint increases its stability, preventing unwanted movement from occurring. This disparity in muscle strength may explain why males demonstrate less valgus angulation of the knee upon landing from a jump as compared to females. Because of their increased strength, they are able to increase the stability of the knee and prevent the knee from moving into the unwanted valgus position. It also helps to clarify the reason why the disparity in ACL injury rates begins to appear around the age of puberty. As females mature, they do not benefit from a concomitant increase in muscle strength and power as males do, setting them up for increased chance of ACL injury.

Tibial rotation

It is apparent that a complex, interrelated sequence of movements and positions occurs prior to ACL injury, rather than just one discrete action in one specific plane of movement. Adding a rotation moment to a slightly flexed, valgus knee, such as during an attempted change of direction, increases the tension on the ACL and can lead to injury (Silvers et al., 2005). However, some authors (Boden, Dean & Feagin, 2000; Olsen, Myklebust & Engebretsen, 2004) have found minimal tibial rotation at the time of ACL injury. Olsen and colleagues (2004) found 10 degrees or less of tibial rotation in 90% of cases. This is well within the normal limits of 30 degrees medial rotation and 40 degrees lateral rotation for tibial range of motion (Magee, 1997). Therefore, tibial rotation is not likely to be the only contributor to ACL injury. Other factors must be involved to bring the ligament to its breaking point.

Trunk flexion and pelvic rotation

Ireland (2002) described the knee as being a "victim" to the movements and forces occurring more proximally in the hip, pelvis and trunk. She claimed that females assume a position of increased anterior pelvic rotation and lumbar lordosis that contributes to the pathokinetic chain described by Silvers and colleagues (2005).

Two studies (Dugan, 2005; Myer, Chu, Brent & Hewett, 2008) agreed that the knee is dependent upon proximal positioning, stating that the inability of females to have proper and sufficient neuromuscular control in the core abdominal and large hip muscles dictates the position and stresses on the distal leg structures, most notably the knee joint and ACL. The loss of neuromuscular control occurs during puberty, when the tibia and femur grow at relatively rapid rates. This increases the height of the centre of mass which makes it more difficult to control the trunk (Myer et al. 2008). The increase in the length of the legs also makes it more difficult for the athlete to control lower extremity positioning. Because females do not show a concomitant increase in muscular strength and power with maturity as males do (Hewett, Myer & Ford, 2008), they have a higher risk of injury to the ACL.

Even though females lack the trunk muscle strength of males during and after puberty, they have the ability to compensate in other ways. A recent study reported that female athletes were able to positively change their jump landing biomechanics after receiving instruction, regardless of their existing trunk strength (Mizner et al., 2008). This suggests that there is still benefit to be had from jump landing training even if muscle strength is lacking.

Renstrom and colleagues (2008) stated that increased trunk motion during landing can put an athlete at risk for ACL injury, but they do not discuss the data to substantiate that claim. Ireland (2002) believed that an anterior rotation of the pelvis leads to femoral internal rotation and a valgus knee, putting the female athlete at increased risk of ACL injury. However, she came to this conclusion after observing male and female athletes performing a minisquat off a low stool (See Figure 2.7).

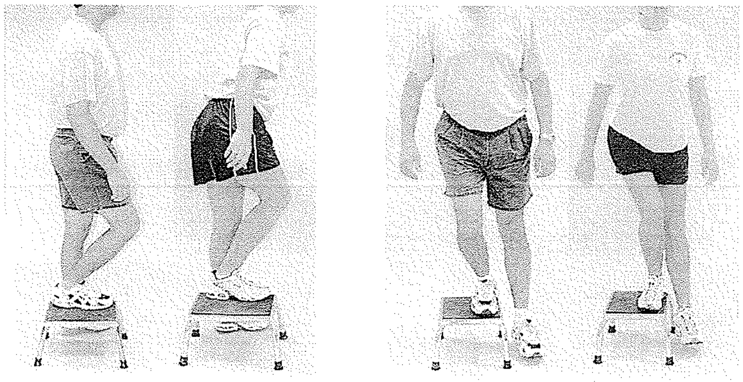


Figure 2.7: Minisquat performed by a male (on the left in each picture) and a female (on the right in each picture). Note the different movement patterns of the trunk, pelvis and lower extremity between genders (Reprinted with permission from Ireland, 2002).

The athletes showed different movement patterns, but to recommend that athletes should use a normal lumbar lordosis during sport skills such as landing from a jump is a misrepresentation of the findings. By decreasing lumbar lordosis and increasing trunk flexion during a jump landing, the athlete is in a position to decrease vertical ground reaction forces.

Flexing the trunk causes the centre of mass of the entire body to move in a downwards direction during the landing. The athlete who flexes her trunk more will displace her centre of mass a larger distance downwards. This will have a direct impact on the velocity and therefore the acceleration of the body's centre of mass as it comes to a stop. Linear downward acceleration is important in this situation because of the relationship of acceleration to force, as stated by Newton's First Law (Force = Mass x Acceleration). The vertical ground reaction force acting on the athlete landing from a jump is proportional to the mass and the acceleration of the athlete. It can be calculated by determining the total magnitude of the forces present in the vertical (y) direction, and then subtracting the weight of the athlete. Because there are only two vertical forces acting on the system (body weight and vertical ground reaction force), this will result in the determination of the ground reaction force.

A sample calculation taken from data within the current study is included in Figure 2.8 to illustrate the differences between an athlete who uses trunk flexion during landing and one who does not.

Minimal trunk flexion on landing	Increased trunk flexion on landing
$\Sigma F_y = m \times a_y$	$\Sigma F_y = m \times a_y$
$\Sigma F_y = m \times \frac{v_f - v_i}{\text{time}}$	$\Sigma F_y = m \times \frac{v_f - v_i}{\text{time}}$
$\Sigma F_y = 52\text{ kg} \times \frac{(-0.2\text{ m/s} - (-2.6\text{ m/s}))}{0.15\text{ s}}$	$\Sigma F_y = 52\text{ kg} \times \frac{(-0.6\text{ m/s} - (-2.2\text{ m/s}))}{0.15\text{ s}}$
$\Sigma F_y = 832\text{ N}$	$\Sigma F_y = 554\text{ N}$
$\Sigma F_y = R_y - W$	$\Sigma F_y = R_y - W$
$832\text{ N} = R_y - (52 \times 9.81\text{ m/s}^2)$	$554\text{ N} = R_y - (52 \times 9.81\text{ m/s}^2)$
$R_y = 1342\text{ N}$	$R_y = 1064\text{ N}$

Figure 2.8: Sample calculation of ground reaction forces (ΣF_y = sum of the forces in the vertical (y) direction; v_f = final velocity; v_i = initial velocity; R_y = vertical ground reaction forces; W = bodyweight).

The centre of gravity (CG) of the two athletes in the example moved through approximately the same displacement during the first 0.15 seconds of the jump landing. However, the athlete in the example on the left landed with a “stiffer” landing, with the downward movement arrested quickly during the first half of the 0.15 seconds. Her CG initially moved through its displacement rapidly, resulting in a larger initial velocity compared to the other athlete. The CG of the athlete who used more trunk flexion continued to move through its displacement at a fairly uniform pace, resulting in a larger final velocity as compared to the other athlete. The athlete who used more trunk flexion continued to lower her CG even after the 0.15 second time frame was up, whereas the CG of the other athlete had already reached its lowest point.

The result of these differences is that the athlete who used more trunk flexion experienced less vertical ground reaction force than the athlete who landed with a stiffer landing. The vertical ground reaction force experienced by the athlete who completed the stiff landing was 2.6 times bodyweight, whereas the force experienced by the other athlete was 2.1 times bodyweight.

Blackburn and Padua (2007) suggested an additional benefit to increasing trunk movement during jump landings. After studying 40 recreational adult athletes during a drop jump, it was determined that having the participants actively flex their trunk during landing resulted in an increase in hip flexion of six degrees at initial ground contact as well as an increase of 31 degrees at peak hip flexion and 22 degrees at peak knee flexion. Since increased hip and knee flexion upon landing have been found to decrease ACL injury risk (Hewett et al., 2005; Silvers et al., 2007), these authors suggested that encouraging athletes to adopt a more trunk flexed position during landing should be incorporated into ACL prevention programs. They also found that trunk flexion when landing had no deleterious effect on hip internal rotation or knee valgus, two additional movements that have been found to be associated with ACL injury (Delfico & Garrett, 1998; Kirkendall & Garrett, 2000).

More support for trunk flexion during jump landing exists. When landing from a jump, there is a flexor moment created at the knee joint. In response, the quadriceps contract strongly to produce an extensor moment in order to prevent the athlete from falling. A recent study (Shimokochi et al., 2009) found that by moving the centre of gravity of the body anteriorly, as would occur during trunk flexion, knee extensor torque was decreased. This is because torque is equal to force x moment arm. A flexed forward trunk position decreases the moment arm for the body weight (Figure 2.9), which decreases the flexor torque. In turn, the magnitude of the necessary extensor torque to prevent falling decreases. A decrease in the contraction of the quadriceps would decrease the anterior shear force acting on the ACL and potentially decrease the risk of ACL injury.

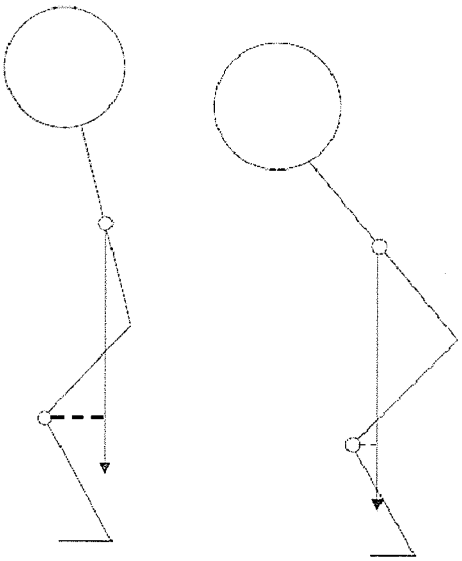


Figure 2.9: The effect of trunk position on the moment arm (dotted line) for the weight of the upper body (arrow). Erect landing position on the left, flexed landing position on the right.

Salci et al., (2004) suggested that trunk flexion tends not to be recommended as a strategy to prevent ACL injury because an excessive amount of trunk flexion may hinder performance. However, this has not been studied to date.

Maximum flexion angles, landing phase times and angular velocities

A recent study examining landing biomechanics from volleyball spike and block jumps found that female university players demonstrated 20 degrees less peak knee flexion and 15 degrees less peak hip flexion upon landing compared to the male athletes in the study (Salci et al., 2004). This study simulated landing from a spike and block by stepping off a platform, so no actual volleyball skill was required, calling into question the ability to generalize to an actual volleyball situation.

A significant difference existed in duration of stance phase between stiff and soft landings, according to Devita & Skelley (1991). In soft landings the time from initial contact until maximum knee flexion was 342 milliseconds, and during a stiff landing, that time decreased significantly to 152 milliseconds. The increased time to land in the soft landing affords the body more time over which to absorb the force and bring the body to a stop. Lower forces are required of the muscles because of the increased time frame, resulting in a decrease in injury risk. The impulse-momentum relationship explains this connection. It states that Force x Time (Impulse) = a change in momentum (the quantity of motion a body possesses). Momentum is calculated by subtracting the body's initial momentum from its final momentum. To balance this equation if time is increased, the force on the muscles must decrease.

For example:

With increased time

$$\text{Force} \times \text{Time} = (\text{mass}_2 \times \text{velocity}_2) - (\text{mass}_1 \times \text{velocity}_1)$$

$$\text{Force} = \frac{(\text{mass}_2 \times \text{velocity}_2) - (\text{mass}_1 \times \text{velocity}_1)}{\text{Time}}$$

$$\text{Force required by the muscles} = \frac{(65\text{ kg} \times 0\text{ metres/sec}) - (65\text{ kg} \times 5\text{ metres/sec})}{0.3\text{ seconds}}$$

Force required by the muscles to bring the body to a stop = **1083.3 Newtons**

With decreased time

$$\text{Force x Time} = (\text{mass}_2 \text{ x velocity}_2) - (\text{mass}_1 \text{ x velocity}_1)$$

$$\text{Force} = \frac{(\text{mass}_2 \text{ x velocity}_2) - (\text{mass}_1 \text{ x velocity}_1)}{\text{Time}}$$

$$\text{Force required by the muscles} = \frac{(65 \text{ kg x } 0 \text{ metres/sec}) - (65 \text{ kg x } 5 \text{ metres/sec})}{0.15 \text{ seconds}}$$

Force required by the muscles to bring the body to a stop = **2166.6 Newtons**

Clearly, an increase in time for the landing will decrease the amount of force required by the muscles of the body to bring the body to a stop.

Decker et al. (2003) found that females and males demonstrated similar landing phase times and maximum knee flexion angles during a drop jump. The female subjects had a larger overall range of motion by 12 degrees in the knee and 17 degrees in the ankle joints during the jump landing than the males, which resulted in the females having a greater peak angular velocity. The authors suggested the females may be attempting to disperse the landing forces over a larger range of motion, whereas the males were able to absorb the forces over a smaller range of motion with their greater muscle strength. This study contradicts the findings of other authors that females possess decreased knee flexion angles upon landing compared to males (Huston et al., 2001; Ireland, 2002; Malinzak et al., 2001; Salci et al., 2004). As well, Huston and colleagues (2001) found no difference in overall knee range of motion during the jump landing between genders, as Decker et al. (2003) found.

Kernozek and colleagues (2005) looked at university aged recreational athletes and compared males to females in terms of their biomechanics when dropped from a "hang bar". They found no difference between genders in landing phase times, which agreed with Decker et al. (2003). Females however demonstrated increased peak values and overall range of motion of ankle dorsiflexion, knee valgus and foot pronation angles.

Vertical ground reaction forces

Peak ground reaction forces increase significantly when landing via a stiff landing versus a soft landing (Devita & Skelley, 1991). These authors found that a stiff landing, with an average knee flexion angle upon landing of 77 degrees, resulted in a 23% increase in ground reaction forces compared to a soft landing with an average knee flexion angle of 117 degrees.

Kernozek and colleagues (2005) showed that females had higher vertical ground reaction forces than males when dropping from a "hang bar", showing their inability to absorb forces gradually with their landing technique. A study by Hewett and colleagues (2005) found that athletes who suffered an ACL tear had demonstrated vertical ground reaction forces 20% higher during testing of a drop landing task previous to sustaining the injury than those athletes who were injury free.

Another study, by Salci and colleagues (2004), also found higher vertical ground reaction forces in females as compared to males. The magnitude of the difference was approximately 0.6 times bodyweight. In a large study involving middle school and high school aged youth, Hewett et al. (2006) determined that males had a lower ratio of landing forces to take off forces in a jump landing task than did females as they matured. This indicated that males develop the ability to both increase their takeoff forces for increased jump height as well as dampen the forces of landing. Females do not develop these abilities to the same extent. This may partially explain females' increased risk of injury, including ACL injury.

Foot position

Renstrom et al. (2008) suggested an additional factor that would decrease the chance of ACL injury is foot placement on landing from a jump. Landing with most or all of the force on one leg, especially when the foot is positioned away from the body's center of mass, increases the stress on the knee and ACL. It is suggested that any athlete landing from a jump employ both feet equally to absorb the force of the landing. A previous study (Tillman, Hass, Brunt, & Bennett, 2004) found that 35% of elite female volleyball players landed on the left foot only after a spike. The authors suggested this reflected the fact that the majority of the population is right handed. When hitting the volleyball, the athlete side flexed towards the left in order to contact the ball at the highest possible point with the right hand. This side flexion raised the right side of the body and may have led to the athlete landing on the left foot only. Recognizing this unique situation with the volleyball spike is the first step to taking measures to prevent ACL injury.

Kovacs and colleagues (1999) suggested that the method an athlete uses to land from a jump may decrease the chance of ACL injury. They proposed that landing from a jump using a forefoot landing (Figure 2.10) encourages greater energy absorption in the muscles of the leg compared to a heel toe landing.

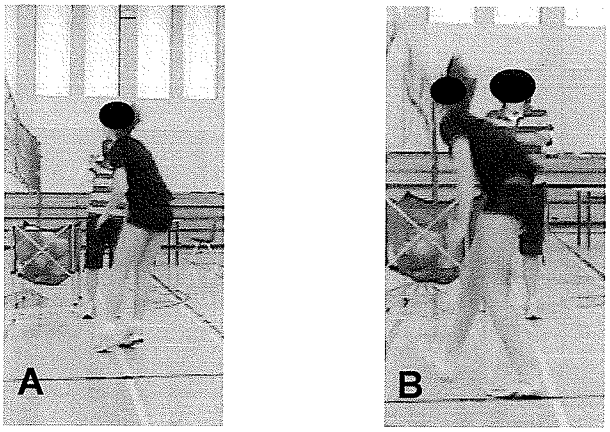


Figure 2.10: Forefoot landing on both feet (A); heel landing on the right foot after landing toe to heel on the left foot (B).

When landing on the toes, the gastrocnemius muscle of the calf is in a shortened position. As the athlete rolls to their heels, the calf muscles lengthen. This is an eccentric contraction. An eccentric muscle contraction is the strongest type of muscle contraction. This strong contraction by the calf muscles allows the athlete to slowly absorb the energy of the jump landing while the muscles are lengthening. Absorbing energy via the muscular system prevents the ligamentous structures of the lower extremity from having to bear the increased load, possibly sparing the athlete from ACL tears, among other injuries.

Gender differences during one foot jump landings

Coronal plane differences

Often in landing from a volleyball spike, the athlete is required to land on one foot because of positioning close to the net, or an awkwardly set ball. Ford and colleagues (2006) found gender differences in the coronal plane in athletes landing on one leg from a drop jump. All kinematic variables in that study were measured with the use of a three dimensional motion analysis system. Females demonstrated increased knee valgus at both initial touchdown and at maximum valgus compared to males. At initial touchdown, females possessed 2.4 degrees of valgus, whereas males demonstrated 1.7 degrees of varus. At maximum valgus, females had 4.9 degrees of valgus compared to the males' 0.1 degrees of varus. Females also showed a larger overall hip abduction/adduction excursion, at 17 degrees versus 13 degrees for the males during the landing maneuver. The authors found a correlation between the degree of hip adduction and knee valgus at initial contact. This points to control of the proximal segments as being of utmost importance in preventing valgus strain on the knee and the potential for ACL injury, as suggested by Dugan (2005) and Ireland (1999).

Sagittal plane differences

Schmitz et al. (2007) found sagittal plane differences in single leg landings between genders. Females exhibited significantly less hip and knee flexion range of motion during the landing task. Females also took approximately half as much time to reach peak hip and knee flexion angles and demonstrated a nine percent increase in peak ground reaction forces compared to males. Hewett et al. (2005) showed that increased ground reaction forces increased the chance of ACL injury. The female athletes in Schmitz's study exhibited an ankle dominant landing pattern, with limited energy absorption contributed by the muscles surrounding the knees or hips. The more upright landing position of the females precluded use of these larger muscle groups to attenuate some of the forces involved in landing, leading to increased ground reaction forces.

Linking ACL injury with specific landing biomechanics

In a landmark study, Hewett et al., (2005) followed 205 female adolescent athletes prospectively after analyzing their biomechanics during a drop jump task. A number of kinematic variables were initially measured with the use of 3-dimensional motion analysis software. Segment motion was tracked with the placement of reflective markers on each of the subjects. Subsequently, nine of the athletes suffered a non-contact ACL rupture during their competitive sport season. The authors were then able to return to their data and identify key biomechanical characteristics that may have put these athletes at risk. Knee valgus angles at initial contact of the jump landing as well as maximum attained knee valgus angles were significantly greater in ACL injured athletes than in the non-injured group.

The maximum knee flexion angle achieved during the landing was decreased in the injured group, but not the knee flexion angle at initial contact. Vertical ground reaction forces were 20% higher in the ACL injured group than in the non-injured group. Another significant finding was that injured females had a 16% shorter stance time than did the control group. The ACL injured group was also found to have a significant difference in loading between legs, whereas the non-injured group shared the landing load equally on right and left legs. With this knowledge of the key biomechanical features that differentiate athletes at risk for ACL injury, prevention programs can be developed and put into place.

Additional movement patterns that could affect ACL injury risk

As stated in the introduction, the role of the arms in jump landing has not been investigated in the ACL injury literature. In fact, in many studies that employ the drop jump testing technique, the arms are purposely excluded by having the subject cross them over their chest (Figure 2.11) (Huston et al., 2001), putting their hands on their hips (Schmitz et al., 2007) or by positioning them over the head (Renstrom et al., 2008). Many studies do not mention the position of the arms in their protocols.

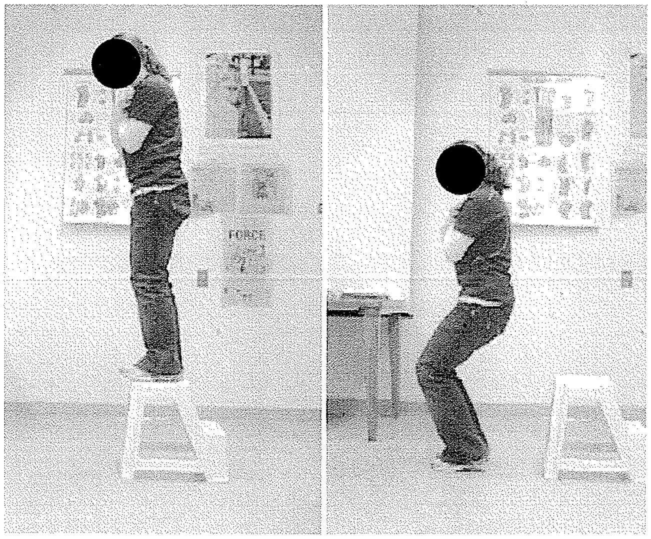


Figure 2.11: A typical position for the arms during jump landing testing.

One study (Chaudhari et al., 2005) investigated whether arm position changed the knee valgus moment in athletes completing a 90 degree cutting maneuver. The authors indeed found that holding the arms in front of the body during the cut and tucking the plant side arm (as when holding a football) significantly increased the valgus torque on the knee joint. A 90 degree cutting maneuver has been identified as a high risk motion for female athletes in terms of ACL injury. However, the effect of the arms cannot be extrapolated to jump landing, as they are two distinctly different skills.

Theoretically, swinging the arms inferiorly while landing from a jump would decrease ground reaction forces. This would function in a similar manner to accelerating the trunk in a downwards direction, as discussed on page 51-52. By accelerating the arms in a downwards direction upon landing, the ground reaction forces pushing back on the athlete are decreased compared to an athlete who does not use their arms. However, in a real life volleyball spike scenario it would be difficult to use the arms to their maximum potential because of the nature of the spike motion with the upper body, when one arm is extended and adducted into the trunk at ball contact. The athlete is more focused on using the arms to execute a skillful hit rather than using them to dissipate landing forces. In a game situation, the player also would not have time to complete the full downward arm-swing before moving on to the next play. The downward arm-swing when landing from a jump holds potential for assisting in knee injury prevention and warrants future investigation.

MODELS OF MOTOR LEARNING

The act of landing from a volleyball spike jump is a motor skill. It is classified as a skill because there is a definite goal associated with the task, i.e. landing successfully from the jump. A motor skill denotes a "skill that requires voluntary body and/or limb movement to achieve its goal" (Magill, 2001). Furthermore, the volleyball spike jump landing can be considered an open motor skill, because the environment is unstable and ever-changing. The athlete is in motion throughout the skill, as is the volleyball. The behavior of the athlete must adapt to the changing parameters surrounding her as she executes the skill. The landing may be altered because of a less than perfect set by the team setter, or the presence of an opponent's foot under the net. The presence of one of the athlete's own team members close by may even affect how and where she can land from the spike jump.

In order to change the methods the athlete uses to land and potentially protect her from ACL injury, motor learning has to occur. There are two models of learning that are traditionally referred to in the motor learning literature; the Fitts and Posner Three-Stage Model and Gentile's Two-Stage Model.

Fitts and Posner Three-Stage Model (1967)

In the first stage of Fitts and Posner's model, the cognitive stage, the athlete focuses on practical questions and problems. She has to consciously think about what position her leg is in at a certain point in the skill, or where her arms should be in relation to her trunk. As the athlete receives instruction and coaching, she must undertake cognitive processes to translate the directions into actions. Performance of the skill at this point shows large variability and inconsistencies from one trial to the next, and there are many gross errors in execution. In the second stage of learning, the associative stage, the athlete's variability between trials decreases as she learns to relate her movements to environmental cues. She is also able to detect her own errors in performance.

The final stage of Fitts and Posner's model is the autonomous stage. It takes many years and much repetitive practice to reach this stage and not all people may attain this level of proficiency (Magill, 2001). At this point in the process, the motor skill has become second nature to the athlete, and the task can be completed without conscious thought and sometimes concomitant with another task. Variability is very low between task trials and the athlete can not only detect when she makes an error, but also take steps to erase the error.

Gentile's Two-Stage Model

Gentile's model for motor learning takes its basis from the desired goal of the skill. The first stage involves "getting the idea of the movement" (Magill, 2001). The athlete is determining which movement patterns are appropriate to reach the end goal of landing successfully from a jump, such as the amount of knee flexion required, or the position of the feet at initial impact. In addition, the athlete begins to understand and delineate between factors that exist in the environment that will and will not have an effect on the outcome of the skill. For instance, she is learning that the amount of light in the gymnasium will not affect her landing pattern, but the distance she lands from the net may very well determine her landing pattern. This first stage is characterized by many repetitions of the skill, on a trial and error basis, to determine what is successful and what is not.

The second stage of Gentile's model for an open motor skill is known as "diversification". During this stage, the athlete must learn to adapt her motor pattern in order to respond to an endless array of environmental situations. She must also become consistent in the execution of the skill, and complete it with as little effort as possible (Magill, 2001).

Motor learning in jump landing training

A characteristic common to both approaches of viewing motor learning is that the athlete moves through the stages gradually. There is no abrupt shift from one stage to another; there is only a gradual development of the skill. In attempting to change landing biomechanics in adolescent female volleyball players, it was the first stage in both Fitts and Posner's and Gentile's models of motor learning at which the athletes began their learning process. None of the athletes had previous jump landing training, and so the mechanics had to be cognitively processed at first as they performed their practice trials.

PREVENTION PROGRAMS

There have been many studies completed looking at the effect of specific exercise and training programs on landing biomechanics and ACL injury rates. These programs typically are implemented for at least one month, and often for a full competitive sports season, so the mechanism of improvement would involve strength, coordination and proprioception gains by the athlete.

Programs causing a positive change in landing biomechanics

Jump landing training combined with neuromuscular training exercises

Chappell and Limpisvasti (2008) found that after a six week neuromuscular training program including jump training focusing on improving technique, female university aged athletes demonstrated five degrees more knee flexion at initial impact of a drop jump test, as well as an increase of six degrees during maximum knee flexion.

A study by Pollard et al., (2006) demonstrated that an injury prevention program undertaken by adolescent female soccer players over an entire season had the effect of decreasing hip internal rotation and adduction when performing a drop jump landing. It had no effect, however, on knee valgus or flexion, as hypothesized. The intervention consisted of replacing the team's regular warm-up with one that included jump landing instructions emphasizing soft landings and the importance of hip and knee flexion when landing.

Both of these studies resulted in positive adaptations on the part of the athlete. As suggested by Ireland (1999), a safer landing technique involves decreased hip adduction and internal rotation. She stated that hip adduction and internal rotation contributes to knee valgus, which has been linked with a higher risk of ACL injury (Hewett et al., 2005).

Myer et al., (2005) instituted a neuromuscular retraining program with high school aged female athletes. A soft landing, using increased knee flexion and knees centered over toes was encouraged throughout the tasks. The program was offered three times per week for six weeks, with each training session lasting about one and a half hours. Landing biomechanics post-intervention showed the females landed with significantly increased overall knee flexion range of motion, increasing from 72 to 77 degrees. The athletes also demonstrated drastically decreased valgus and varus torques about the knee after the training program. As an added benefit, the athletes were found to improve their physical fitness in terms of vertical jump and horizontal hop distance and strength during squat and bench press tests.

Active jump training

Hewett, Stroupe, Nance, and Noyes (1996), in a small cohort of female volleyball players, found that an intensive program of jump training three days a week for two hours over a six week time frame was successful in decreasing peak ground reaction forces by 22% when landing from a jump. Valgus and varus knee moments were significantly decreased by 50% as a result of the program. In contrast to other authors (Chappel & Limpisvasti, 2008; Lephart, Abt, Ferris, Sell, Nagai, Myers et al. 2005; Mizner et al., 2008; Myer et al., 2005), this study failed to find a difference in peak and overall knee and hip flexion angles upon landing. However, this may have been a result of the small study size of eleven athletes. Peak vertical jump heights increased by one and a half inches over the six week training period, demonstrating that training programs can have both an injury preventative effect and a performance enhancement effect.

Plyometrics

Another group of researchers implemented a nine week plyometric program with female university aged athletes which included instruction on jump landing technique (Irmischer, Harris, Pfeiffer, Debeliso, Adams, & Shea, 2004). The workout lasted for approximately twenty minutes, twice a week. Following the intervention, significantly decreased ground reaction forces were recorded during a jump task for the workout group compared to the control group. The rate of force production was also decreased by over 20%, indicating that the trained individuals learned how to dissipate forces over a longer period of time. Both of these factors have been found to decrease the chance of ACL injury (McNair & Marshall, 1994).

Strength training versus plyometrics

Lephart and colleagues (2005) also found an improvement in jump landing technique after an eight week intervention program in high school female athletes. These researchers compared a plyometric exercise group with a strength training group. They found that both groups significantly increased their hip flexion angle at initial contact, peak hip and knee flexion angles and time to peak knee flexion, but neither group was superior to the other. There was no difference found pre and post intervention on vertical ground reaction forces as some authors have found after intervention (Cronin et al., 2008; McNair et al., 2000; Onate et al., 2001; Prapavessis & McNair, 1999). This study failed to describe whether specific instructions on landing technique were given to the subjects, or whether they were just instructed to complete the designated exercises.

Programs causing a decrease in the incidence of ACL injury

Jump landing training combined with neuromuscular training exercises

In a recent study, the PEP (Prevent Injury and Enhance Performance) program was introduced to 52 female adolescent soccer teams and included written and video instruction on proper landing technique as well as plyometric and strength exercises (Mandelbaum et al., 2005). The investigators emphasized a soft landing, with deep hip and knee flexion and landing on the balls of the feet. With participation in this program, ACL ruptures decreased by 88% compared to the control group in the first year of competition and by 74% in the second year.

Conversely, Petersen et al. (2005) were unable to demonstrate a significant decrease in ACL injuries after the institution of their plyometric and jump landing training program. The athletes in this study were encouraged to land with more knee flexion and to keep the “knee over the toe”. Although a significant difference was not found between control and intervention groups, the trend seemed to point to a positive effect of the program. There were five ACL ruptures in the control group, all non-contact in nature. There was only one ACL rupture in the intervention group, which was caused by direct contact. The results suggest that more study of this program is needed, perhaps with a larger cohort or more direct supervision for increased compliance with the program.

Heidt, Sweeterman, Carlonas, Traub, and Tekulve (2000) also failed to find a decreased incidence of ACL injury after participation in a neuromuscular retraining program in female adolescent soccer players. There was a trend towards the intervention group having fewer ACL injuries, but the result was not significant. Overall injury rates were significantly decreased in the trained group compared to the control group. The authors cite the lack of significance concerning ACL injury prevention as related to the small sample size of 42. Proper landing technique by keeping knees in line with the toes was emphasized during this protocol.

A Norwegian study (Myklebust et al., 2003) also found a trend toward a decrease in ACL injuries after implementing a plyometric and jump landing training program, but it had limited significance. A significant decrease in ACL injuries was only found in the most elite European team handball players compared to the lower divisions. They did however find a significant reduction in the number of non-contact ACL injuries in the intervention group as compared to contact ACL injuries. The emphasis of their exercises was similar to Petersen et al. (2005), including increased knee flexion with landing from a jump and keeping the knees over the toes.

Another large Norwegian study (Olsen et al., 2005) involving male and female adolescent team handball players found that incorporating a neuromuscular retraining program decreased the overall rate of injury by nine percent, the rate of injury to the lower extremity by six percent, and the rate of knee ligament ruptures by 80% compared to a control group. The knee over toe position was again emphasized in this study, with athletes urged to focus on lower extremity positioning during the workout tasks. The drawback of this study is that no distinction was made between injury rates of females and males and ACL injury rates were not individually analyzed.

Balance and proprioception training

A large Italian study found a sevenfold decrease in ACL injuries in male soccer players who undertook a month long proprioception program involving balance activities on various balance boards (Caraffa, Cerulli, Projetti, Aisa, & Rizza, 1996). No specific joint positioning instructions were given for this study, only the prescribed exercises with set repetitions and durations. Although this study cannot be generalized to female athletes, the results certainly warrant further research into the effect of this type of program on women.

Active jump and agility training

Henning's work (in Griffin, 2000) was instrumental in guiding ACL injury prevention programs. Unfortunately because of his passing in 1991, his results were never formally published, but they are widely recognized as an important contribution to understanding ACL injury prevention. He found an 89% decrease in ACL injuries in female university basketball players over an eight year period with the use of agility and jump landing training. Increasing hip and knee flexion during jump landing was emphasized during this protocol, as was minimizing knee valgus.

Plyometrics

A recent study which evaluated the effectiveness of a plyometric intervention program on decreasing the risk of ACL injury found that there was no difference between the intervention group and the control group (Pfeiffer, Shea, Roberts, Grandstrand, & Bond, 2006). Both study groups had equal numbers of noncontact ACL injuries occur during the two competitive seasons of the study. It appears, however, that the frequency of participation in this program was low compared to other training protocols, in that athletes averaged 18-22 training sessions over the two seasons. Considering that the program only took 20 minutes to complete, there was obviously not enough time to produce a training effect on the neuromuscular system of the athletes.

Prevention programs in Manitoba

Currently, there are no formal jump landing training programs offered through the public school system in Manitoba (Brian Hatherly, personal communication, April 30, 2009). However, physical education teachers have broad educational guidelines that encompass topics such as balance and learning safe and controlled movements. There is an emphasis on the jump take-off in physical education curriculum to maximize performance, but very little on how to land safely from that jump. It is currently up to the individual teacher to decide how to teach the skills that satisfy each of the outcomes as put forth by the mandated curriculum.

Coaching Manitoba offers coaching education through the National Coaching Certification Program. The biomechanics of landing from a jump safely in order to prevent injury is not introduced until the Level 3 course, which a very small number of coaches in Manitoba actually attend (Sheldon Reynolds, personal communication, April 21, 2009). Even then, the education provided to the coaches by the instructor is entirely dependent on the knowledge level of that instructor. If he/she is not aware of all the factors involved in safe landing mechanics, he/she will be unable to properly instruct the coaches.

Clearly there is a lack of proper education regarding ACL injury prevention in Manitoba. Inclusion of safe landing biomechanics should be included in the educational curriculum so that all athletes, recreational or competitive, can decrease their risk of injury.

FEEDBACK ON SKILL LEARNING

Feedback on the success of a skill can be divided into two categories.

Task-intrinsic feedback

Task-intrinsic feedback is the sensory-perceptual data that is an innate part of executing the task (Magill, 2001). This includes the visual feedback of hitting a target with the ball, the sound of the ball hitting the hand, or the proprioceptive information from the body as the skill is completed.

Augmented feedback

Augmented feedback is the second category, and exists in addition to task-intrinsic feedback. It can take two forms, knowledge of results or knowledge of performance.

Knowledge of results

Knowledge of results only involves giving the athlete feedback about the final outcome of the skill, or whether they achieved the goal of the skill or not. It does not address why the goal was or was not achieved.

Knowledge of performance

Knowledge of performance generates information regarding the movement properties that led to the outcome. This informs the athlete about the reasons for the outcome and can occur in verbal form, or, more commonly, video replay. This type of feedback can give the athlete valuable information on the execution of their skill that they are unable to attain from the intrinsic feedback provided by the skill. Studies have shown that augmented feedback can enhance or even be essential to the acquisition of skills (E. Bilodeau, I. Bilodeau

& Schumsky, 1959; Trowbridge and Cason, 1932; Wallace & Hagler, 1979), especially when undertaking a complex motor task such as landing from a volleyball spike jump. Because the method of landing was novel to the athletes in this study, they were not able to process the intrinsic feedback effectively, since they had no reference point with which to compare the new movement pattern. This lack of experience was replaced by augmented feedback, and specifically, knowledge of performance feedback, which supplied a "standard" that the athlete could work towards.

Complex skills requiring multi-limb patterns of movement can be acquired by repetitive practice. However it has been found that augmented feedback can significantly speed up the process and allow the athlete to reach a performance level beyond what would be possible with only intrinsic feedback (Wallace & Hagler, 1979).

Verbal instruction

Various types of knowledge of performance feedback exist. The most common is verbal instruction. Magill (2001) emphasized the importance of completing a skill analysis and developing a checklist of key movements before giving verbal instruction to ensure the feedback is correct and will lead to the desired result. *De*scriptive knowledge of performance strictly describes the error in the skill but does not give any suggestion for correction of the error. This type of feedback is best for more advanced athletes who already possess the knowledge of how to fix their performance. *Pre*scriptive knowledge of performance points out the error to the athlete and subsequently gives instruction for correct technique. This works well for beginners who do not have enough knowledge to self-correct. Because a new method of landing from a jump was introduced to the volleyball subjects in this study, prescriptive knowledge of performance was used.

Video feedback

Increasingly, video playback is being used as a form of augmented feedback. There has been conflicting evidence that video feedback is effective in assisting athletes to attain a new skill (Rothstein & Arnold, 1976). One of the most consistent findings is that athletes, and especially beginners, benefit from video feedback more if an instructor or coach points out errors and deficits in performance and suggests movement patterns to correct the errors (Kernodle & Carlton, 1992).

In terms of the amount of time required to cause a change in performance using video feedback, Selder & Del Rolan (1979) found that there was no difference at four weeks between a video intervention group and a control group attempting to learn a gymnastics skill, but that a significant difference existed at the six week mark.

Another study looking at the performance of golfers after video intervention found a significant improvement in performance after two weeks (Guadagnoli, Holcomb & Davis, 2002). An interesting aspect of this study was that initially, on the first post-test that took place two days after the intervention, performance actually decreased. The authors suggest that video feedback is indeed effective, but the positive results may take some time to develop.

The frequency of feedback needed to exact a change in performance has also been studied. It has been determined that feedback after every single trial of a skill is not necessary for learning, and may in fact produce a reliance on the feedback for achievement of the task goal (Winstein & Schmidt, 1990). Summary augmented feedback involves giving performance based feedback after a given number of trials, instead of after each trial. There has been no optimal number of trials suggested between feedback sessions, although a study by Boyce (1991) found the effectiveness of feedback after every fifth trial to be identical to feedback after every trial.

Guadagnoli, Dornier and Tandy (1996) suggested that the number of trials between feedback sessions is dependent upon the skill being performed. A large number of trials are better for simple skills, whereas smaller numbers are better for more complex skills. More complex skills require feedback regarding a number of different joint and segment movements and therefore more frequent feedback is necessary to address all the movement components. In a simple task where perhaps only one movement is required, a longer time between feedback sessions can be used successfully. Landing from a volleyball spike jump is a complex skill requiring coordinated movement of the entire body; therefore feedback was given after a smaller number of skill attempts.

SUPPORT FOR MODIFYING MOTOR PATTERNS USING FEEDBACK

There have been many studies investigating the effects of augmented feedback on improving jump landing biomechanics as well as ACL injury rates. Prapavessis and McNair (1999) and McNair et al. (2000) were the first investigators to examine if instructing athletes in proper landing techniques could be effective. They indeed found that there was a significant improvement, as determined by a lower peak ground reaction force, after instruction. A correlation has been shown (McNair and Marshall, 1994) between increased vertical ground reaction forces and increased anterior tibial acceleration when landing from a jump, suggesting damage to the ACL is possible with increased landing forces. This is because the ACL is responsible for limiting anterior movement of the tibia on the femur. If the structural integrity of the ligament is challenged by high ground reaction forces, injury may occur.

Verbal feedback

McNair et al., (2000) found that both technical feedback (instructing participants to land on the balls of their feet, bend their knees upon landing, and absorb the force of landing over a greater time period); as well as sound feedback (merely instructing athletes to use the sound of their landing to subsequently land more softly on following jumps) were useful in decreasing ground reaction forces. The magnitude of the decrease was 0.4 times bodyweight, or a 13% drop in ground reaction forces.

Mizner et al., (2008) found immediate positive results in jump landing biomechanics in female collegiate athletes after five minutes of instruction. Athletes increased their peak hip flexion angle by nine degrees and their peak knee flexion angle by eleven degrees. Peak knee valgus values decreased significantly by just over one degree. An increased landing time was noted after receiving verbal instruction from the investigator, with an increase of 0.05 seconds.

An additional benefit found in this study was that the athletes' peak jump height was not adversely affected by the intervention. This should ease any concerns coaches and athletes may have that performance needs to be sacrificed in order to decrease their chance of injury.

These authors also could not identify a relationship between lower extremity and trunk strength and the degree to which landing biomechanics were altered with the intervention. This is a very positive finding of this study, as it shows it is likely that any female athlete can benefit from jump landing training, regardless of their muscle strength.

A recent volleyball specific study showed that after two minutes of feedback verbally, Division I collegiate athletes were able to decrease their vertical ground reaction forces by 23% while spiking a tossed volleyball (Cronin et al., 2008). The instructions for proper landing technique included landing on the forefoot and rolling to the rearfoot, landing evenly on both legs, and performing knee flexion close to 90 degrees upon landing from the spike. Post-intervention, the athletes were also able to increase the time taken from landing on their forefoot to rolling back on their heels. The result was that after an individual intervention, the athletes were able to decrease vertical landing forces as well as spread the absorption of those forces over a longer period of time. Medial/lateral and anterior/posterior ground reaction forces remained unchanged post-instruction, however the authors point out that their verbal instructions were more specifically aimed at decreasing the vertical force of landing rather than forces in the other planes of movement.

Video feedback

Onate et al., (2001) found that augmented video feedback was superior to sensory feedback or no feedback in terms of reducing peak vertical ground reaction forces when landing from a jump in a group of college aged males and females. In the augmented group, peak vertical ground reaction forces were decreased by approximately 0.8 bodyweight at both a two minute post-test and a one week post-test. In this study, augmented feedback consisted of two minutes of viewing their jump attempts as the investigator reviewed with them a checklist of desirable joint movements including normal knee valgus, forefoot to rearfoot landing and knee flexion upon landing. This study included a one week post-baseline test that presented the same findings as the two minute post-baseline test, that is, the augmented group had significantly decreased peak vertical ground reaction forces. The authors fail to say, however, if feedback was provided at the one week re-test or whether the learning effect was a carryover from the initial baseline test.

These same authors went on to establish the effect of various types of video feedback on jump landing technique (Onate et al., 2005). They divided their subjects into three feedback groups; those that viewed an "expert" video of the skill, those that viewed only themselves performing the jump landing, and those that viewed a combination of expert and self video. The authors concluded that when the subjects viewed themselves completing the skill, or a combination of expert and self, they were able to decrease their peak vertical ground reaction forces and increase their overall knee flexion angles significantly with immediate re-testing and a one week re-test. There was no difference between the expert only group and the control group. This underlines the fact that an individual must be an active participant in the learning process in order to retain new knowledge and performance. The athletes benefited from watching themselves perform the skill, rather than only an "expert" that they could not relate to.

More supportive evidence for video feedback has come recently from a German study, which showed young elite table tennis players were able to improve their technique more quickly and effectively by incorporating video feedback into their training regime (Raab, Masters & Maxwell, 2005).

Over the years, some studies have shown video feedback to have no benefit in improving performance. Two studies (Emmen, Wesseling, Bootsma, Whiting and Van Wieringen, 1985; Van Wieringen, Emmen, Bootsma, Hoogesteger & Whiting, 1988) failed to find improved motor performance after using video feedback in intermediate level competitors performing the tennis serve as compared to traditional training. A similar study reviewing whether video feedback would be beneficial in teaching trampoline skills to male youths reported no significant difference between the intervention and control groups (James, 1971).

Rothstein and Arnold (1976) reviewed the earlier video feedback literature and found that less than half of the studies showed a positive result by using video feedback rather than other more traditional forms of training. Their suggestions for the attainment of the most favorable results using video feedback include using it for a minimum of five weeks, giving verbal instruction along with video replay to direct the athletes' attention to important aspects of the skill to change, and that video feedback is perhaps most effective with athletes of greater skill levels.

Chapter III

Methods

DESCRIPTION OF STUDY

Female adolescent volleyball players from two separate high school teams were videotaped performing five spike jump landing sequences, after hitting a volleyball tossed by their coach. The athletes were 12 to 14 years of age and had successfully tried out for and made their school volleyball team. One of the teams served as a control group, only filmed at the beginning and at the end of the study period, with no intervention offered to these athletes. At the initial filming session, the intervention group demonstrated their spike jumps and then viewed themselves on video performing the skill. As well, they received feedback from the researcher on how to improve their landing technique to prevent injury (Appendix E). This group of athletes was then filmed again immediately after the feedback and on a bi-weekly basis for four weeks. The study finished when the competitive volleyball season for the two teams ended, which allowed for two follow-up filming sessions after the initial intervention. The pre and post-intervention video was analyzed using Dartfish film analysis software to determine whether the intervention group improved their landing technique with video and verbal feedback, whether there was sustained learning, and whether the intervention group showed greater improvement compared to the control group.

Subjects

Nineteen female adolescent athletes from two Winnipeg area private schools were the subjects for this study. Nine of the subjects came from one school and consisted of the control group, receiving no intervention. The other ten subjects consisted of the volleyball team from the other school and comprised the experimental group for the study. All subjects were between 12 and 14 years of age and were selected to be a member of the Grade 8 volleyball team at their respective school. The athletes were recruited via personal communication between the investigator and the coach and school principal.

The athlete's hand dominance, number of years playing volleyball, and age was recorded before the initial spike jumps were attempted. Informed consent (Appendix B) was obtained from the subjects' parents or guardians before participation in this study. Ethics approval for the study was received from the Education/Nursing Research Ethics Board at the University of Manitoba.

This age group was chosen for study based on the fact that the increased risk for ACL injuries among females begins to appear at puberty (Shea et al., 2004). Therefore it was considered important to conduct the study on the at-risk population to determine if an intervention could be effective before injuries start occurring. Private school athletes were chosen due to ease of access by the investigator. They are less often approached for inclusion in research studies due to the smaller numbers of students enrolled in private versus public schools. There is less bureaucracy as well, with approval from the principal and volleyball coach required for inclusion in the study, instead of permission from a school board, superintendent, principal and coach. Since all subjects were minors, informed written consent was obtained for all subjects from their parents or guardians before the study began.

Test protocol

The two volleyball teams were filmed during regularly scheduled practice times. A general introduction and description of the study was given to the athletes at the start of their practice. Subjects then participated in the team's warm-up, after which time filming of the athletes commenced. As each subject was being filmed, the remainder of the team was engaging in practice drills as planned by their coach.

Two pieces of tape were placed on the floor in the number four position on the volleyball court, designating a start point and an end point for the spike approach (See Figure 3.2). This was to ensure that the athlete's movements were as directly in line with the cameras as possible, allowing accurate biomechanical analysis. At the initial filming session, each subject in the control group was filmed completing five successful spikes as the coach or assistant tossed the volleyball. A spike was considered successful if the spike approach and landing occurred within the tape marks on the floor and the ball passed over the net and landed in the court. The subject completed the spikes at their own pace, taking a rest break between trials as needed.

The athletes in the control group received no feedback, verbal or visual, other than notification whether the spike had been successful or not. The initial filming of the intervention group began exactly as for the control group. However, after completion of five successful spikes, the athlete was shown the video of herself performing the spike and landing. At the same time, the researcher reviewed a checklist of desired movements and positions for landing safely from a jump (Appendix E). This included instruction to land on both feet with their weight distributed equally between their feet, and using a toe to heel landing pattern. The athlete was encouraged to land with deeper knee and hip flexion at initial contact as well as an increased maximum knee and hip flexion angle at the lowest point of the jump. Instruction was given to the subjects to concentrate on keeping the lower extremity aligned during the landing, ensuring that the hips stayed over the knees, and the knees stayed over the toes. The athlete was told to absorb the force of the landing instead of landing stiffly.

After reading out the checklist, the researcher directed the athlete's attention to her video and specific positions relevant to her performance that could be improved. Two of the athlete's successful spike jumps were shown to her, once at full speed and once in slow motion, stopping at relevant frames that illustrated where the athlete could improve on her jump landing performance. The athlete was allowed time to ask questions in order to clarify the jump landing instructions. The video and verbal feedback was a two-way conversation with the athlete. It did not take a strictly didactic approach. After viewing the videotape and hearing the instructional checklist, the athlete then repeated the spike jumps, completing another five spikes successfully.

Filming of five volleyball spikes for each athlete was repeated once every two weeks for the intervention group, with a reminder of good landing biomechanics including a demonstration by the researcher at each subsequent filming session. Figure 3.1 shows a visual representation of the filming timeline for each group.

WEEK	0	2	4
Group filmed	Control	Control not filmed	Control
	Intervention (pre and immediately post-feedback)	Intervention	Intervention

Figure 3.1: Outline of filming timeline.

The same camera set-up was used throughout each of the filming sessions. Selder and Del Rolan (1979) suggested a positive change in performance after six weeks of practice. There were only two subsequent filming sessions with the intervention group, after two weeks and four weeks, as their competitive season ended quite early and there was not enough time to extend the study to six weeks as originally planned. After four weeks, both the intervention and control groups were filmed again completing five successful spike jumps and landings. After completion of the final filming, the data was analyzed with Dartfish computer software to determine if there was a significant difference between groups in terms of desirable landing mechanics. The intervention group was also analyzed to determine if the correct landing pattern taught during the first filming and intervention session was retained over the study period.

Filming protocol

The athletes were filmed using four digital camcorders; two Canon GL2 models, a Canon ZR500 and a Canon ZR700. One Canon GL2 was placed in front of the athlete, approximately two meters from the end position of the spike, on the opposite side of the net, to capture a frontal view of the spike approach and landing. The other Canon GL2 was situated six meters to the left of the athlete to capture the left side of the body during spike landing in the sagittal view. The remaining two cameras were placed two meters behind the athlete's start position, and six meters to the right, capturing the rear frontal view and the right sagittal view, respectively. All cameras were affixed to tripods to ensure they remained stationary for the duration of the trials. Before any spike trials were begun, a meter stick was videotaped within the camera field by all cameras, in order to act as a conversion factor for measuring distances when analysis was undertaken.

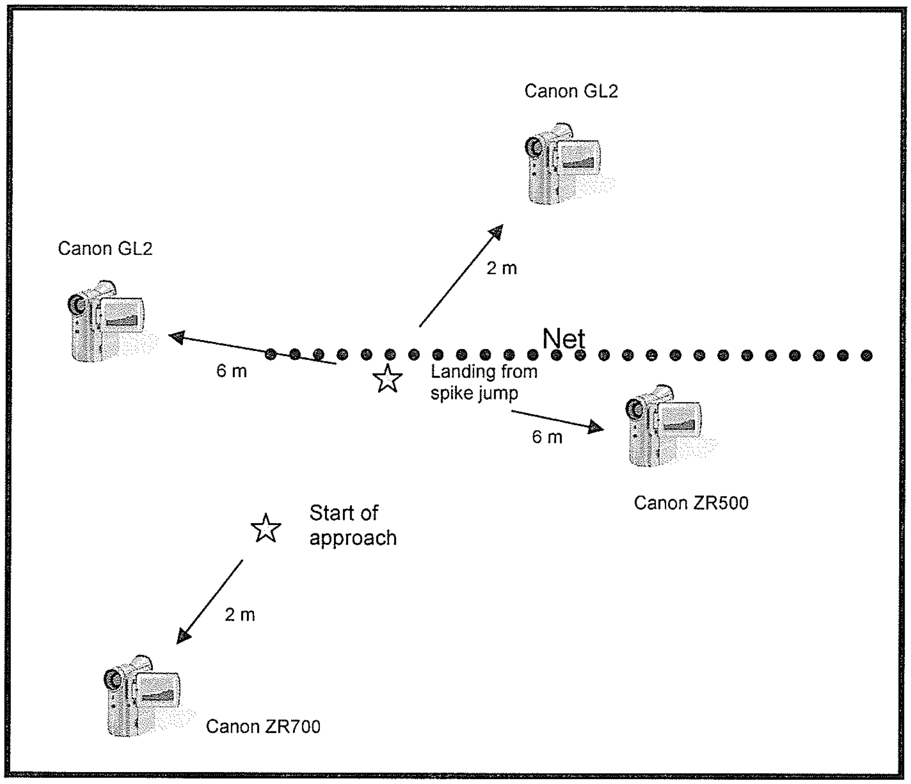


Figure 3.2: Camera set-up for videotaping spike jump trials.

Spike jump landing phases

Initial touchdown

Landing from the spike jump was divided into two phases. The first phase was initial touchdown, which was designated as the first frame of video in which the athlete's foot came into contact with the floor. This may have been different for the right and left legs if the athlete did not land evenly on both feet. In that case, the point of initial touchdown of the right foot was used for measuring variables of the right lower extremity, and the point of initial touchdown of the left foot was used to measure the variables of the left leg.

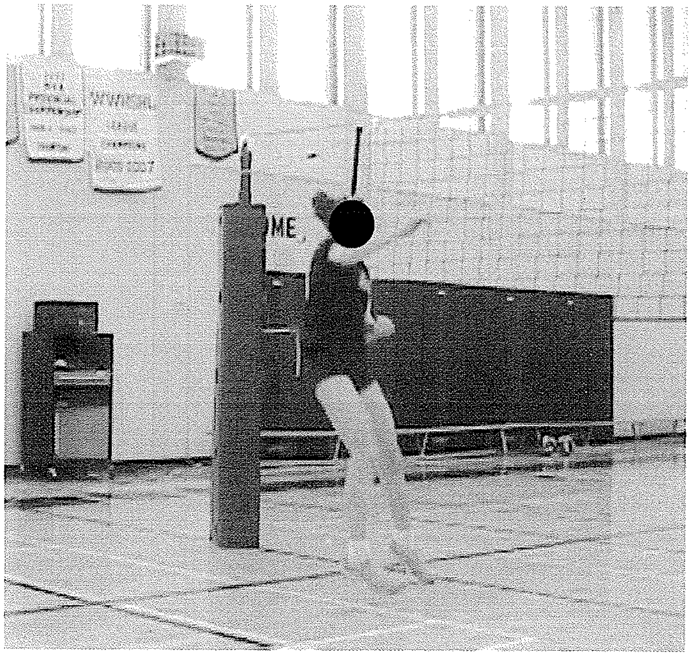


Figure 3.3: Position of initial touchdown.

Position of maximum flexion

The second phase of the jump landing was the position of maximum flexion. This was the position of maximum range of motion of the flexion movement of interest reached by the athlete during the spike jump landing. For example, the position of maximum flexion for right knee flexion was the frame of video where the athlete reached maximum right knee flexion during landing.

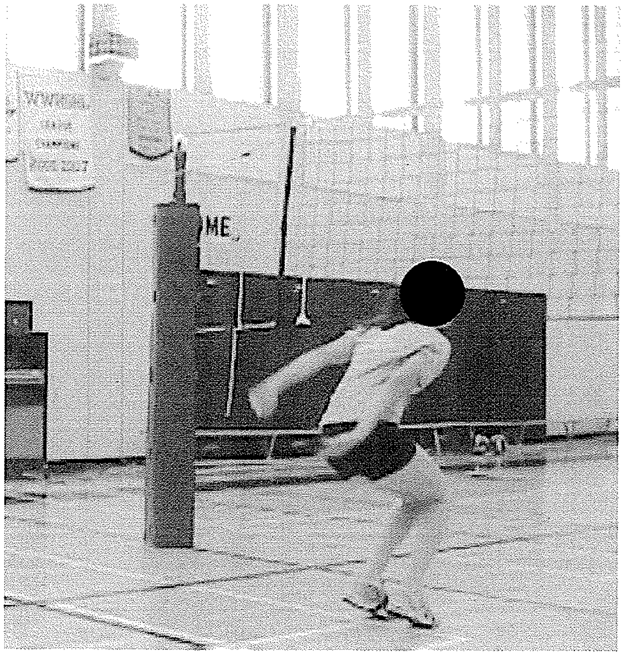


Figure 3.4: Position of maximum flexion of the right and left knee.

Variables Measured

From the video footage, key variables related to the jump landing were measured to determine whether a significant difference existed between the control and intervention groups, and whether there was retained learning in the intervention group from week one to week four. Important variables as identified in the literature for decreasing risk of injury during a jump landing included a decreased amount of knee valgus, an increase in knee and hip flexion angle at initial ground contact and at the position of maximum flexion, landing on two feet versus one foot, landing on the toes and rolling to the heels, and a long stance phase. (Appendix D).

Trunk flexion has been suggested to influence landing biomechanics of the lower extremity, however there are conflicting reports on whether increased trunk flexion is positive (Blackburn & Padua, 2008; Shimokochi et al., 2009) or negative (Ireland, 2002). The review of literature in the preceding chapter offered an overview of the existing evidence surrounding the suggested trunk position for ACL prevention. Because trunk position may play an important role in landing safely from a jump, this variable was measured and included in the analysis. The athletes were not given any specific instruction as to which position to assume with their trunk as they attempted their subsequent spike trials after instruction, however the variable was measured. A complete list of measured variables can be found in Table 3.1.

Table 3.1: Variables measured during the volleyball spike jump landing.

Phase of Landing Skill	**Variable Measured (units)**
Initial touchdown	Right and left knee valgus (degrees) Right and left knee flexion (degrees) Right and left hip flexion (degrees) Right and left ankle position (degrees) Toe versus heel landing bilaterally Two-foot vs. one-foot landing Trunk flexion (degrees)
Position of maximum flexion	Right and left knee valgus (degrees) Right and left knee flexion (degrees) Right and left hip flexion (degrees) Right and left ankle dorsiflexion (degrees) Trunk flexion (degrees) Anterior/posterior distance between the toe of the right foot and the toe of the left foot (metres) Medial/lateral width of stance (metres) Length of stance phase from initial touchdown to end of force absorption bilaterally (seconds)

BIOMECHANICAL ANALYSIS FROM THE VIDEO FOOTAGE

Footage from the camera to the left of the athlete and from the anterior view of the athlete was uploaded directly to a Toshiba laptop computer during filming via the use of a two way interface. This tool allowed the simultaneous capturing of the skill from two different angles and avoided the time needed to download the individual trials from the videotape after filming. It also allowed immediate viewing of the video clips by the athlete and principal investigator. The video footage from the additional two cameras was manually downloaded into the Toshiba laptop computer after filming using the Dartfish computer software.

Measurement of flexion range of motion in the extremities

Dartfish computer software is designed for use in the field in practical situations. As such, it is not often used in research studies. A common method of kinematic measurement in a laboratory setting is via the use of multi-camera, computer generated 3-D motion analysis software such as the Vicon motion measurement system (http://www.vicon.com). This type of instrumentation is extremely expensive and not conducive to use outside a laboratory setting. All studies found in the course of the literature review for this research project used these complex motion analysis systems in a laboratory setting to examine the biomechanics of the jump landing. Since the purpose of this study was to examine a practical situation, Dartfish was the computer software of choice.

"The accuracy and reliability of Dartfish is highly dependent upon camera positioning, camera resolution, the distances of the objects from the cameras, the angles of objects and movements with respect to the cameras, and the precision with which the operator can visually identify and mark the positions" of the joints in question (Abercromby, Thaxton, Onady & Rajulu, 2006). Camera set-up for each filming session was undertaken solely by the principal researcher, so as to guarantee consistency in camera placement and settings. This ensured the most accurate collection of video possible.

Angular variables in the extremities in the present study were measured using relative angles. This technique involved measuring the angle between the long axis of one body segment and the long axis of the adjacent body segment at the joint of interest. The measurement was taken using the 180 degree scale. In anatomical position, according to the 180 degree system, all joints are in a position of zero degrees. Any deviation from anatomical position is measured and designated the joint angle (Hall, 2007). Angular variables were measured using Dartfish software by the use of the angular measurement tool. Hip and knee flexion were designated as a positive number for the purposes of statistical analysis. Extension was designated as a negative number. Plantarflexion of the ankle was measured as a positive number, and dorsiflexion as a negative number. Hip, knee and ankle flexion angles were measured using the sagittal view cameras. The camera with the best view of the variable of interest was used. See Figure 3.5 for an example of knee angle measurement.

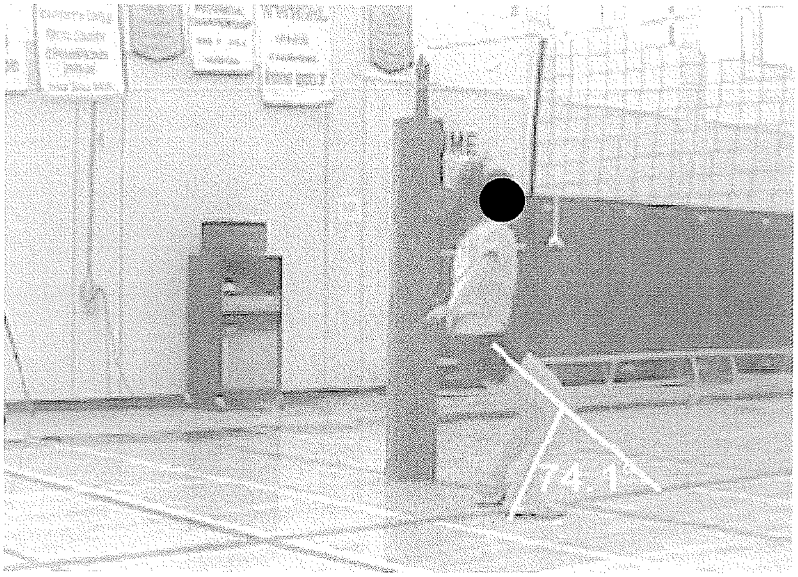


Figure 3.5: Knee flexion angle measured with the Dartfish angular measurement tool, between a line joining the hip and knee joint centres (anatomical position), and a line joining the knee and ankle joint centres.

Measurement of trunk flexion range of motion

Trunk flexion was measured using the Dartfish angle measurement tool as well. The trunk angle was measured as an absolute angle, between the long axis of the trunk and the vertical axis. The angle was measured from a line joining the ipsilateral hip and shoulder joints, representing the long axis of the trunk, to a vertical line representing anatomical position. For the purposes of statistical analysis, trunk flexion was designated as a positive number and trunk extension as a negative number. See Figure 3.6 for an example of trunk flexion measurement.

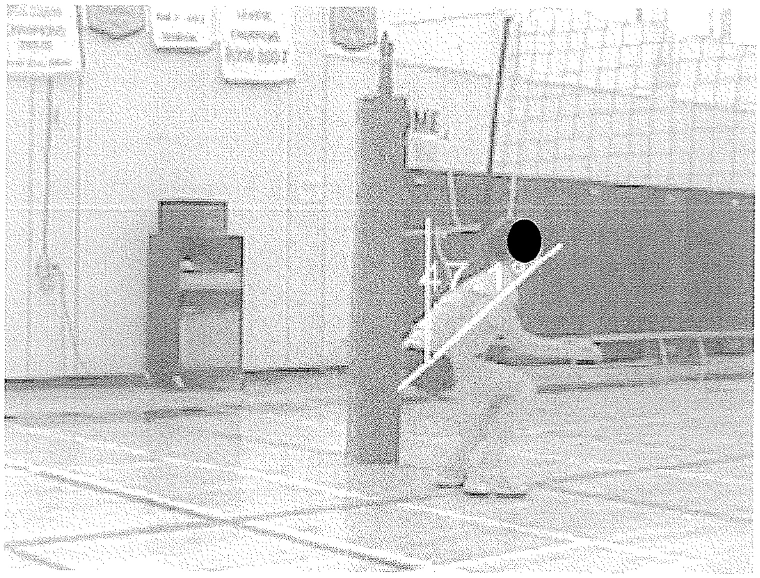


Figure 3.6: Measurement of trunk flexion angle using the vertical position as anatomical position.

Measurement of knee valgus range of motion

The valgus knee angle was measured via the frontal view film footage utilizing a technique developed by the present researcher. A straight line was first drawn to join the ankle and hip joint on the ipsilateral side. A line was then drawn from the middle of the ankle joint to the center of the patella. The angle between those two lines was measured, and designated the valgus or varus angle of the knee. A valgus knee position was designated as a negative number and a varus knee position was designated as a positive number. See Figure 3.7 for an example of knee varus/valgus measurement.

This new method of measuring knee varus/valgus was developed to suit the real world situation in which filming took place. Another method of measuring knee varus/valgus using Dartfish has been used in the past (Glass, Priest & Hayward; n.d), however, it was developed for a controlled laboratory based study and was not conducive to use in a real life sport situation. If an athlete landed with any amount of hip abduction, the measurement proposed by Glass and colleagues was not valid. As seen in Figure 3.8, measuring the valgus angle of the knee using a vertical line as reference does not accurately reflect the true frontal plane position of the knee if the athlete is in hip abduction. The true valgus angle can only be measured using a straight line between the hip and ankle as a reference.

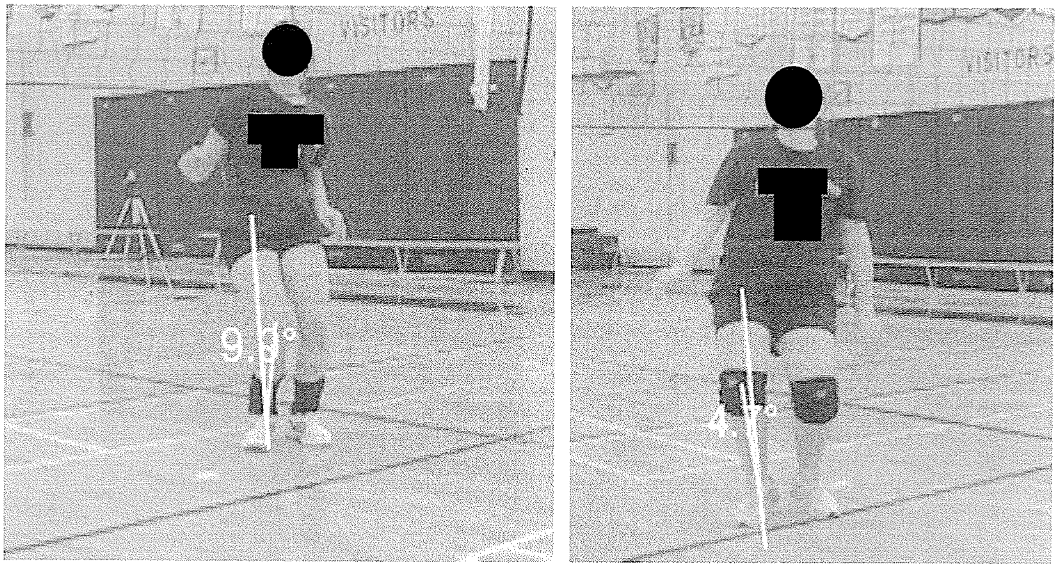


Figure 3.7: Knee valgus measurement technique used in the current study. On the left, the athlete has landed with 9.9 degrees of right knee valgus, while on the right, the athlete has landed with 4.7 degrees of right knee varus. Knee valgus was designated as negative and varus as positive during statistical analysis.

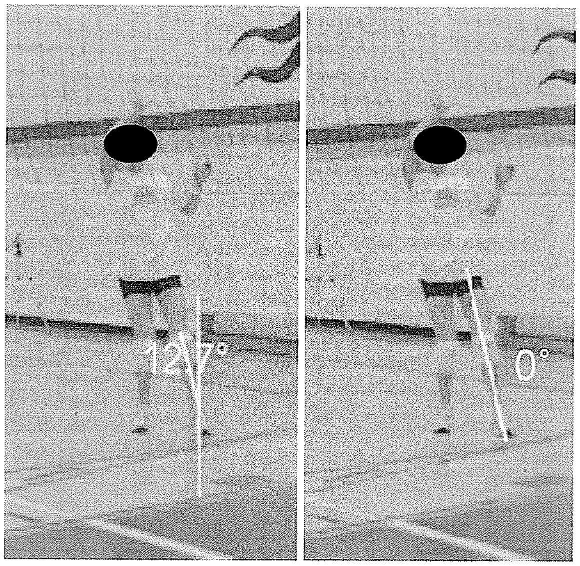


Figure 3.8: Measurement of knee valgus using the method developed by Glass and colleagues (left) and using the method developed by the current investigator.

Measurement of stance phase duration and one vs. two foot landing

The length of stance phase was determined by viewing the sagittal camera footage and using the time tool within Dartfish. Timing began at the instant of first contact with the floor, and ended at the position of maximum flexion. Determining whether the athlete landed on one foot or two required a combination of all camera views, depending on which camera had the best vantage point for that particular trial.

Measurement of medial/lateral and anterior/posterior stance width

The distance tool was used to measure the medial/lateral stance width as well as the anterior/posterior distance between the feet of the athlete. The distance tool automatically calculated a conversion factor from digitizing of the video clip of the meter stick taken during the filming session. Because the camcorders were not moved during filming, the conversion factor provided an accurate, efficient way to measure actual distances within the film clips using Dartfish.

STATISTICAL ANALYSIS

The variables in Table 3.1 for the three best spike jump trials were analyzed for each volleyball athlete. The "best" spike jump trials were chosen by the quality of the video clips and the ability to visualize and measure the variables accurately. Means and standard deviations for all variables for each athlete were calculated using the Microsoft Excel software program. These variables included trunk, hip and knee flexion, ankle plantarflexion/dorsiflexion, knee valgus, duration of stance, medial/lateral stance width and anterior/posterior distance between the toe of the right foot and the toe of the left foot (see Table

3.1 for a detailed list of variables). An average value from the three best trials was calculated for each continuous variable for each athlete and was combined with the values for the other athletes to produce an overall mean for that particular variable. That mean was then used to compare the variable across time within groups as well as across groups.

Paired t-tests were used to compare the control group between their initial filming session and final filming session. Twenty-one continuous variables were analyzed in this manner, necessitating the use of a correction factor to decrease the risk of a type I error occurring. A critical p value of 0.025 was chosen in order to account for the increased chance of type I error with 21 individual tests being conducted, but at the same time attempting to minimize the risk of a type II error occurring with the use of an overly strict p value (T. Hassard, personal communication, April 7, 2009). Three categorical variables were also analyzed for significance using a Wilcoxon signed rank sum test (Hassard, 1991). This is a nonparametric test, which does not assume the data follow a normal distribution. This test allowed the data to be analyzed in pairs, as each individual athlete was compared between time one and time two. It analyzed the difference between the data at time one and time two, instead of the actual value of the data at time one or time two. A numerical value was assigned to each of the four possible outcomes of the three jump landing trials for each athlete. Zero denoted that the athlete did not land on two feet for any of her trials. One was assigned if the athlete landed on two feet once during her three landing trials. A two or a three was assigned if the athlete landed on two feet twice or three times, respectively, during her three jump landing attempts. When analyzed in this manner, the sample size, N, remained at nine. A p value of 0.025 was used, along with the sample size, to determine the critical value of the Wilcoxon signed rank sum test for each analysis.

A one-way repeated measures analysis of variance (ANOVA) was used to compare the pre-intervention variable means with each of the three post-intervention variable means to see if there was a significant change over time within the intervention group. A repeated measures ANOVA was used because the current study examined the same subjects' behaviour at different points in time. Therefore, the means from each testing session were not independent of each other, which is a prerequisite for using a standard one-way ANOVA. The repeated measures ANOVA was beneficial because it allowed the removal of variability due to individual differences. Because the leftover variability was largely a result of the intervention only, the power of the study was increased. The power of a study indicates the likelihood that the test will find a difference if one exists (Hassard, 1991).

The independent variable in this study was the time post-intervention. A separate one-way repeated measures ANOVA was completed for each dependent variable, including knee, hip and trunk flexion and knee valgus at initial ground contact and the position of maximum flexion. Table 3.1 lists all dependent variables that were analyzed. Again, a critical p value of 0.025 was employed in order to acceptably decrease the type I error while not being excessively strict as to increase the chance of a type II error occurring. If a significant difference was found between times within the intervention group, a Newman-Keul's (Hassard, 1991) multiple comparison post hoc test was utilized in order to determine where the significant differences existed between filming sessions.

Three categorical variables were compared within the intervention group across time using a Friedman's test. This is an extension of the one-way nonparametric analysis of variance (Hassard, 1991). Using this test allowed the elimination of between-subjects variation. As a result, the comparisons between subjects became more sensitive. Again, a p value of 0.025 was used, along with the degrees of freedom, to determine the critical value for each analysis. Friedman's test statistic follows a Chi square distribution and therefore Chi square tables can be used to determine if the calculated Friedman's value is of significance (Hassard, 1991).

A two-way repeated measures analysis of variance (ANOVA) was used to determine if there were any significant differences between intervention and control groups from initial filming session to final filming session. A p-value of 0.025 was used as the level of significance to determine if a true difference existed between groups. If a difference was found, a Newman-Keul's post hoc test was employed to determine where the difference existed.

The three categorical variables were compared between groups using Mann-Whitney *U* tests. This type of analysis allowed the comparison of categorical data between the intervention and control groups at time one and time two. All the results from the two groups were pooled and ranked from smallest to largest. The sum of the ranks from each group was then calculated. The test value for the Mann-Whitney *U* test was calculated using the total rank sum from each group as well as the size of the group. The test value was then compared to a table of critical values to determine whether the groups differed significantly. The critical value of the Mann-Whitney *U* test was identified using the sample size of each of the two groups and a p value of 0.025.

CHAPTER IV
Results

Chapter 4 will outline the results from the statistical analyses performed on the data collected from the control and intervention groups. Several key differences were found across the two groups and across the four different filming sessions. The age of the subjects and number of years' experience playing volleyball are reported in Table 4.1. All subjects were in Grade 8 and were members of their school's Grade 8 competitive volleyball team. All subjects displayed right hand dominance.

Table 4.1: Descriptive characteristics of subjects

	Control Group		Intervention Group	
	N = 9		N = 10	
	Mean	SD	Mean	SD
Age (years)	13.1	0.33	13.2	0.42
Volleyball experience (years)	1.9	0.6	1.8	0.63

COMPARISON OF MEANS AND STANDARD DEVIATIONS FOR THE CONTROL GROUP AND INTERVENTION GROUP ACROSS TIME

The following section will present the means and standard deviations of all measured variables of the two groups in the study over the four weeks of the study period. Three trials of the jump landing were filmed for each athlete. The variables of interest were measured using Dartfish software and an average for each subject was calculated for each variable from the three trials. These averages were then compared across time and across groups. The control group was filmed on two occasions; once at the beginning of the study period and once at the end of the four week study period. The intervention group was filmed a total of four times; before and immediately after the verbal and video feedback session, two weeks after the feedback session, and four weeks after the feedback session. In this chapter, the means and standard deviations of the variables for each group are presented separately across time, as well as between groups over time. Variables are divided into those measured from the initial touchdown phase and those measured from the position of maximum flexion as discussed in the methods section. They are also divided into continuous and categorical variables which are reflected by the different statistical analyses that were undertaken for each type of data.

Control group across time

Initial touchdown

Nine continuous variables were measured for the control group at the moment of initial touchdown in the jump landing at time one and time two. For the purposes of the following discussion, time one refers to the group's initial filming session and time two refers to the group's final filming session. These continuous variables, as well as the corresponding means and standard deviations at time one and time two are reported in Table 4.2. All tests were evaluated for significance at the $p \leq 0.025$ level, because of the number of independent tests being conducted (21), and the associated increase in risk of a type I error occurring. This level was chosen to acknowledge the increased risk of type I error when multiple tests are done, but also to balance that fact with the increased risk of a type II error which comes from an overly demanding p value. Only one variable, right knee flexion at initial touchdown (see Figure 4.1), was found to be statistically significant using this critical value, with a p value of 0.012. This indicates that generally, the control group did not change in terms of their lower body biomechanics from their initial filming session to their final filming session as measured at the moment of initial touchdown. The control group's average right knee flexion at time one was 21.65 degrees, and at time two it decreased to 17.23 degrees (See Figure 4.2). This finding actually suggests that the landing biomechanics of the control group may have deteriorated over the study period.

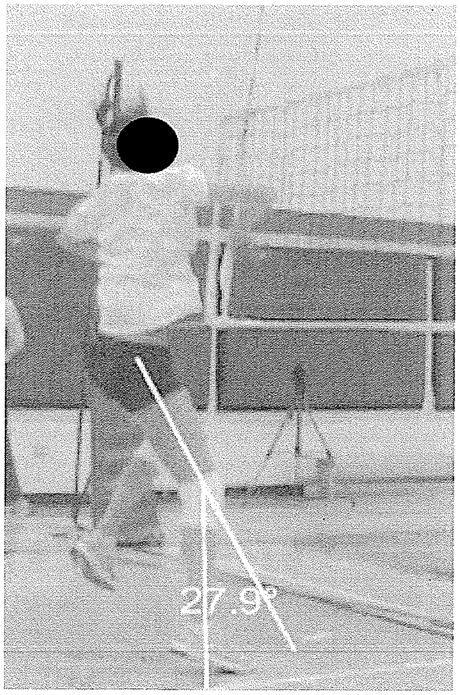


Figure 4.1: Right knee flexion at the moment of initial touchdown.

Table 4.2: Means, standard deviations and t-test comparisons of the measured continuous variables for the control group at the moment of initial touchdown (* p ≤ 0.025).

	Time 1		Time 2		
Variable	N=9		N=9		
	Mean	**SD**	**Mean**	**SD**	**p-value**
Right ankle plantarflexion at initial touchdown (degrees)	-26.87	17.88	-35.35	14.91	0.318
Left ankle plantarflexion at initial touchdown (degrees)	-38.58	5.05	-34.34	4.70	0.091
Right knee flexion at initial touchdown (degrees)	21.66	7.31	17.23	7.71	**0.012***
Left knee flexion at initial touchdown (degrees)	24.14	9.40	22.33	12.73	0.747
Right knee valgus at initial touchdown (degrees)	-3.68	4.52	-2.20	3.20	0.479
Left knee valgus at initial touchdown (degrees)	2.46	5.53	1.80	2.29	0.746
Right hip flexion at initial touchdown (degrees)	16.74	17.32	9.96	9.39	0.159
Left hip flexion at initial touchdown (degrees)	20.56	9.99	14.20	6.56	0.185
Trunk flexion at initial touchdown (degrees)	-2.86	8.20	-8.27	3.76	0.095

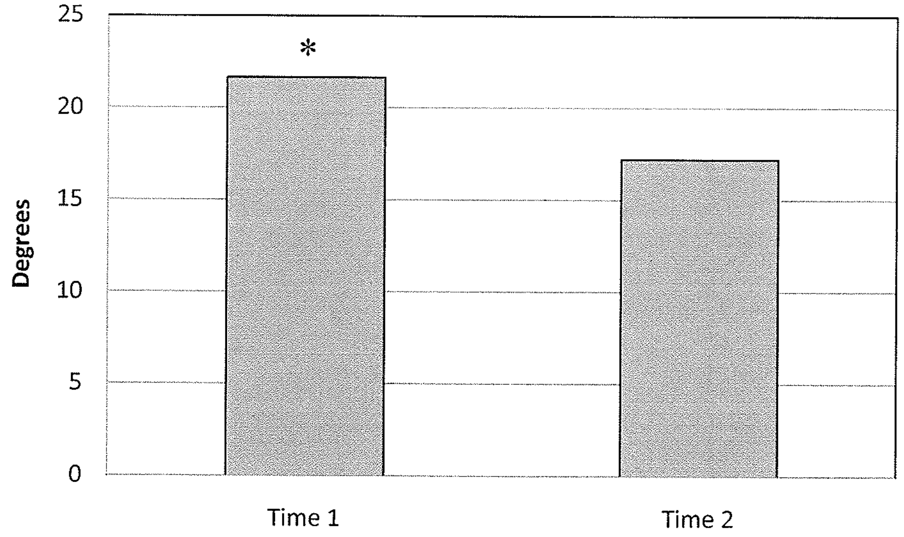


Figure 4.2: Right knee flexion at initial touchdown in the control group across time (*p ≤ 0.025).

Three categorical variables were measured at the position of initial touchdown; landing on one foot versus two feet as well as landing heel first or toe first on the right foot and left foot. A Wilcoxon signed rank sum test was performed for each of the three categorical variables. A paired test was chosen because the same individuals were compared between the two filming sessions. Summaries of the categorical variables are found in Tables 4.3, 4.4 and 4.5. The critical value for a sample size of nine and p of 0.025 was calculated to be ≤ 4. This determined that the calculated value from each of the three individual analyses had to equal or be less than 4 in order for that variable to be considered statistically significant. None of the three categorical variables were found to be significantly different, indicating that the control group did not change their jump landing technique between filming sessions.

Table 4.3: Number of times the control group athletes landed on two feet at time one and time two (Not Significant (N.S.)).

Time 1	Time 2
9	12

Table 4.4: Number of times the control group athletes landed toe first on their right foot at time one and time two (N.S.).

Time 1	Time 2
20	21

Table 4.5: Number of times the control group athletes landed toe first on their left foot at time one and time two (N.S.).

Time 1	Time 2
27	27

Position of maximum flexion

Twelve continuous variables were measured for the control group at the position of maximum flexion during the jump landing. This was the point during the landing at which the athlete attained her lowest position. The continuous variables for the control group measured at time one and time two are reported in Table 4.6. Using a paired t-test comparison and employing a critical value of $p \leq 0.025$, one of the continuous variables was shown to be statistically significant. Left knee maximum valgus (see Figure 4.3) at both time one and time two were actually varus angles, as they were positive numbers. At time one, average left knee varus was 3.6 degrees, and at time two it increased to 11.84 degrees. This is a positive result in terms of injury prevention, because males, who have a decreased rate of ACL injuries as compared to females, tend to land with a varus knee position (Malinzak, Kirkendall & Yu, 2001; Kernozek et al., 2005).

Figure 4.3: Left knee varus at the position of maximum flexion in the control group at time one (left) and time two (right).

Table 4.6: Means, standard deviations & t-test comparisons of the measured continuous variables for the control group at the position of maximum flexion (*p≤ 0.025).

	Time 1		**Time 2**		
Variable	**N=9**		**N=9**		**p-value**
	Mean	**SD**	**Mean**	**SD**	
Right ankle at max flexion (degrees)	13.09	13.45	15.65	9.42	0.658
Left ankle at max flexion (degrees)	17.44	7.47	21.06	5.68	0.239
Right knee at max flexion (degrees)	62.65	15.99	60.46	8.27	0.568
Left knee at max flexion (degrees)	65.63	14.67	66.15	12.30	0.921
Right knee max valgus (degrees)	-8.71	9.03	-11.94	9.28	0.594
Left knee max valgus (degrees)	3.60	6.91	11.84	8.27	**0.020***
Right hip flexion at max flexion (degrees)	42.13	29.27	38.41	14.34	0.634
Left hip flexion at max flexion (degrees)	45.39	26.62	35.75	11.06	0.263
Trunk flexion at max flexion (degrees)	6.65	16.24	0.53	8.51	0.242
Stance phase time (seconds)	0.19	0.08	0.18	0.04	0.373
Anterior/posterior stance (metres)	0.26	0.20	0.14	0.07	0.049
Medial/lateral stance (metres)	0.34	0.12	0.34	0.13	0.968

Intervention group comparisons across time

Initial touchdown

The intervention group was analyzed using a one-way repeated measures analysis of variance. The means, standard deviations and p values of the nine continuous variables measured at initial touchdown for the intervention group across their four filming sessions are reported in Table 4.7. Significance was determined using a value of $p \leq 0.025$ because multiple independent tests were performed, however none of the nine variables were found to be significantly different across filming sessions.

Table 4.7: Means, standard deviations and p values of the variables measured at initial touchdown for the intervention group across time.

	Time 1	Time 2	Time 3	Time 4		
Variable	**N=10**	**N=10**	**N=10**	**N=10**		
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**f value**	**p value**
Right ankle plantarflexion at initial touchdown (degrees)	-39.64 (11.42)	-39.53 (14.43)	-39.09 (10.09)	-30.32 (16.37)	1.29	0.298
Left ankle plantarflexion at initial touchdown (degrees)	-46.29 (4.39)	-42.22 (6.15)	-40.85 (9.84)	-40.82 (12.37)	2.12	0.121
Right knee flexion at initial touchdown (degrees)	20.38 (10.56)	25.61 (6.83)	20.71 (6.69)	28.55 (12.08)	2.03	0.134
Left knee flexion at initial touchdown (degrees)	15.98 (6.34)	21.92 (6.04)	22.87 (8.49)	24.89 (10.99)	2.97	0.050
Right knee valgus at initial touchdown (degrees)	-0.39 (1.29)	-0.36 (3.37)	-0.57 (2.59)	-0.93 (2.46)	0.11	0.953
Left knee valgus at initial touchdown (degrees)	0.07 (2.34)	1.09 (2.30)	3.06 (5.56)	0.69 (2.27)	1.62	0.208
Right hip flexion at initial touchdown (degrees)	19.88 (9.15)	24.80 (13.57)	23.85 (8.48)	30.99 (14.21)	1.87	0.159
Left hip flexion at initial touchdown (degrees)	18.17 (8.73)	23.31 (11.90)	25.38 (8.23)	24.74 (16.75)	0.99	0.410
Trunk flexion at initial touchdown (degrees)	-4.50 (6.50)	-1.17 (8.60)	0.88 (6.66)	3.78 (8.91)	2.68	0.067

Three categorical variables were measured at initial touchdown of the jump landing for the intervention group. None of the variables were found to be significantly different. However, the frequency of landing on one foot versus two feet (see Figure 4.4) showed a trend towards a change over time in the intervention group. It appeared that subjects were more likely to land on two feet at time one and three as compared to time two or time four. The summary of the results for the measured categorical variables in the intervention group across time can be found in Tables 4.8, 4.9 and 4.10.

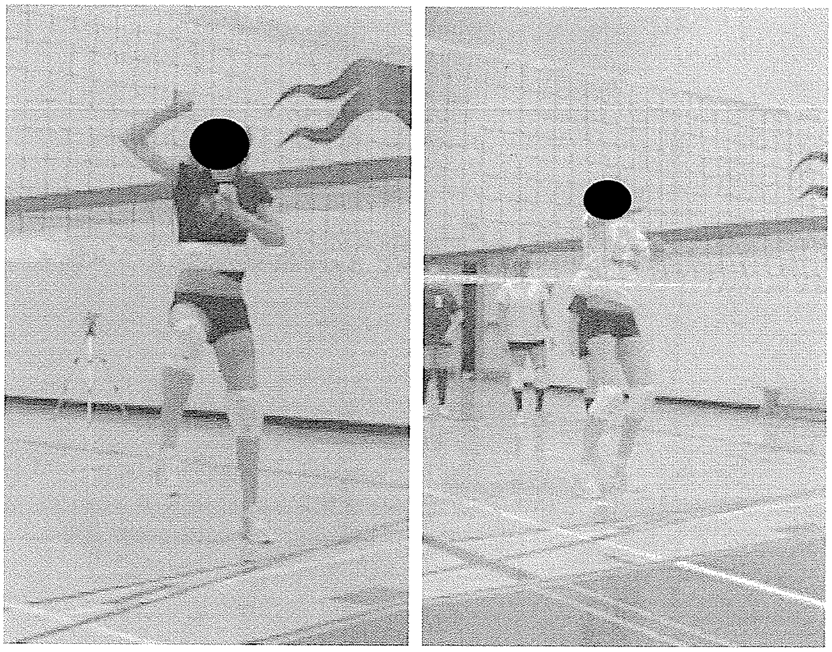


Figure 4.4: A comparison of one foot versus two foot landings. The two foot landing is preferred due to lower force per foot.

Table 4.8: Number of times the intervention group athletes landed on two feet at each filming session (N.S.).

Time 1	Time 2	Time 3	Time 4
20	14	24	14

Table 4.9: Number of times the intervention group athletes landed toe first on the right foot at each filming session (N.S.).

Time 1	Time 2	Time 3	Time 4
25	27	28	27

Table 4.10: Number of times the intervention group athletes landed toe first on the left foot at each filming session (N.S.).

Time 1	Time 2	Time 3	Time 4
30	30	30	29

Position of maximum flexion

Twelve continuous variables were measured in the intervention group across all four filming sessions at the position of maximum flexion of the jump landing. The variables were statistically analyzed using a one-way repeated measures analysis of variance. A p value of ≤ 0.025 was used to identify statistically significant differences between times. If a variable showed significance at the $p \leq 0.025$ value, a Newman-Keul's multiple comparison post hoc test was completed to determine where exactly between times the differences occurred. Three of the twelve variables were found to be significantly different across time in the position of maximum flexion. These included right knee flexion, right ankle dorsiflexion and left ankle dorsiflexion. It was found that generally, flexion angles at these joints increased after verbal and video intervention. Right knee flexion range of motion showed a marked increase at time two, three and four over time one (Table 4.11).

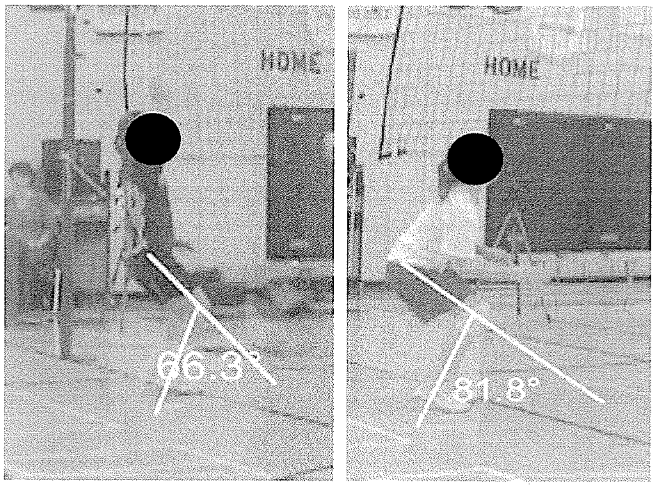


Figure 4.5: Comparison of right knee flexion at position of maximum flexion between time one (left) and time four (right).

Right ankle dorsiflexion increased from time one to time two, but then decreased from time two to time three (Figure 4.6). Left ankle dorsiflexion range of motion was largest at time two compared with time one, time three and time four (Figure 4.7). Table 4.11 presents a summary of the means, standard deviations and p values of the continuous variables measured in the intervention group at the position of maximum flexion across four filming sessions.

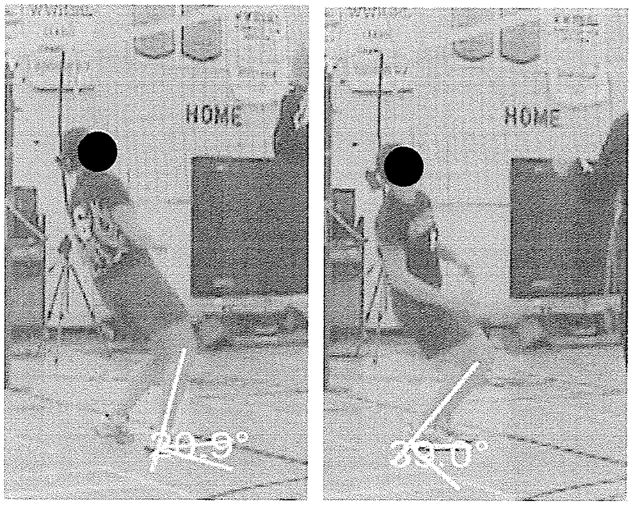


Figure 4.6: Comparison of right ankle dorsiflexion at position of maximum flexion between time one (left) and time two (right).

Table 4.11: Means, standard deviations and p values of the variables measured at the position of maximum flexion for the intervention group across time (* † ‡ - variable means with the same symbol are significantly different at the p ≤ 0.025 level).

	Time 1	**Time 2**	**Time 3**	**Time 4**		
Variable	**N=10**	**N=10**	**N=10**	**N=10**		
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**f value**	**p value**
Right ankle dorsiflexion at max flexion (degrees)	13.03* (7.46)	20.84*† (8.39)	12.64† (6.48)	17.27 (6.91)	3.78	**0.022*†**
Left ankle dorsiflexion at max flexion (degrees)	14.36* (7.83)	24.18*†‡ (6.96)	13.51† (10.87)	15.34‡ (9.25)	3.51	**0.02*†‡**
Right knee flexion at max flexion (degrees)	66.60*†‡ (7.15)	84.91* (12.00)	85.48† (19.78)	85.26‡ (23.18)	5.38	**0.005*†‡**
Left knee flexion at max flexion (degrees)	71.89 (10.29)	89.03 (12.95)	86.71 (19.54)	86.39 (24.28)	3.25	0.035
Right knee max valgus (degrees)	-4.39 (6.00)	-4.97 (10.20)	-3.94 (11.96)	-6.85 (8.55)	0.22	0.88
Left knee max valgus (degrees)	1.99 (7.30)	3.86 (8.59)	9.54 (13.30)	5.82 (9.66)	1.25	0.31
Right hip flexion at max flexion (degrees)	42.23 (12.10)	63.39 (25.99)	65.29 (28.31)	69.60 (30.06)	3.39	0.032
Left hip flexion at max flexion (degrees)	44.10 (12.44)	65.63 (25.02)	63.26 (27.75)	59.35 (18.78)	2.09	0.13
Trunk flexion at max flexion (degrees)	-1.21 (7.46)	8.93 (15.43)	11.42 (12.44)	14.35 (14.04)	3.08	0.044
Stance phase time (seconds)	0.17 (0.03)	0.23 (0.07)	0.21 (0.07)	0.22 (0.08)	2.43	0.09
Anterior/posterior stance (metres)	0.10 (0.10)	0.09 (0.06)	0.10 (0.05)	0.08 (0.03)	0.34	0.80
Medial/lateral stance (metres)	0.25 (0.06)	0.27 (0.09)	0.24 (0.12)	0.32 (0.09)	1.5	0.24

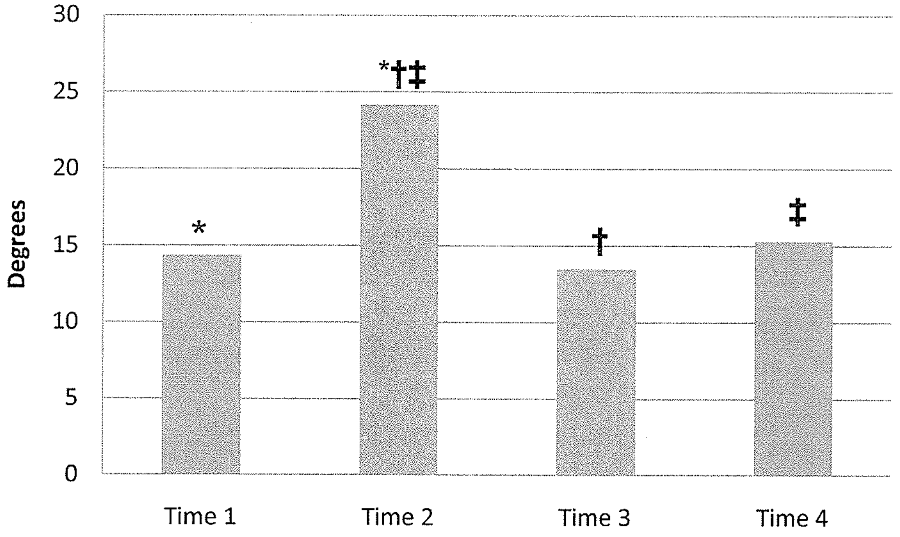


Figure 4.7: Comparison of left ankle dorsiflexion at the position of maximum flexion in the intervention group across time (*, †, ‡ symbolize variable means that are significantly different at the $p \leq 0.025$ level).

Variables compared across groups

Initial touchdown

Nine continuous variables measured at the moment of initial touchdown of the jump landing were compared across groups using a two-way repeated measures analysis of variance (Table 4.12). The statistical outcome of interest was the presence of an interaction between group and time, indicating that the groups actually differed from one another. If an interaction was found, a Newman-Keul's multiple comparison post hoc test was undertaken to determine where the differences occurred. The control and intervention groups were compared between time one, the initial filming session, and time two, the final filming session at the end of the four week study period. For the control group, time two was actually the second time they were filmed performing spike jump landings. For the intervention group, time two, as will be described during the two-way ANOVA results, was actually their fourth time being filmed. These two times are meant to represent the "before" and "after" scenarios which will help to determine whether verbal and video intervention was effective in changing the landing biomechanics of the intervention group. Trunk flexion at initial touchdown (Figure 4.8) showed an interaction of main effects, with a p value of 0.016. Using a Newman-Keul's post hoc test, it was determined that the intervention group and control group were significantly different at time two, but not at time one (Figure 4.9). The control group at time two demonstrated an average of 8.27 degrees of trunk *extension*, whereas the intervention group at time two demonstrated an average of 3.78 degrees of trunk *flexion.* Table 4.12 summarizes the means, standard deviations and p values of the nine continuous variables measured at initial touchdown.

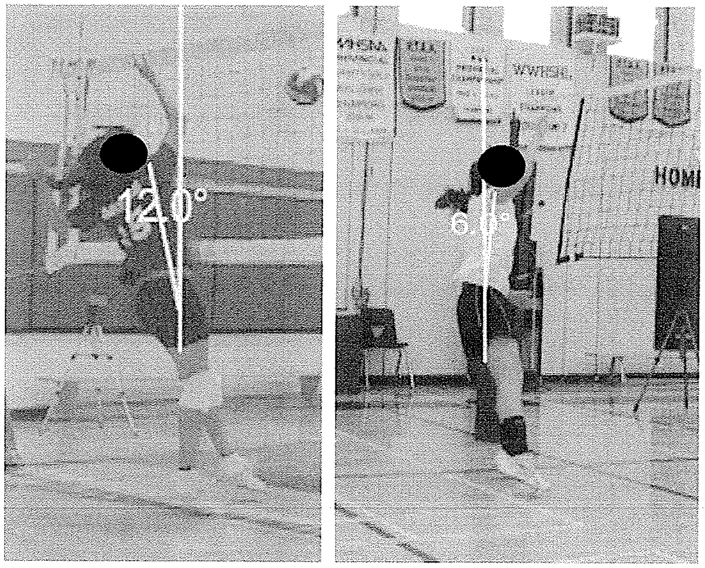


Figure 4.8: Comparison of trunk position at the position of initial touchdown between the control group at time two (left) and the intervention group at time two (right).

Table 4.12: Means, standard deviations and p values of the variables measured at initial touchdown for both groups at Time 1 and Time 2 (* p ≤ 0.025) (Int.= Intervention).

	Control Group Time 1	Control Group Time 2	Int. Group Time 1	Int. Group Time 2	f value	p value
	N = 9	N = 9	N = 10	N = 10		
Variable	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**		
Right ankle plantarflexion at initial touchdown (degrees)	-26.87 (17.88)	-35.35 (14.91)	-39.64 (11.42)	-30.32 (16.37)	3.49	0.08
Left ankle plantarflexion at initial touchdown (degrees)	-38.58 (5.05)	-34.34 (4.70)	-46.29 (4.39)	-40.82 (12.37)	0.10	0.75
Right knee flexion at initial touchdown (degrees)	21.66 (7.31)	17.23 (7.71)	20.38 (10.56)	28.55 (12.08)	4.31	0.054
Left knee flexion at initial touchdown (degrees)	24.14 (9.40)	22.33 (12.73)	15.98 (6.34)	24.89 (10.99)	2.99	0.101
Right knee valgus at initial touchdown (degrees)	-3.68 (4.52)	-2.20 (3.20)	-0.39 (1.29)	-0.93 (2.46)	0.93	0.35
Left knee valgus at initial touchdown (degrees)	2.46 (5.53)	1.80 (2.29)	0.07 (2.34)	0.69 (2.27)	0.36	0.557
Right hip flexion at initial touchdown (degrees)	16.74 (17.32)	9.96 (9.39)	19.88 (9.15)	30.99 (14.21)	4.86	0.042
Left hip flexion at initial touchdown (degrees)	20.56 (9.99)	14.20 (6.56)	18.17 (8.73)	24.74 (16.75)	2.68	0.12
Trunk flexion at initial touchdown (degrees)	-2.86 (8.20)	-8.27* (3.76)	-4.50 (6.50)	3.78* (8.91)	7.18	**0.016***

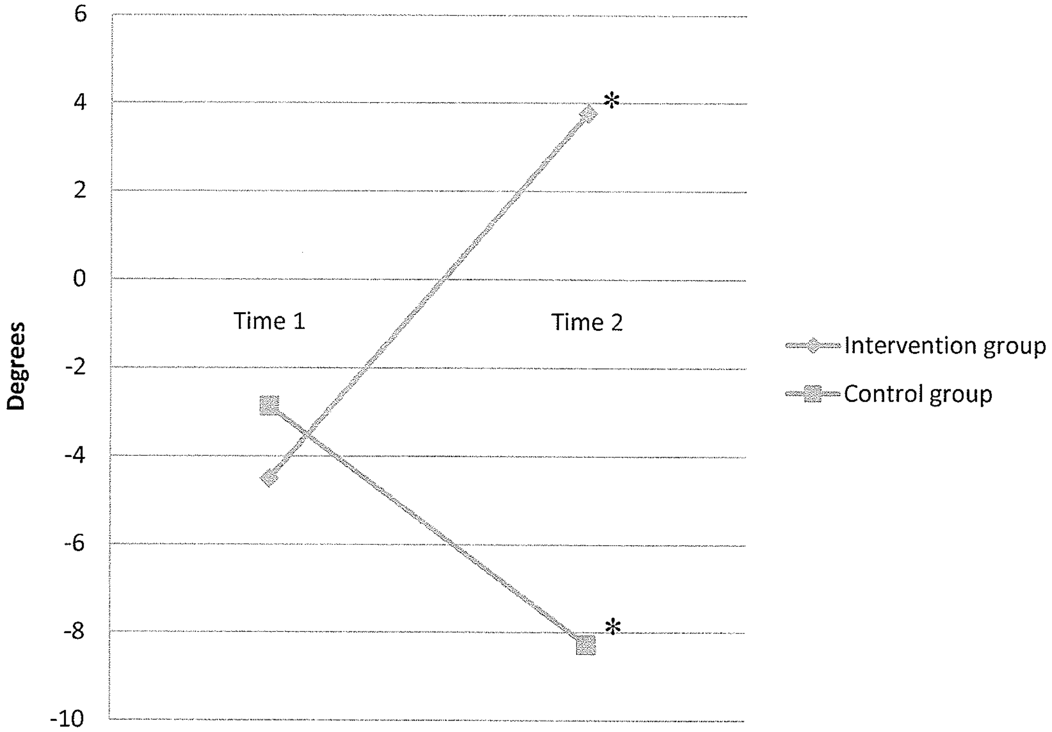


Figure 4.9: The interaction between group and time for trunk flexion at initial touchdown (* p ≤ 0.025).

Three categorical variables were measured at the moment of initial touchdown across groups and across time. Landing on two feet versus one foot, and landing on heels versus toes for both the right and left feet were measured and analyzed using a Mann-Whitney *U* test. This analysis showed that there were no significant differences between the intervention and control groups at time one or time two.

Position of maximum flexion

Twelve continuous variables were measured at the position of maximum flexion of the jump landing and compared across groups using a two-way repeated measures analysis of variance. Trunk flexion at maximum flexion (see

Figure 4.10) produced an interaction, with a p value of 0.016. A Newman-Keul's post hoc test was conducted and indicated that trunk flexion at time two in the control group was significantly different than trunk flexion at time two in the intervention group. Table 4.13 summarizes the means, standard deviations and p values of the variables measured at the position of maximum flexion across groups and across time.

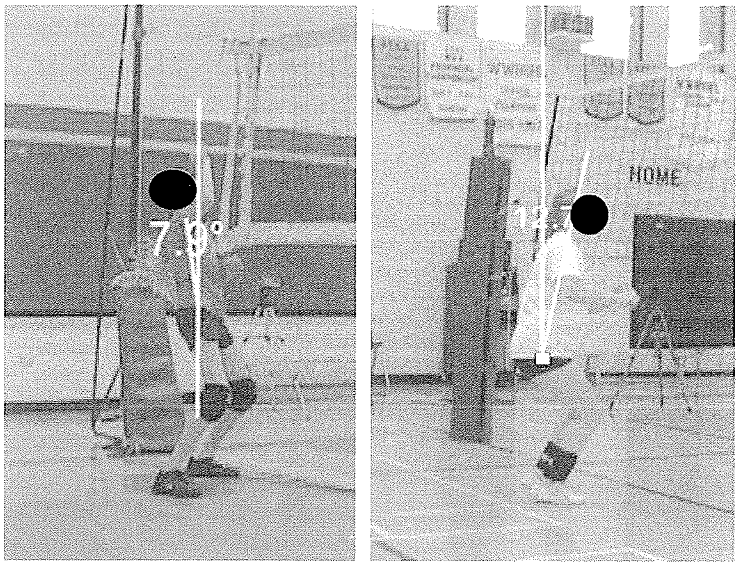


Figure 4.10: Comparison of trunk position in the control group at time two (left) and in the intervention group at time two (right).

Table 4.13: Means, standard deviations and p values of the variables measured at the position of maximum flexion for both groups at Time 1 and Time 2 (*p ≤ 0.025) (Int. = Intervention).

	Control Group Time 1	**Control Group Time 2**	**Int. Group Time 1**	**Int. Group Time 2**		
	N = 9	**N = 9**	**N = 10**	**N = 10**		
Variable	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**f value**	**p value**
Right ankle dorsiflexion at maximum flexion (degrees)	13.09 (13.45)	15.65 (9.42)	13.03 (7.46)	17.27 (6.91)	0.09	0.77
Left ankle dorsiflexion at maximum flexion (degrees)	17.44 (7.46)	21.06 (5.68)	14.36 (7.83)	15.34 (9.25)	0.34	0.57
Right knee flexion at maximum flexion (degrees)	62.65 (15.99)	60.46 (8.27)	66.6 (7.15)	85.26 (23.18)	4.98	0.04
Left knee flexion at maximum flexion (degrees)	65.63 (14.67)	66.15 (12.3)	71.89 (10.29)	86.39 (24.28)	1.75	0.2
Right knee max valgus (degrees)	-8.71 (9.03)	-11.94 (9.28)	-4.39 (6.0)	-6.85 (8.55)	0.01	0.91
Left knee max valgus (degrees)	3.6 (6.91)	11.84 (8.27)	1.99 (7.3)	5.82 (9.66)	0.7	0.41
Right hip flexion at maximum flexion (degrees)	42.13 (29.27)	38.41 (14.34)	42.23 (12.1)	69.6 (30.06)	4.49	0.05
Left hip flexion at maximum flexion (degrees)	45.39 (26.62)	35.75 (11.06)	44.1 (12.44)	68.63 (34.47)	4.64	0.046
Trunk flexion at maximum flexion (degrees)	6.65 (16.24)	0.53* (8.51)	-1.21 (7.46)	14.35* (14.04)	7.23	**0.016***
Stance phase time (seconds)	0.2 (0.08)	0.18 (0.04)	0.17 (0.03)	0.22 (0.08)	5.67	0.029
Anterior/posterior stance (metres)	0.26 (0.02)	0.14 (0.07)	0.1 (0.01)	0.08 (0.03)	2.57	0.13
Medial/lateral stance (metres)	0.34 (0.12)	0.34 (0.13)	0.25 (0.06)	0.32 (0.09)	4.22	0.057

In order to better appreciate the interaction relationships between groups and times, the variable found to have an interaction during the two-way analysis of variance is illustrated in Figure 4.11.

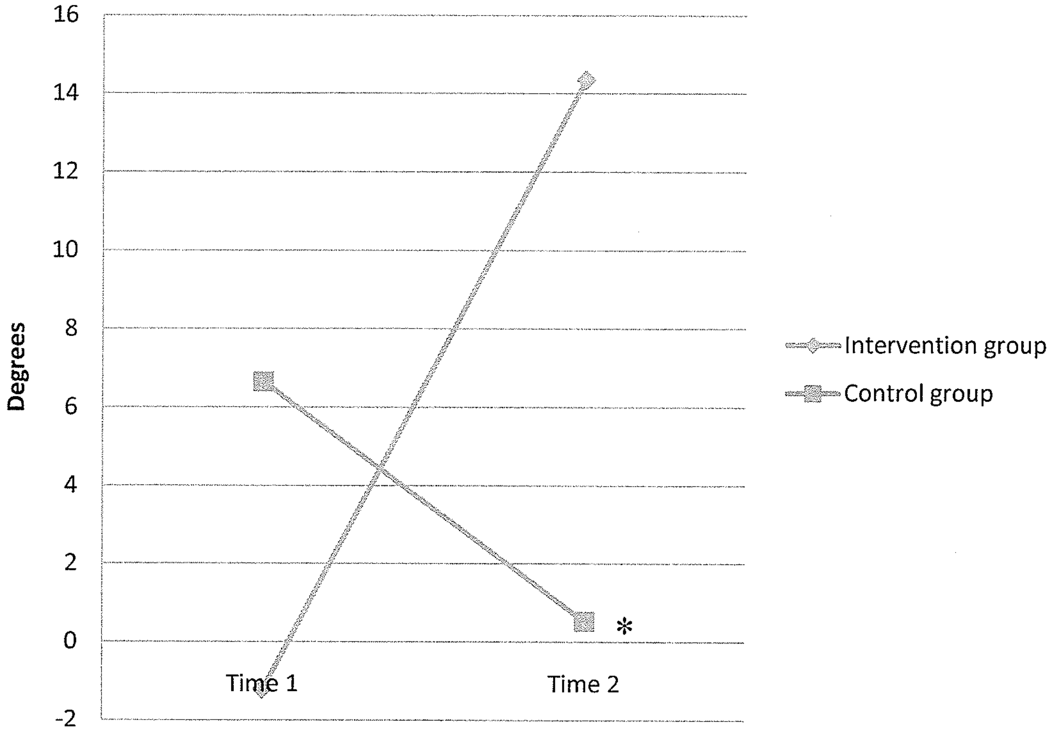


Figure 4.11: The interaction between group and time for trunk flexion at the position of maximum flexion (* $p \leq 0.025$).

A number of significant differences were found between groups and between times in the present study. They are summarized in the next section.

SUMMARY OF STATISTICALLY SIGNIFICANT FINDINGS

Within the control group, between initial filming and final filming sessions

Initial touchdown

1. Right knee flexion angle at initial touchdown decreased from 22 degrees to 17 degrees.

Position of maximum flexion

1. Left knee varus increased from 3.6 degrees to 11.84 degrees.

Within the intervention group, between all four filming sessions

Position of maximum flexion

1. Right knee flexion increased from 67 degrees to 85 degrees between time one and time two, three and four.
2. Right ankle dorsiflexion increased from 13 to 21 degrees between time one and two, but then decreased from 21 to 13 between time two and three.
3. Left ankle dorsiflexion first increased from 14 to 24 degrees between time one two, but then decreased from 24 degrees to 14 degrees at time three and to 15 degrees at time four.

Between groups and between initial and final filming sessions

Initial touchdown

1. Trunk flexion (4 degrees of flexion) in the intervention group at the final filming session was greater than that of the control group (8 degrees extension) at the final filming session.

Position of maximum flexion

1. Trunk flexion in the control group at time two was 0.53 degrees, while in the intervention group at time two it was 14.35 degrees.

CHAPTER V
Discussion
INTRODUCTION

One purpose of this study was to examine whether jump landing mechanics could be altered in adolescent female volleyball players using video and verbal feedback. It was important to identify whether the use of these types of feedback was effective in altering landing biomechanics in order to help coaches and other professionals who are involved with the development of these young athletes. It is common knowledge that ACL injuries are a real risk in adolescent female volleyball players. It was a goal of this study to give coaches an effective, relatively simple method of helping their athletes avoid ACL injury.

An intervention group was filmed on four occasions; once before the feedback session as well as three subsequent times. A control group was filmed on two occasions, at the beginning and at the end of the four week study period. The control group was included to help determine if just participating in a volleyball season improved jump landing biomechanics or whether intervention was required to cause that change.

The jump landing was divided into two key positions for analysis, which included the moment of initial touchdown as well as the position of maximum flexion. Variables measured during these two time periods within the jump landing skill have been extensively investigated by other researchers and have been found to differ between males and females (Huston et al., 2001; Kernozek et al., 2005; Schmitz et al., 2007). Because males experience far fewer ACL injuries than females (Hewett et al., 2005), these biomechanical differences during jump landings are of interest to the sport community. A few of the variables measured have been directly linked to an increased risk of ACL injury (Hewett et al., 2005). These included knee valgus angles at both initial touchdown and the position of maximum flexion as well as maximum knee flexion angle.

Additional variables, such as duration of stance phase and stance width and length were also analyzed using Dartfish video analysis software.

After the variables were measured, statistical analyses were performed to identify any significant differences between groups and between times. The control group was compared between the initial filming session and the final filming session to determine if landing biomechanics changed solely due to participation in four weeks of competitive volleyball. The intervention group was compared between all four filming sessions to determine if the feedback intervention was effective in eliciting a change in jump landing biomechanics. The control and intervention groups were then compared between the initial filming session and the final filming session. This helped to determine if the feedback was an added benefit to the intervention group in addition to just competing in a volleyball season.

CONTROL GROUP ACROSS TIME

Initial touchdown

Of the nine continuous variables measured at the moment of initial touchdown in the control group, only one was found to be significantly different between time one and time two. This indicates that without an intervention which emphasized proper jump landing biomechanics, the control group did not improve just by simply practicing and playing volleyball over the four weeks of the study period. Magill (2001) defines learning as "a change in the capability of a person to perform a skill....as a result of practice or experience." None of the athletes in the present study had ever been exposed to jump landing training either from coaches or by physical educators. They did not have exposure to proper jump landing technique in order to gain practice or experience in the skill, therefore it follows that they did not demonstrate a change in their capability to perform the skill.

The one variable that differed between time one and time two in the control group was right knee flexion. The amount of knee flexion at the instant of initial touchdown decreased from 22 degrees at time one to 17 degrees at time two. This is a negative change in landing biomechanics in terms of ACL injury prevention. A straighter knee at landing is deleterious for a number of reasons. First, landing with decreased knee flexion decreases the amount of torque that the hamstrings are able to produce because of a shorter moment arm in that position (Figure 5.1a and 5.1b). Decreased torque production in the hamstrings could therefore result in an increased anterior shear force of the tibia on the femur, thus stressing the ACL (Silvers & Mandelbaum, 2007).

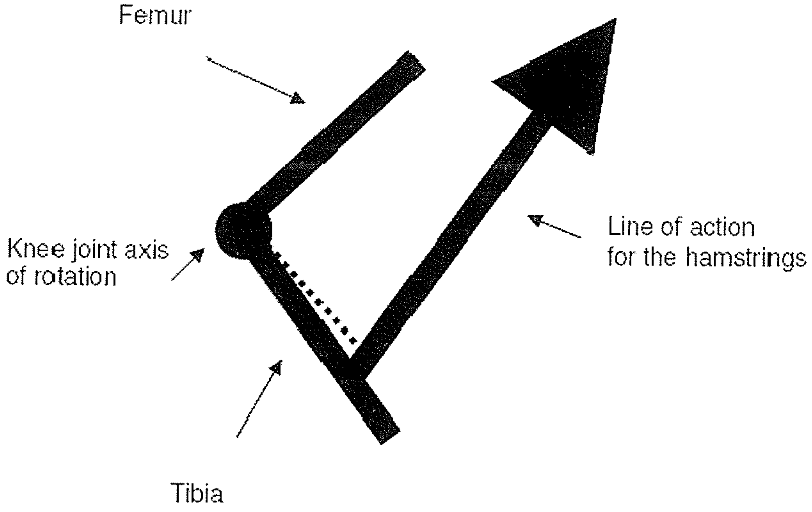


Figure 5.1a: Sagittal close-up view of the moment arm for the hamstrings in a flexed knee position (dashed line between the axis of rotation and the line of action for the hamstrings).

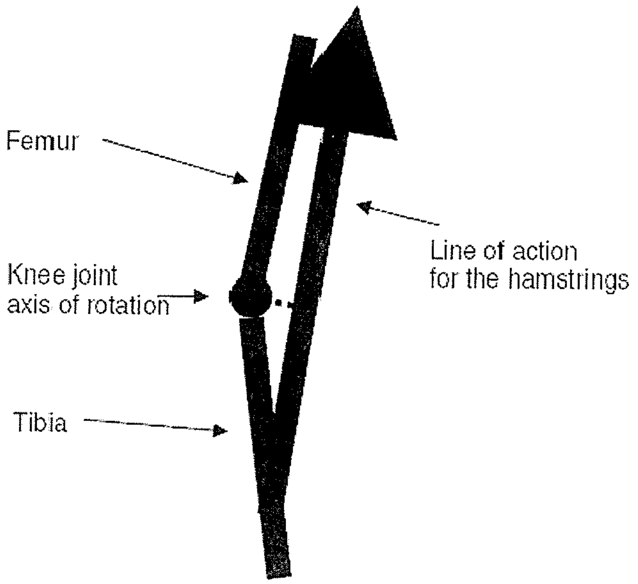


Figure 5.1b: Sagittal close-up view of the moment arm for the hamstrings in a more extended position. The moment arm is decreased in this situation (dashed line between axis of rotation and line of action for the hamstrings).

It has been found that in females, the hamstrings are not recruited as strongly compared to males during some athletic tasks. Malinzak and colleagues (2001) recruited 11 male and 9 female recreational athletes from a university campus. The athletes completed running, side-cutting and cross-cutting tasks while EMG information was recorded from the quadricep and hamstring muscle groups. The female athletes consistently demonstrated increased quadriceps activity and decreased hamstring activity compared to the male subjects. If females have the drawback of decreased hamstring recruitment to begin with, it is in their best interest to increase knee flexion during athletic tasks in order to take full advantage of a long moment arm. The longer the moment arm for the hamstrings, the larger the potential for torque production.

Secondly, when the knee is in a relatively extended position, the ACL is taut. When the knee is flexed, the ligament is on slack (Moore et al., 2010). With the ACL already strained in an extended position, the addition of another force could be enough to exceed the capacity of the ligament. In a small study of 20 university athletes, McLean, Su and Van Den Bogert (2004) used mathematical modeling to determine the forces involved with completing a side-step maneuver. They found that sagittal plane forces only were not sufficient to rupture the ACL. Only with valgus loading did the ACL reach the breaking point of 2000 Newtons. In another recent study (Withrow et al., 2006), cadaveric knees were loaded to simulate a jump landing with and without a valgus torque. The results showed that a position of knee valgus increased the strain rate within the ACL, bringing it closer to its rupture point (Withrow et al., 2006). The findings of these two studies suggest that the addition of coronal plane forces to a knee in a position of extension can be injurious to the ACL.

Thirdly, a study by Huston and colleagues (2001) found that for every degree decrease in knee flexion when landing, the vertical ground reaction forces increased by about one percent. Relating that study to increased injury risk, a study by Hewett and colleagues (2005) found that athletes who suffered an ACL tear had demonstrated vertical ground reaction forces that were 20% higher than those athletes who were injury free during testing of a drop landing task previous to sustaining the injury.

The knee flexion at initial touchdown in the control group was similar to values found by other researchers in athletes with no history of jump landing training. The athletes in a study by Decker and colleagues (2003) demonstrated 22.8 degrees of knee flexion at initial touchdown. In a study by Onate and colleagues (2005) the athletes demonstrated 21.5 degrees of knee flexion prior to verbal and video feedback.

None of the three categorical variables measured at the instant of initial touchdown in the control group were significantly different across time. About a third of the athletes landed on one foot instead of two during the two filming sessions. Although the number of feet contacted at landing was not found to be significantly different over time, it suggests the fact that these athletes, and perhaps this population as a whole, demonstrate less than ideal biomechanics when landing. All the force of the landing must be absorbed through one limb with a one foot landing, increasing the demand on that limb's muscles, joints and ligaments. With a two foot landing, the force of the landing would be dispersed between the two limbs, drastically decreasing the load compared to the one-foot landing.

Position of maximum flexion

Of the twelve continuous variables measured at this point during the jump landing skill, only one proved to be significantly different between time one and time two. The frontal plane position of the left knee increased from 3.6 degrees of varus at time one to 11.8 of varus at time two. Values in the literature for maximal coronal plane position of the knee during a drop jump are varied, however most studies have been conducted on university aged athletes, therefore their relevance to the current study is questionable. Two studies found that female athletes display significant valgus angulation of their knees during landing. Chappell & Limpisvasti (2008) tested 30 female university athletes completing a drop jump and found that their peak knee angle in the frontal plane was 25 degrees of valgus. Similarly, Blackburn et al., (2008) tested 40 adult recreational athletes completing a drop jump. This group also demonstrated a valgus knee position with landing, at 15 degrees.

Two additional studies also found valgus knee angles with landing, however, to a lesser amount. Mizner et al. (2008), in a study of 37 university athletes, found a valgus angle of 7.1 degrees when the subjects landed from a drop jump. Of particular interest is a study conducted by Pollard et al. in 2006. These authors looked at the landing characteristics of 18 adolescent female competitive athletes. The young athletes landed with 1.6 degrees of knee valgus. The athletes were between the ages of 14 and 17 and therefore the results of this study are the most comparable to the current study.

Generally, in terms of ACL injury prevention, a varus knee position is desirable. It has been found by previous researchers that females, who have up to eight times the number of ACL injuries (Hewett et al., 2005), exhibit more knee valgus than males upon landing from a jump (Malinzak, Kirkendall & Yu, 2001). Therefore, it is recommended that females attempt to land in a varus knee position (Figure 5.2).

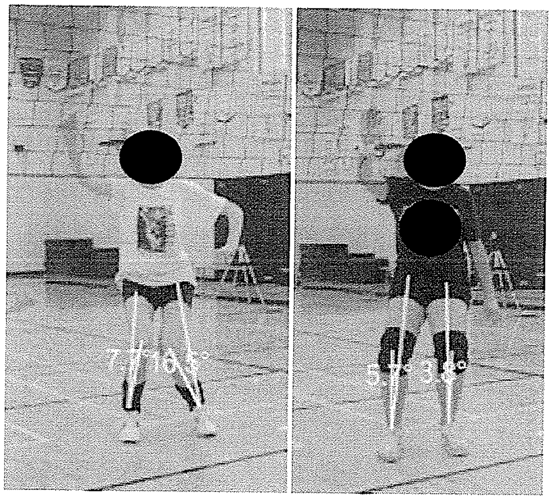


Figure 5.2: Unsafe bilateral knee valgus position (left); safe bilateral varus knee position (right).

The current investigator did not expect to find an increased varus knee position in the control group over time. Lacking any intervention on proper landing mechanics, it was unexpected that this group would adopt a safer landing strategy. However, the varus and valgus knee angle measurements in this study must be interpreted cautiously. Because the angle to be measured in most cases was quite small (<10 degrees), the position of the athlete upon landing needed to be perfectly square to the frontal view camera in order to get an accurate measurement. These athletes were young and relatively inexperienced and so lacked the coordination and motor control to land perfectly every time. This sometimes resulted in having to measure knee valgus or varus from video footage that was not perfectly aligned in the frontal plane.

The "real-life" situation of this study was another factor that contributed to measuring knee frontal plane position from less than ideal video. The athletes had to concentrate first on jumping up and hitting the volleyball and then think about where they were going to land. Even though they were given tape marks on the floor to take off from and land on, the athletes were unable to be consistent in their jump landings, leaving the researcher an imperfect frontal view from which to measure varus and valgus knee position.

Another possibility that could explain the increased varus knee angle in the control group was the presence of a pre-existing anatomical varus alignment. No pre-screening was done to measure the bony alignment of the athletes before they participated in the study. It has recently been found that a pre-existing varus alignment of the leg can cause a dynamic varus "thrust" during loading, in which the lateral joint line of the knee increases in width. Van de pol et al., (2009) discovered that with increased varus alignment, there was increased tension on the ACL. Without further study, it is difficult to confidently state the reason for the increased knee varus in the control group across time, and whether that change was positive or negative.

The control group in the current study landed with an average hip flexion of 35-45 degrees. Average hip flexion angles at the position of peak flexion found in previous studies include 40° (Blackburn &Padua, 2008), 52° (Mizner et al, 2008), 57° (Salci et al., 2004), and 85° (Chappell & Limpisvasti, 2008). However, all of the studies used university aged subjects. Because the subjects in the current study were significantly younger than any of the subjects in the previous studies, they would likely have less muscular strength. Attaining a lower, more flexed position when landing requires a great amount of strength. In a low, squat position, the quadriceps and gluteal muscles are in a lengthened position, and therefore are contracting eccentrically. In a lengthened position, there is less cross-bridging of the actin and myosin filaments possible in the muscle bellies, resulting in less force production (McArdle, Katch & Katch, 2000). However the stretch on the soft tissues stores strain energy which can serve to increase the force output to some extent. This difference in age, and therefore strength level, is a possible explanation for the lower values of peak hip flexion found in the current study as compared to previous studies.

INTERVENTION GROUP ACROSS TIME

Initial touchdown

In the literature, the average knee flexion values for women at initial touchdown were 6 degrees (Blackburn & Padua, 2008), 23° (Decker et al., 2003), and 30° (Chappell & Limpisvasti, 2008). Hip flexion values in the literature ranged from 14° (Blackburn & Padua, 2008) to 55° (Chappell & Limpisvasti, 2008). The intervention group in the current study demonstrated an average knee flexion angle of 16-28 degrees and an average hip flexion angle of 18-31 degrees, which fall into the range found in previous studies. However, ankle plantarflexion at initial touchdown was markedly increased in the current study

(40 degrees) compared to a previous finding of 21 degrees (Decker et al., 2003). None of the continuous variables measured at the moment of initial touchdown were shown to be significantly different over time in the intervention group. This may have been due to the large variability that the athletes displayed in their jump landing skill. This led to the calculation of an increased standard deviation and therefore an increase in the calculated p value. The large variability was directly related to their age and relative inexperience in playing volleyball. The subjects were also at the age of puberty, when quick growth spurts can negatively influence muscular coordination and therefore affect the performance of a skill (Baechle & Earle, 2000).

The relatively small number of subjects in this study may also have contributed to the lack of significant findings. In viewing the video footage, it seemed to the current investigator that many of the athletes in the intervention group appeared to change their landing biomechanics after the intervention session (Figure 5.3).

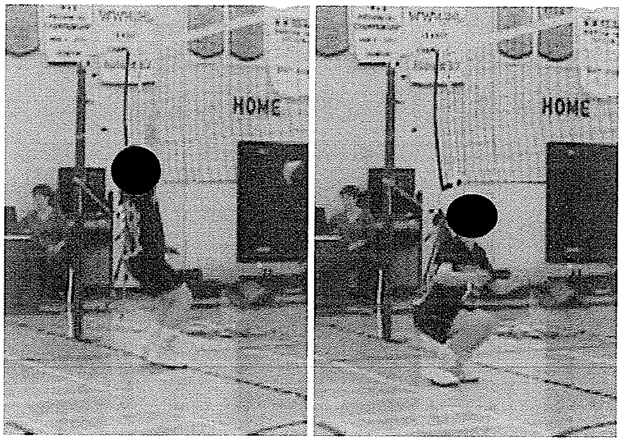


Figure 5.3: An athlete demonstrates a considerable change in jump landing mechanics pre (left) and post (right) video and verbal feedback.

Several variables measured at the instant of initial touchdown for the intervention group increased by as much as 10 degrees after the intervention, but this did not translate into statistically different findings when analysis was undertaken.

The same video and verbal intervention was given to all subjects in this study. Because not all individuals learn in exactly the same manner (Magill, 2001), this may have affected the results. When viewing the video footage, some subjects displayed much more improvement in technique than others. The subjects who did not appear to improve their jump landing technique perhaps had the potential to improve, but did not respond positively to the type of feedback they were given. Perhaps some subjects required written statements regarding good landing technique, or a step by step demonstration and trial of the technique in order to fully understand the new skill. Because not all the subjects responded to the intervention in the same way, the subjects who changed their technique significantly were "washed out" when statistical analyses were undertaken.

One categorical variable, landing on one foot versus two feet, demonstrated a tendency to differ over time in the intervention group. At time three, 24 of the trial landings were on two feet, and 6 were on one foot. This was quite different than the 14 landings on two feet and 16 landings on one foot at time two and time four. There was no significant change between time one and time two. It was expected that there would be an increase in the number of two-foot landings at time two, compared to time one.

It seems plausible that the most two footed landings would be expected immediately after the video and verbal feedback session, when the proper landing instructions were fresh in the mind of the athlete. However, it appears that the best performance by the athletes was at time three, which was two weeks after the initial feedback session. This may reflect the result of having two weeks to practice the proper jump landing biomechanics. The coach of the intervention group stated that he reviewed the jump landing technique with his athletes for a few days after the initial intervention, however, the education dropped off as the priorities of the team changed (T. Falconer, personal communication, April 21, 2009).

However, at the next filming session at the end of the four week study period, the positive effect was no longer present and the number of athletes landing on two feet had decreased. This may have been because the instructions and feedback the athletes received at week one had been forgotten over the four week period. As well, no additional education was given during practices between time three and time four, so the positive feedback ended. In hindsight, more time could have been spent by the investigator in teaching and reviewing the proper landing technique over the four week period, rather than requiring the coach to deliver the information. The coach was already busy with planning and implementing the practices and did not need the extra task of delivering feedback.

Position of maximum flexion

When viewing the video clips of the intervention group across time, it appeared that there was an improvement in technique after the intervention. In the right and left hip as well as the left knee, there was an increase of at least 20 degrees of flexion over time. As discussed previously, a more flexed position of the extremities is desirable in terms of ACL injury prevention, as it decreases the anterior shear force on the ACL and decreases vertical ground reaction forces. However, because of the small number of subjects involved in this study, the large variability of their performance, and the comparatively large number of variables measured, some of these apparent improvements did not prove to be significantly different over time.

Right knee flexion did significantly increase over all time periods. Initially, it was 66 degrees, and increased to 84, 85 and 85 degrees at time two, time three and time four respectively. Left and right ankle dorsiflexion both increased from time one (pre-intervention) to time two (immediately post-intervention). This reflects the lower overall body position attained after intervention. The athlete would have a difficult time achieving greater knee, hip and trunk flexion without a simultaneous increase in dorsiflexion. Right ankle dorsiflexion then dropped off significantly at time three, and left ankle dorsiflexion decreased significantly at both time three and time four. Again, this may have been due to the passage of time (Magill, 2001). The further in time from the initial intervention, the less of a sustained learning effect the athletes demonstrated.

However, at time three and four, knee, hip and trunk flexion were maintained in a more flexed state. It would make sense that a simultaneous increase in dorsiflexion would occur as well. The fact that dorsiflexion was significantly less at those time points suggests another cause for this movement.

The only way to land in a deeply flexed knee and hip position and not have a high degree of ankle dorsiflexion is to have excellent "squat" technique, similar to sitting back in a chair (Figure 5.4). This movement pattern is taught extensively in strength training exercises, to avoid the knees moving farther forward than the toes (Rippetoe &Kilgore, 2005).

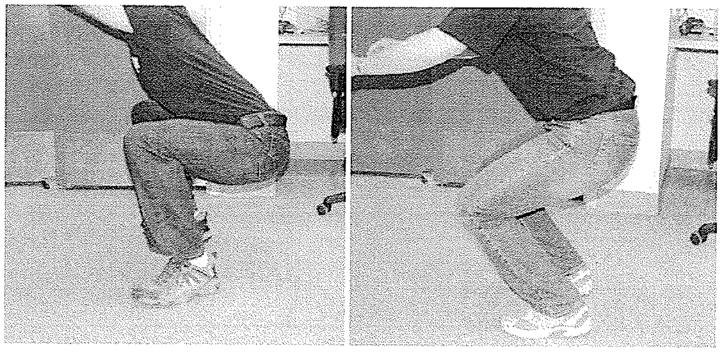


Figure 5.4: High degree of knee, hip and trunk flexion with minimal dorsiflexion in a good squat position (left); knees protruding farther forward than the toes in a poor squat position (right).

Keeping the knees directly over top or posterior to the toes is generally accepted as being a safe squat position (Nordin & Frankel, 2005). Figure 5.5 (right) shows a volleyball athlete in a superior squat position in time three, with less dorsiflexion. The decreased dorsiflexion has allowed her to keep her knees further back, over her toes. Her trunk, hip and knee flexion have all decreased from time two (Figure 5.5, centre). However, the joints still show improvement over time one (Figure 5.5, left). They are maintained within a range of motion similar to that demonstrated by male athletes of 67 degrees of hip flexion and 80 degrees of knee flexion (Salci et al., 2004). Since male athletes have a much decreased risk of ACL injuries, the position of this female athlete at time three would still be considered a "safe" landing position.

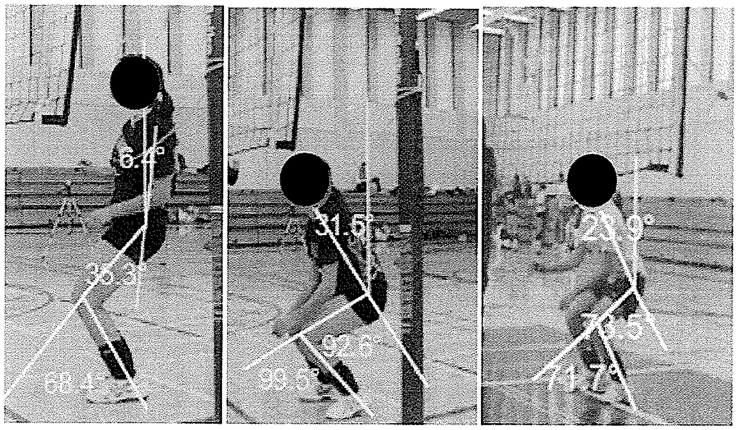


Figure 5.5: Squat landing position at time one (left), time two (centre) and time three (right). A superior position exists on the right, with less dorsiflexion but with safe landing mechanics maintained.

Considering this rationale, the fact that the athletes in the intervention group did not sustain their increased dorsiflexion angle at the position of maximum flexion over time is actually misleading. When initially considered, it would seem to be detrimental, however it could actually indicate an improved landing "squat" position.

VARIABLES COMPARED ACROSS GROUPS

Initial touchdown

The control group and intervention group did not differ significantly at time one, indicating that the groups were similar initially. This finding adds credibility to the comparisons between the two groups and helps address concerns with the design in which the subjects were not randomly placed in the control or intervention group. Of the nine continuous variables compared at initial touchdown, only trunk flexion was significantly different between groups at time two. Right and left hip flexion as well as right knee flexion showed a tendency to increase in the intervention group at time two compared to the control group at time two. Again, in viewing the video footage subjectively, there appeared to be a difference between the two groups, with the biomechanics of the intervention group seeming to improve after receiving verbal and video feedback. However, because of the high degree of variability within the subjects and the relatively low number of subjects, many of these differences were not isolated in the statistical analyses.

Position of maximum flexion

The same trend occurred at the position of maximum flexion. Only trunk flexion proved to be significantly different between the control group and intervention group at time two. Many of the other joint angle variables, including right and left knee flexion, and right and left hip flexion, were larger in the intervention group at time two, but did not result in a significant difference after statistical analyses were performed.

It is interesting that the only variable which proved to significantly change over time between groups was trunk flexion. This is a variable which has not been reported often in the literature, and there is conflicting opinion on whether more or less trunk flexion during jump landing is desirable. Ireland (1999) suggests that female athletes should maintain a normal lumbar lordosis to avoid the dangerous “position of no return” that can lead to ACL injury. However, maintaining a lumbar lordosis precludes using trunk flexion during the jump landing. It is the current investigator’s opinion that trunk flexion should be encouraged in order to cause increased flexion in the joints of the lower extremities, as found by Blackburn and Padua (2007). In that study, 40 physically active university aged subjects underwent drop jump testing from a height of 60 cm. Trunk, hip and knee kinematic variables were measured when the subject landed with their natural, “preferred” biomechanics. The task was then repeated and the subject was asked to actively flex the trunk as they landed. There was no instruction given regarding the positioning of the other lower extremity joints. The authors found that as a result of flexing the trunk, the knee and hip flexion of the subjects significantly increased. Increased knee and hip flexion are associated with a “safer” landing position, as discussed previously.

Increased trunk flexion helps to decrease the force required of the muscles to bring the body to a stop during a jump landing. By increasing the range of motion over which the landing force is absorbed, the time that the muscles have to stop the body’s downward motion is increased. This situation is described by the impulse-momentum relationship. Momentum is the quantity of motion that an object possesses. In the case of landing from a jump, the volleyball athlete possesses linear momentum as she falls from the height of her jump to the floor. The impulse-momentum relationship states that a change in momentum is produced by the application of an impulse. An impulse is equal to force times time. A change in momentum must occur in order to bring the body to a stop during the jump landing. The impulse-momentum relationship is represented by the following equation:

$Ft = \Delta M$

$Ft = mv_f - mv_i$

(M = momentum; m = mass; v_f = final velocity; v_i = initial velocity)

For example, a 45 kg athlete lands from a jump with an initial velocity of 2.45 m/s. Her final velocity is zero, as her downward motion is coming to a stop. If it takes 0.18 seconds to bring the body to a stop, the force required of the muscles would be:

$F\ (0.18) = 45\ (0) - 45\ (2.45)$

$F = 612.5$ Newtons

If the athlete uses more trunk flexion to prolong the duration of the landing, the force required of the muscles would be:

$F\ (0.25) = 45\ (0) - 45\ (2.45)$

$F = 441$ Newtons

Less force exerted by the muscles decreases the load on the body. In terms of ACL injury prevention, the decreased load on the quadriceps muscle is of most interest. When the quadriceps contract with less force, there is less anterior shear applied across the tibiofemoral joint which decreases the stress on the ACL.

A flexed trunk position can also decrease the quadriceps force during a jump landing because it decreases the moment arm for the weight of the body about the knee joint. In an erect position, the perpendicular distance between the axis of rotation and the line of force of the weight of the body is much greater than in a flexed forward position (Figure 5.6). By having a decreased moment arm, the torque created in a flexion direction about the knee is decreased. This requires decreased torque production by the quadriceps in the extension direction. As a result, there is decreased anterior shear force on the tibia and on the ACL.

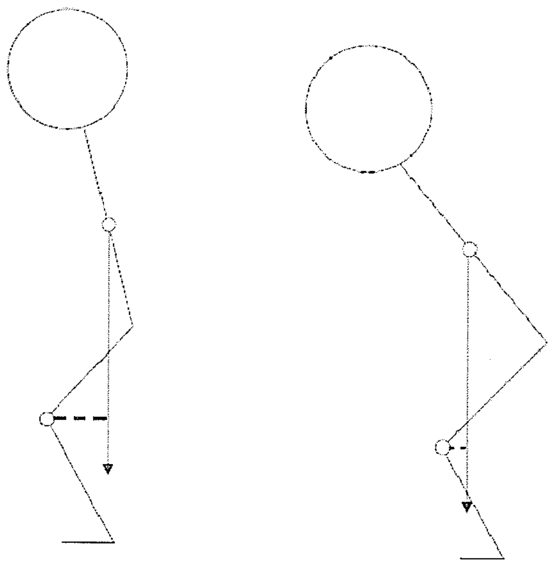


Figure 5.6: The effect of trunk position on the moment arm (dotted line) for the weight of the upper body (arrow). Erect landing position on the left, flexed landing position on the right.

Increased trunk flexion while landing from a jump can also help decrease the vertical ground reaction forces the athlete experiences, which has been linked to a decrease in ACL injury risk (Hewett et al., 2005). Flexing the trunk causes the centre of mass of the entire body to move in a downwards direction during the landing. The athlete who flexes her trunk more will displace her centre of mass a larger distance downwards. This will have a direct impact on the velocity and therefore the acceleration of the body's centre of mass as it comes to a stop. Linear downward acceleration is important in this situation because of the relationship of acceleration to force, as stated in Newton's First Law (Force = Mass x Acceleration). The vertical ground reaction force acting on the athlete landing from a jump is proportional to the mass and acceleration of the athlete. It can be calculated by determining the total magnitude of the forces present in the vertical (y) direction, and then subtracting the weight of the athlete. Because there are only two vertical forces acting on the system (body weight and vertical ground reaction force), this will result in the determination of the ground reaction force. A sample calculation is included below to illustrate the differences between an athlete who uses trunk flexion during landing and one who does not.

Minimal trunk flexion on landing	Increased trunk flexion on landing
$\Sigma F_y = m \times a_y$	$\Sigma F_y = m \times a_y$
$\Sigma F_y = m \times \frac{v_f - v_i}{\text{time}}$	$\Sigma F_y = m \times \frac{v_f - v_i}{\text{time}}$
$\Sigma F_y = 52\ \text{kg} \times \frac{(-0.2\ \text{m/s} - (-2.6\ \text{m/s}))}{0.15\ \text{s}}$	$\Sigma F_y = 52\ \text{kg} \times \frac{(-0.6\ \text{m/s} - (-2.2\ \text{m/s}))}{0.15\ \text{s}}$
$\Sigma F_y = 832\ \text{N}$	$\Sigma F_y = 554\ \text{N}$
$\Sigma F_y = R_y - W$	$\Sigma F_y = R_y - W$
$832\ \text{N} = R_y - (52 \times 9.81\ \text{m/s}^2)$	$554\ \text{N} = R_y - (52 \times 9.81\ \text{m/s}^2)$
$R_y = 1342\ \text{N}$	$R_y = 1064\ \text{N}$

Figure 5.7: Sample calculation of ground reaction forces (ΣF_y = sum of the forces in the vertical (y) direction; v_f = final velocity; v_i = initial velocity; R_y = vertical ground reaction forces; W = bodyweight).

The centre of gravity of the two athletes in the example moved through approximately the same displacement during the first 0.15 seconds of the jump landing. However, the athlete in the example on the left landed with a "stiffer" landing, with the downward movement arrested more quickly. Her CG initially moved through its displacement rapidly, resulting in a larger initial velocity compared to the other athlete. The CG of the athlete who used more trunk flexion continued to move through its displacement at a fairly uniform pace, resulting in a larger final velocity as compared to the other athlete. The athlete who used more trunk flexion continued to lower her CG even after the 0.15 second time frame was up, whereas the CG of the other athlete had already reached its lowest point. The result of these differences is that the athlete who used more trunk flexion experienced less vertical ground reaction force than the athlete who landed with a stiffer landing. The vertical ground reaction force experienced by the athlete who completed the stiff landing was 2.6 times bodyweight, whereas the vertical force experienced by the other athlete was 2.1 times bodyweight.

The erector spinae muscles situated on the dorsal aspect of the trunk can control trunk flexion eccentrically when landing from a jump. When landing with slight flexion, there is a flexion moment created about the lumbosacral junction. This is due to the force of gravity acting downward on the trunk. In order to control the descent of the trunk and resist the tendency of gravity to cause flexion, the erector spinae muscles must contract while lengthening. The athlete must possess excellent trunk strength and coordination to be able to allow this eccentric contraction.

Often in volleyball, the athlete lands vertically upright or in a position of trunk extension because of the nature of the game. In this case, she will have to concentrically contract her abdominals in order to achieve the benefits of trunk flexion. The trunk muscles that could help with flexion are the rectus abdominus and external oblique muscles. These are large, broad muscles spanning the anterior and lateral abdomen from the pelvis to the ribs. Because of their size and orientation, they have the potential to very forcefully flex the trunk upon landing from a jump (Figure 5.8).

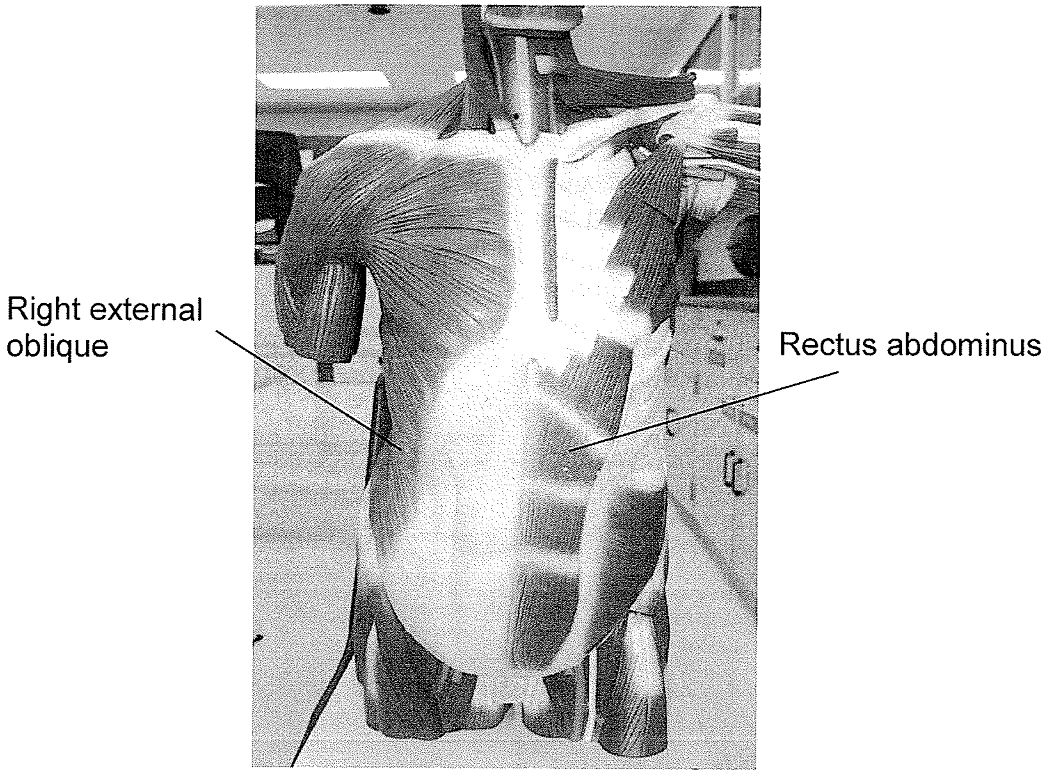


Figure 5.8: Frontal view of the abdomen, showing the orientation of the rectus abdominus and external oblique muscles.

The external oblique muscles must contract simultaneously to produce trunk flexion. If they contract independently of one another, they will produce ipsilateral side flexion and contralateral rotation.

All trunk muscles, in order to exert influence on body position, require the pelvis to be fixed and stable (Moore et al., 2010). This includes the muscles that can act to cause trunk flexion, or those that control the eccentric contraction of the erector spinae. This requires coordinated contraction of the stabilizing trunk and hip muscles to create a rigid platform of the pelvis. The transverse abdominus, internal oblique, multifidus and gluteal muscles are some of the more important muscles that have a strong stabilizing effect on the pelvis, and are often referred to as the "core" muscles (Rippetoe & Kilgore, 2005). Their vital role emphasizes the need for comprehensive core strengthening programs for all athletes who need to safely execute jump landing on a regular basis. Without a strong core, the athlete is not able to stabilize the pelvis, which decreases the benefit that may be gained from increasing the magnitude of trunk flexion when landing.

A strong core, including the gluteal muscles, is also vitally important for controlling the position the lower extremities assume upon landing from a jump. Dugan (2005) discussed the important role the proximal joints and muscles can play in determining whether the leg will enter the "position of no return". The gluteus medius and gluteus minimus muscles are the primary abductors of the hip joint (Moore et al., 2010) (Figure 5.9).

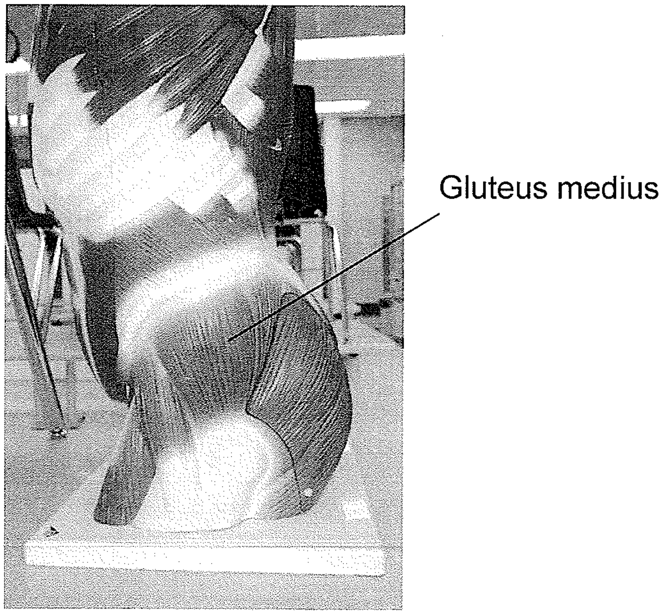


Figure 5.9: Lateral view of the primary abductor muscle of the hip.

Upon landing from a jump, if they are not sufficiently strong, the pelvis will sag downwards and the hip will adduct. This is easily identified using the Trendelenburg test (Figure 5.10) (Prentice, 2009). By asking the athlete to stand on one leg, it can be observed whether the contralateral hip drops downward, indicating a weak gluteus medius muscle on the stance leg.

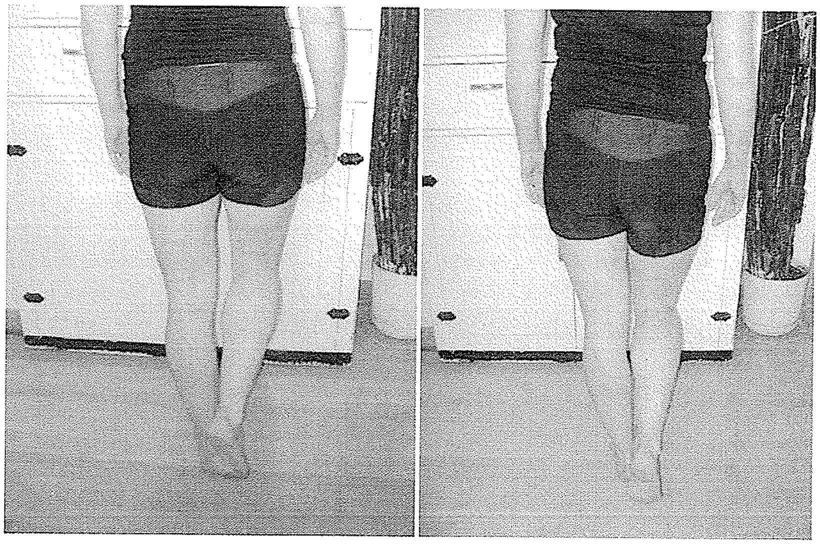


Figure 5.10: Negative Trendelenburg test (left); positive Trendelenburg test (right) indicating weak hip abductors on the left.

This test could easily be done on a routine basis at the beginning of the volleyball season to identify those individuals who may be at increased risk of ACL injury due to weak hip abductors. A preventative strengthening program could then be put in place to address the deficits.

The adducted position of the hip sets up the lower extremity to enter a dangerous position of an internally rotated, adducted hip and externally rotated, valgus knee (Figure 5.11).

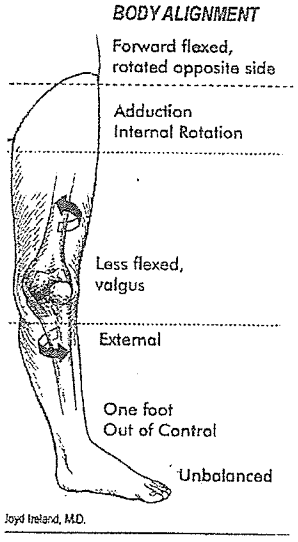


Figure 5.11: Anterior view of the position of no return (Reprinted with permission from Ireland, 1999).

The athletes in this study adopted a more forward flexed position of the trunk after an intervention session which did not refer directly to trunk flexion as a movement to modify (see Appendix E). This suggests that the athletes independently altered this body position to help them to attain the desirable movements reviewed during the intervention, which included increased knee and hip flexion, decreased knee valgus, and landing evenly on two feet. Blackburn and Padua (2007) found evidence to support the coupling of trunk and lower extremity movements in their study. When asked to purposefully attain more trunk flexion on landing, the knee and hip flexion of the athletes in the study increased at both the instant of initial touchdown and at the position of maximum flexion. This lower, more flexed position is a position that puts the ACL at less risk of injury and so should be encouraged in any athlete who is required to land from a jump during participation in their sport.

There have been many studies that have looked at the effects of neuromuscular training programs on jump landing biomechanics (Lephart et al., 2005; Myer et al., 2005; Myer et al., 2008) and in preventing ACL injury (Mandelbaum et al., 2005; Myklebust et al.; 2003 Petersen et al., 2005). All of these prevention programs included exercises to improve the function of the trunk and gluteal muscles. They used a variety of exercises, with some of the researchers focusing on a combination of strength and agility. Myer et al., (2005) included such exercises as squats, leg curls, and various jumping and bounding sequences. The emphasis was on landing softly and the exercises progressed from two leg to one leg jumps to increase the intensity. Mandelbaum et al., (2005) also used jump training, including lateral and forward hops, to improve agility. In addition, the athletes in their study did strength exercises such as walking lunges and toe raises. A further study reported by Lephart et al., (2005) included single and double leg forward hops and double leg backward hops.

Other studies focused on proprioception and balance (Myklebust et al., 2003; Petersen et al., 2005). The tasks in these studies involved balancing on a wobble board, maintaining balance on one leg while an external perturbation was applied, and balancing on a balance board while throwing and catching a ball.

In a recent study, Myer et al., (2008) proposed that a lack of trunk control as a result of a growth spurt at puberty may be the underlying cause of the detrimental lower extremity biomechanics seen in young female athletes. They outlined a neuromuscular training program that emphasized trunk and hip muscle development and control. They suggested that training the proximal joints and muscles could correct most of the poor biomechanics that are observed more distally, especially at the knee.

To ensure that the trunk flexion demonstrated by the athletes in the current study is actually effective in decreasing vertical ground reaction forces, the pelvis must be suitably stable and controlled by the core muscles. Without a strong stable platform, the external obliques cannot function correctly to produce forceful trunk flexion. The evidence from the current study suggests that the trunk plays a larger role than previously thought in improving jump landing biomechanics. Coaches, strength and conditioning specialists, and sport medicine professionals must consider this evidence and incorporate appropriate injury prevention methods whenever possible in order to bring ACL injury rates to an acceptable level.

CHAPTER VI
Summary, Conclusions & Recommendations

SUMMARY

The rate of ACL injury in females is much higher than in males. The reasons behind this disparity are many, and include anatomical, hormonal and biomechanical factors. The interrelationship between these factors is the subject of many studies, as research attempts to explain why females are at greater risk. The eventual goal is to put effective preventative measures into place so that females can avoid this devastating injury.

Increased hip and knee flexion and avoiding a knee valgus ("knock-kneed") position have been described as a "safe" landing position (Ireland, 1999). Young females tend to land from a jump in a more erect, extended position, with excessive knee valgus as compared to males. This is suggested to put them at increased risk of ACL injury. The purpose of the present study was to examine whether using verbal and video feedback could improve spike jump landing mechanics in adolescent female volleyball players. If proven effective, this would provide an efficient, inexpensive method of injury prevention that coaches could easily implement into their training sessions.

A control group was analyzed to fulfill the secondary purpose of the study. This was to determine whether participating in a competitive volleyball season was enough to improve jump landing technique, without the benefit of feedback.

Kinematic data was collected from a total of 19 subjects. The intervention group that received verbal and video feedback consisted of ten female volleyball athletes from a private school in Winnipeg, Manitoba. The other nine subjects that comprised the control group and did not receive intervention were from an alternate private school in the same city. All subjects were members of the Grade 8 volleyball team at their respective school.

The athletes were filmed using a four camera set-up while participating in regularly scheduled volleyball practices. The cameras captured the frontal and sagittal views of the athlete. The video was uploaded into Dartfish analysis software via a Toshiba laptop. The intervention group was filmed four times over a four week period, while the control group was only filmed twice.

Twenty-four variables were measured at various points during the spike jump landing skill. Nine continuous kinematic variables were measured at the point of initial touchdown. Three categorical variables were also measured at this point during the skill and included two foot versus one foot landing and toe versus heel landing. The same nine continuous variables were then measured at the position of maximum flexion. Three additional variables were also measured at this point in the skill and included the stance phase time, anterior/posterior stance width and medial/lateral stance width.

Each group was compared separately over time to determine whether there was any change in jump landing biomechanics with practice. In addition, the two groups were compared to each other at time one and time two to establish whether receiving verbal and video feedback was more effective in changing technique compared to participating in a volleyball season. The variables were statistically analyzed using t-tests, one-way and two-way repeated measures ANOVA tests, Wilcoxon signed rank sum tests, Friedman's tests and Mann Whitney U tests.

RESULTS

Using paired t-tests, only one variable was found to be significantly different between time one and time two within the control group. This indicated that their jump landing biomechanics remained relatively unchanged throughout the volleyball season. In the absence of any video or verbal feedback regarding their landing technique, the members of the group did not change the way they functioned. However, right knee flexion decreased by approximately 5 degrees between time one and time two. This suggested that the landing technique of the control group worsened slightly over the study period. For ACL injury prevention, increased knee flexion is encouraged and desirable (Hewett et al., 2005; Salci et al., 2004).

At the position of maximum flexion during the jump landing, one variable was found to be significantly different at time two as compared to time one. The frontal plane position of the left knee at time two increased by eight degrees of varus. This was an unexpected finding, as a varus angle of the knee is advantageous in terms of ACL injury prevention (Ireland, 1999; Kernozek et al., 2005). Since this group did not receive the benefits of verbal and video feedback on avoiding ACL injury mechanisms, it was not expected that they would actually improve their jump landing biomechanics. However, as noted in the discussion, there were a number of factors that may have contributed to an overestimation of the varus angle in the control group. Among them were camera placement and pre-existing anatomical varus angulation of the lower extremity.

None of the nine continuous variables measured at initial touchdown in the intervention group were found to be significantly different over the four filming sessions when a one-way repeated measures ANOVA statistical analysis was performed. Some of the flexion variables increased by as much as ten degrees but were not found to be significantly different when the adjusted p value of 0.025 was applied. When subjectively viewing the video, the intervention group appeared to improve their jump landing technique. But with the small number of subjects and relatively large variability, the variables were not found to be significantly different.

Three categorical variables were measured at this point during the jump landing skill, however none were found to be significantly different. The athletes appeared to land more frequently on two feet at time three than at time two or four, but this did not reach significance with $p \leq 0.025$.

Three of the continuous variables at the position of maximum flexion were found to be notably different over time in the intervention group. Right knee flexion increased by 20 degrees at time two, three and four over time one. This flexed position of the knee will help to decrease the strain on the ACL, and therefore the risk of injury to the structure. It is a beneficial alteration in landing biomechanics, brought about by the verbal and video feedback offered to this group at the beginning of the study period.

Right and left ankle dorsiflexion both increased at time two as compared to time one. Then, dorsiflexion of the right ankle decreased significantly between time two and time three. Left ankle dorsiflexion decreased significantly at both time three and time four. Generally, less dorsiflexion would suggest that the athlete did not achieve as low a position at time two or three. However, hip, knee and trunk flexion angles were relatively maintained in a flexed position at time two and three. This suggests that the athletes adopted an improved "squat" position upon landing, whereby they achieved a low, flexed position while keeping their knees behind their toes. This resulted in decreased dorsiflexion, but maintained knee, hip and trunk flexion at time two, three and four.

The intervention group and the control group differed significantly at time two in terms of the amount of trunk flexion present during the jump landing. The control group landed with an average of eight degrees of trunk extension, whereas the intervention group landed in four degrees of trunk flexion. Trunk flexion was not a variable that was specifically mentioned in the checklist that was read aloud to the athletes during their feedback session. They adopted the trunk flexion position in response to instruction to get lower during the jump landing. Trunk position is not often cited in the literature as a variable to adjust for the purpose of avoiding ACL injury. However, the trunk has the potential to make a large contribution to ACL injury prevention, as indicated in the discussion section of this paper. It makes up a large proportion of overall bodyweight and therefore cannot be ignored.

Again, the only variable that showed significance at this point in the skill in the present study was trunk flexion. The control group possessed less than one degree of trunk flexion at time two, compared to 14 degrees of flexion at time two in the intervention group. This increased trunk flexion should assist in decreasing ground reaction forces during the jump landing, which have been associated with an increased risk of ACL injury (Hewett et al., 2005). Having increased trunk flexion also decreases the force required by the quadriceps to land from a jump. Decreased force requirements results in a decreased anterior shear force across the knee. This helps to decrease the strain on the ACL and therefore the risk of injury to this structure.

Overall, the changes in jump landing biomechanics brought about by verbal and video feedback were positive in terms of ACL injury prevention. The video of the intervention group athletes suggested that they improved their landing technique during the four weeks of the study. Because of the small number of subjects and the large variability between subjects, many of the measured variables failed to show significance when statistically analyzed.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. Participating in a competitive season of volleyball as a member of a Grade 8 school team does not change jump landing biomechanics either in a positive or negative manner.
2. A one-time verbal and video feedback session seems to result in the visible improvement of some variables during the spike jump landings of adolescent female volleyball players over a four week time period.
3. Knee flexion increases as a result of video and verbal feedback instructing athletes to land in a more flexed position.
4. Ankle dorsiflexion changes as a result of video and verbal feedback instructing athletes to land in a more flexed position. Initially it increases as the

athlete attempts to attain a lower position upon landing. However, as the athlete becomes accustomed to executing a lower squat position when landing, dorsiflexion decreases and the hips and knees flex while staying posterior to the toes.

5. Although not significantly different over time, it appears that athletes who are focusing on landing with increased flexion of their lower extremities may achieve that goal at the expense of landing on two feet.
6. When instructed to land from a jump with increased flexion of the lower extremities, athletes appear to concurrently flex their trunk as well. This may be an indirect mechanism which helps them achieve increased knee and hip flexion. Conversely, this may be a positive result of the knee and hip flexion which further serves to decrease the forces on the ACL.

RECOMMENDATIONS

A number of recommendations are suggested for any future studies that investigate the effects of verbal and video feedback on jump landing biomechanics in female adolescent volleyball players.

1. Future studies should include more subjects in order to increase the power of the study.
2. Improved measurement techniques need to be developed to accurately and reliably measure knee motion in the coronal plane while using Dartfish analysis software. Employing additional cameras as well as the use of joint markers may be of benefit in future studies.

3. Placement of subjects into intervention and control groups could be randomized in future studies to decrease the effect of coaching on the results of the study.
4. More detailed monitoring of the amount of time dedicated by the coach to learning and practicing landing technique would give an indication as to the time commitment required to improve technique.
5. Future studies could include younger subjects to determine whether feedback intervention would be effective at an earlier age.
6. An overhead camera could be used in future studies to capture motion in the transverse plane. For example, internal rotation of the hip has been described as an unsafe landing position (Ireland, 1999).
7. Statistical analysis of each individual athlete over time may offer more information to coaches than comparing groups. Criteria for a meaningful change in performance could be set to determine the effectiveness of the intervention. For example, "if there is a within-subject change of 10% over time, in at least 80% of the subjects, the intervention will be considered successful". This information would allow coaches to determine which athletes respond to which types of feedback, and make modifications if necessary.

COACHING RECOMMENDATIONS

Because jump landing training is currently not extensively available in Manitoba, any mention of the topic by coaches to young athletes would be beneficial. Jump landing training has been proven in the literature to decrease the rate of ACL injuries in female athletes and should be employed much more frequently than it currently is. Every coach involved in sports that require jumping and landing skills can and should demonstrate proper landing technique to their athletes. Important points to include are the following:

1. Landing on two feet is preferential to landing on one foot.
2. Land with the knees, hips and trunk significantly flexed. Close to ninety degrees of hip and knee flexion is desirable.
3. Continue the jump landing into a deeply flexed position until the body comes to a stop. Do not end the landing early just to get out of the way of the next hitter or to retrieve the ball.
4. Land with a toe to heel motion of the feet.
5. Keep the knees in line over the toes. Do not let the knees sag inward into a valgus (knock-kneed) position.
6. Land softy, not stiffly. Try to absorb the force of the landing by flexing your joints on contact with the ground.

REFERENCES

Abercromby, A.F.J., Thaxton, S.S., Onady E.A., Rajulu, S.L. (2006). Reach envelope and field of vision quantification in Mark III space suit using Delaunay triangulation. Retrieved on August 21, 2008 from http://techreports.larc.nasa.gov/cgi-bin/NTRS.

Adrian, J.J., Laughlin, C.K. (1983). Magnitude of ground reaction forces while performing volleyball skills. In: Matsui H. Kobayashi K., eds. Biomechanics VII-B. Champaign, Ill. Human Kinetics: 903-914.

Agel, J., Palmieri-Smith, R.M., Dick, R., Wojtys, E.M., Marshall, S.W. (2007). Descriptive epidemiology of collegiate women's volleyball injuries: national collegiate athletic association injury surveillance system, 1988-1989 through 2003-2004. *Journal of Athletic Training, 42(2),* 295-302.

Alexander, M.J.L., Seaborn, S.J. (1980). Kinesiological analysis of the spike in volleyball. *Volleyball Technical Journal, 5(3),* 65-69.

Andrews, J.R., Axe, M.J. (1985). The classification of knee ligament instability. *Orthopedic Clinics of North America, 16,* 69-82.

Arnheim, D.D., Prentice, W.E. (2003). *Principles of Athletic Training* (11th edition). New York, NY: McGraw-Hill.

Arnold, A.S., Salinas, S., Asakawa, D.J., Delp, S. (2000). Accuracy of muscle moment arms estimated from MRI-based musculoskeletal models of the lower extremity. *Computer Aided Surgery, 5,*108-119.

Baechle, T. R., Earle, R. W. (2000). *Essentials of Strength Training and Conditioning (2nd edition).* Champaign, IL: Human Kinetics.

Bahr, R., Bahr, I.A. (1997). Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scandinavian Journal of Medicine and Science in Sports, 7,* 166-171.

Bilodeau, E.A., Bilodeau, I.M., Schumsky, D.A. (1959). Some effects of introducing and withdrawing knowledge of results early and late in practice. *Journal of Experimental Psychology, 58,* 142-144.

Blackburn, T.J., Padua, D.A. (2009). Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. *Journal of Athletic Training, 44(2),* 174–179.

Blackburn, T.J., Padua, D.A. (2008). Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clinical Biomechanics, 23,* 313-319.

Boden, B.P., Dean, G.S., Feagin, J.A. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics, 23,* 573-578.

Boyce, B.A. (1991). The effects of an instructional strategy with two schedules of augmented KP feedback upon skill acquisition of a selected shooting task. *Journal of Teaching in Physical Education 11,* 47-58.

Brent, J.L. Myer, G.D., Ford, K.R., Hewett, T. (2008). A longitudinal examination of hip abduction strength in adolescent males and females. *Medicine & Science in Sports & Exercise*, 40(5), supplement 1, s50-s51.

Buford, W., Martey Ivery, F., Malone, D., et al. (1997). Muscle balance at the knee: moment arms for the normal knee and the ACL-minus knee. *IEEE Trans. Rehabil. Eng. (5),* 367–379.

Cahalan, R.D., Johnson, M.E., Liu, S., Chao, E.Y. (1989). Quantitative measurements of hip strength in different age groups. *Clinical Orthopedics and Related Research, 246,* 136-145.

Caraffa, A., Cerulli, G. Projetti, M., Aisa, G., Rizza, A. (1996). Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surgery, Sports Traumatology and Arthroscopy, 4,* 19-21.

Chappell, J.D., Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *The American Journal of Sports Medicine, 36(6)*, 1081-1086.

Chaudhari, A.M., Hearn, B.K., Andriacchi, T.P. (2005). Sport-dependent variations in arm position during single-limb landing influence knee loading. *The American Journal of Sports Medicine, 33,* 824-830.

Coleman, S.G., Benham, A.S., Northcott, S.R. (1993). A three-dimensional cinematographical analysis of the volleyball spike. *Journal of Sports Sciences, 11(4),* 295-302.

Colliander, E., Eriksson, E., Heckel, M., Skoeld, P. (1986). Injuries in Swedish elite basketball. *Orthopedics, 9(2),* 225-227.

Cronin, J.B., Bressel, E., Finn, L. (2008). Augmented feedback reduces ground reaction forces in the landing phase of the volleyball spike jump. *Journal of Sport Rehabilitation, 17(2),*148-159.

Daniel, D.M., Stone, M.L., Barnett ,P., Sachs, R. (1988). Use of the quadriceps active test to diagnose posterior cruciate ligament disruption and measure posterior laxity of the knee. *Journal of Bone and Joint Surgery (Am), 70(3),* 386-391.

Decker, M.J., Torry, M.R., Wyland, D.J., Sterett, W.I. Steadman, J.R. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics, 18,* 662-669.

Delfico, A.J., Garrett, W.E. (1998). Mechanisms of injury of the anterior cruciate ligament in soccer players. *Clinics in Sports Medicine, 17(4),* 779-785.

De Loes, M., Dahlstedt, L.J., Thomee, R. (2000). A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scandinavian Journal of Medicine and Science in Sports, 10,* 90-97.

Devita, P., Skelly, W.A. (1991). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise, 24(1),* 108-115.

Dugan, S.A. (2005). Sports-related knee injuries in female athletes; what gives? *American Journal of Physical Medicine and Rehabilitation, 84(2),* 122-130.

Emmen, H.H., Wesseling, L.G., Bootsma, R.J., Whiting, H.T.A., Van Wieringen, P.C.W. (1985). The effect of video-modeling and video-feedback on the learning of the tennis service by novices. *Journal of Sports Sciences, 3(2),*127-38.

Evans Coldeway, A. (1989). *Using Basic Statistics in the Behavioral Sciences.* Scarborough, Ontario: Prentice-Hall Canada Inc.

Ferretti, A., Papandrea, P., Conteduca, F., Mariani, P.P. (1992). Knee ligament injuries in volleyball players. *The American Journal of Sports Medicine, 20(2),* 203-207.

Ford, K.R., Myer, G.D. Smith, R.L., Vianello, R.M., Seiwert, S.L., Hewett, T.E. (2005). A comparison of dynamic coronal plane excursion between matched male and female athletes when performing single leg landings. *Clinical Biomechanics, 21*, 33-40.

Gerberich, S.G., Luhmann, S., Finke, C., Priest, J.D., Beard, B.J. (1987). Analysis of severe injuries associated with volleyball activities. *Physician and Sports Medicine, 15(8),* 75-79.

Glass, R.M., Priest, E.M., Hayward, C.D. (no date). Developing a diagnostic tool to measure valgus collapse in college aged females. Retrieved on August 11, 2008 from www.dartfish.com.

Griffin, L.Y. (2000). *The Henning Program.* Rosemont: American Academy of Orthopaedic Surgeons.

Guadagnoli, M.A., Dornier, L.A., Tandy, R.D. (1996). Optimal length for summary knowledge of results: the influence of task related experience and complexity. *Research Quarterly for Exercise and Sport, 67*, 239-248.

Guadagnoli, M., Holcomb, W., Davis, M. (2002). The efficacy of video feedback for learning the golf swing. *Journal of Sports Sciences, 20,* 615-622.

Hall, S.J. (2007). *Basic Biomechanics* (5th Edition). New York, NY: McGraw-Hill Higher Education.

Hassard, T.H. (1991). *Understanding Biostatistics.* St. Louis, Missouri: Mosby Year Book.

Heidt, R.S. Jr., Sweeterman, L.M., Carlonas, R.L., Traub, J.A., Tekulve, F.X. (2000). Avoidance of soccer injuries with preseason conditioning. *The American Journal of Sports Medicine, 28*, 659.

Hewett, T.E., Myer, G.D., Ford, K.R. (2004). Decrease in neuromuscular control about the knee with maturation in female athletes. *The Journal of Bone and Joint Surgery, 86,* 1601-1608.

Hewett, T.E., Myer, G.D., Ford, K.R., Heidt, R.S., Colosimo, A.J. McLean, S.G., et al. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *The American Journal of Sports Medicine, 33(4),* 492-501.

Hewett, T.E., Myer, G.D., Ford, K.R., Slauterbeck, J.R. (2006). Preparticipation physical examination using a box drop vertical jump test in young athletes. *Clinical Journal of Sport Medicine, 16(4),* 298-304.

Hewett, T.E., Stroupe, A.L., Nance, T.A., Noyes, F.A. (1996). Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *The American Journal of Sports Medicine, 24*, 765.

Hewett, T.E., Zazulak, B.T., Myer, G..D., Ford K.R. (2005c). A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *British Journal of Sports Medicine, 39,* 347-350.

Hruska, R. (1998). Pelvic stability influences lower extremity kinematics. *Biomechanics, 5(6),* 23-29.

Huston, L.J., Vibert, B., Ashton-Miller, J.A., Wojtys, E.M. (2001). Gender differences in knee angle when landing from a drop-jump. *The American Journal of Knee Surgery, 14(4)*, 215-219.

Ireland, M.L. (2002). The female ACL: why is it more prone to injury? *Orthopedic Clinics of North America, 33,* 637-651.

Ireland, M.L. (1999). Anterior cruciate ligament injury in female athletes; epidemiology. *Journal of Athletic Training, 34(2),* 150-154.

Irmischer, B.S., Harris, C., Pfeiffer, R.P., Debeliso, M.A., Adams, K.J., Shea, K.G. (2004). Effects of a knee ligament injury prevention exercise program on impact forces in women. *Journal of Strength and Conditioning Research, 18(4),* 703–707.

James, P.A. (1971). Video feedback in learning beginning trampoline. *Perceptual and Motor Skills, 32*, 669-670.

Jorgensen, U. (1984). Epidemiology of injuries in typical Scandinavian team sports. *British Journal of Sports Medicine, 18,* 59-63.

Kernodle, M.W., Carlton, L.G. (1992). Information feedback and the learning of multiple-degree-of-freedom activities. *Journal of Motor Behavior, 24,* 187-196.

Kernozek, T.W., Torry, M.R., Van Hoof, H., Cowley, H., Tanner, S. (2005). Gender differences in frontal and sagittal plane biomechanics during drop landings. *Medicine and Science in Sports and Exercise, 37(6),* 1003-12.

Kirkendall, D.T., Garrett, W.E. (2000). The anterior cruciate ligament enigma: injury mechanisms and prevention. *Clinical Orthopedics and Related Research, 372,* 64-68.

Kovacs, I., Tihanyi, J., Devita, P., Racz, L., Barrier, J., Hortobagyi, T. (1999). Foot placement modifies kinematics and kinetics during drop jumping. *Medicine and Science in Sports and Exercise, 31(5),* 708-716.

Leetun, D.T., Ireland, M.L., Willson, J.D., Ballantyne, B.T., McClay Davis, I. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine and Science in Sports and Exercise, 36(6),* 926-934.

Lephart, S.M., Abt, J.P., Ferris, C.M., Sell, T.C., Nagai, T., Myers, J.B., et al. (2005). Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *British Journal of Sports Medicine, 39,* 932-938.

Lorentzon, R., Wedren, H., Peitela, T. (1988). Incidence, nature and causes of ice hockey injuries. *The American Journal of Sports Medicine, 16,* 392-396.

Louw, Q., Grimmer, K., Vaughan, C. (2006). Knee movement patterns of injured and uninjured adolescent basketball players when landing from a jump: a case-control study. *BMC Musculoskeletal Disorders, 7(22).* Retrieved June 20, 2008 from www.biomedcentral.com.

McArdle, W., Katch, F., & Katch, V. (2001). *Exercise Physiology* (5th ed.). Baltimore, MD: Lippincott Williams and Wilkins.

Magee, D.J. (1997). *Orthopedic Physical Assessment.* Edmonton: W.B. Saunders Company.

Magill, R.A. (2001). *Motor learning: concepts and applications.* New York: McGraw-Hill.

Majewski, M., Habelt, S., Steinbruck, K. (2006). Epidemiology of athletic knee injuries: a 10-year study. *The Knee, 13,* 184-188.

Malinzak, R.A.C.S., Kirkendall, D.T., Yu, B. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics, 16,* 438-445.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., et al. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. *The American Journal of Sports Medicine, 33(7),* 1003-1010.

Markolf, K.L., Graff-Radford, A., Amstutz, H.C. (1978). In vivo knee stability; a quantitative assessment using an instrumented clinical testing apparatus. *The Journal of Bone and Joint Surgery (Am), 60,* 664-674.

McArdle, W.D., Katch, F.I., Katch, V.L. (2000). *Essentials of Exercise Physiology (Second Ed.).* Philadelphia, PA: Lippincott, Williams & Wilkins.

McLean S.G.H.X., Su, A., Van Den Bogert, A.J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics, 19,* 828–38.

McNair, P.J., Marshall, R.N. (1994). Landing characteristics in subjects with normal and anterior cruciate ligament deficient knee joints. *Archives of Physical Medicine and Rehabilitation, 75,* 584-589.

McNair, P.J., Prapavessis, H., Callender, K. (2000). Decreasing landing forces: effect of instruction. *British Journal of Sports Medicine, 34,* 293-296.

Milne, N. (no date). Human Functional Anatomy 213: Biarticular muscles. Retrieved from www.lab.anhb.uwa.edu.au on May 1, 2009.

Mizner, R.L., Kawaguchi, J.K., Chmielewshi, T.L. (2008). Muscle strength in the lower extremity does not predict postinstruction improvements in the landing patterns of female athletes. *Journal of Orthopedic Sports Physical Therapy, 38(6),* 353-361.

Moore, K. L., Dalley, A.F., Agur, A.M.R. (2010). *Clinically Oriented Anatomy, Sixth Edition.* Baltimore: Lippincott, Williams and Wilkins.

Myer, G.D., Brent, J.L, Ford, K.R., Hewett, T.E. (2008). A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength. *British Journal of Sports Medicine, 42,* 614-619.

Myer, G.D., Chu, D.A., Brent, J.L., Hewett, T.E. (2008). Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clinical Sports Medicine, 27,* 425-448.

Myer, G.D., Ford, K.R., Palumbo, J.P., Hewett, T.E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research, 19(1),* 51-60.

Myklebust, G., & Bahr, R. (2005). Return to play guidelines after anterior cruciate ligament surgery. *British Journal of Sports Medicine, 39,* 127-131.

Myklebust, G., Engebretsen, L., Braekken, I.H., Skjolberg, A., Olsen, O.E. (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clinical Journal of Sport Medicine, 13,* 71-78.

Nordin, M., Frankel, V.H. (2005). *Basic Biomechanics of the Musculoskeletal System.* Baltimore: Lippincott, Williams and Wilkins.

Olsen, O.E., Myklebust, G., Engebretsen, L. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball; a systematic video analysis. *The American Journal of Sports Medicine, 32,* 1002-1012.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I., Bahr, R. (2005). Exercises to prevent lower limb injuries in youth sports: cluster randomized controlled trial. *British Medical Journal, 449(1).* Retrieved August 13, 2008 from http://www.bmj.com.proxy2.lib.umanitoba.ca/cgi/content/full/330/7489/449.

Onate, J.A., Guskiewicz, K.M., Marshall, S.W., Giuliani, C., Yu, B., Garrett, W.E. (2005). Instruction of jump-landing technique using videotape feedback. *The American Journal of Sports Medicine, 33(6),* 831-842.

Onate, J.A., Guskiewicz, K.M., Sullivan, R.J. (2001). Augmented feedback reduces jump landing forces. *Journal of Orthopaedic and Sports Physical Therapy, 31(9),* 511-517.

Petersen, W., Braun, C., Bock, W., Schmidt, K., Weimann, A., Drescher, W., et al. (2005). A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Archives of Orthopedic and Trauma Surgery, 125,* 614-621.

Pfeiffer, R.P., Shea, K.G., Roberts, D., Grandstrand, S., Bond, L. (2006). Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. *American Journal of Bone and Joint Surgery, 88,* 1769-1774.

Pollard, C.D., Sigward, S.M. Ota, S., Langford, K., Powers, C.M. (2006). The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clinical Journal of Sport Medicine, 16(3),* 223-227.

Prapavessis, H., McNair, P.J. (1999). Effects of instruction in jumping technique and experience jumping on ground reaction forces. *Journal of Orthopaedic and Sports Physical Therapy, 29(6),* 352-356.

Prentice, W.E. (2009). *Arnheim's Principles of Athletic Training.* New York: McGraw-Hill.

Raab, M., Masters, R.S.W., Maxwell, J.P. (2005). Improving the "how" and "what" decisions of elite table tennis players. *Human Movement Science, 24(3),* 326-344.

Rauh, M.J., Macera, C.A., Weksten, D.L. (2007). Subsequent injury patterns in girls' high school sports. *Journal of Athletic Training, 42(4),* 486-494.

Renstrom, P., Ljungqvist, A., Arendt, E., Beynnon, B., Fukubayashi, T., Garrett, W. et al. (2008). Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *British Journal of Sports Medicine, 42,* 394-412.

Rippetoe, M & Kilgore, L. (2005). *Starting strength.* Wichita Falls, TX.: Aasgaard Company.

Rothstein, A.L., Arnold, R.K. (1976). Bridging the gap: application of research on videotape feedback and bowling. *Motor Skills: Theory into Practice, 1,* 36-61.

Salci, Y., Kentel, B.B., Heycan, C., Akin, S., Korkusuz, F. (2004). Comparison of landing maneuvers between male and female college volleyball players. *Clinical Biomechanics, 19,* 622-628.

Schafle, M.D., Requa, R.K., Patton, W.L., Garrick, J.G. (1990). Injuries in the 1987 National Amateur Volleyball Tournament. *The American Journal of Sports Medicine, 18,* 624-631.

Schmidt-Olsen, S., Jorgensen, U. (1987). The pattern of injuries in Danish championship volleyball. *Ugeskrift for Laeger, 149(7),* 473-474.

Schmitz, R.J., Kulas, A.S., Perrin, D.H., Riemann, B. L., Shultz, S.J. (2007). Sex differences in lower extremity biomechanics during single leg landings. *Clinical Biomechanics, 22*, 681-688.

Selder, D.J., Del Rolan, N. (1979). Knowledge of performance, skill level and performance on the balance beam. *Canadian Journal of Applied Sport Sciences, 4(3),* 226-229.

Self, B.P., Paine, D. (2001). Ankle biomechanics during four landing techniques. *Medicine & Science in Sports & Exercise, 33(8),* 1338-1344.

Selinger, A. Ackermann-Blount, J. (1985). *Arie Selinger's Power Volleyball.* New York: St. Martin's Press.

Sewell, D., Watkins, P., Griffin, M. (2005). *Sport and Exercise Science.* London: Hodder Arnold.

Shackel, B. (2008). *A biomechanical comparison of starting technique in speed skating and hockey.* Unpublished master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Shea, K.G., Pfeiffer, R.,Wang, J.H., Curtin, M., Apel, P.J. (2004). Anterior cruciate ligament injury in pediatric and adolescent soccer players: an analysis of insurance data. *Journal of Pediatric Orthopaedics, 24,* 623-628.

Shimokocki, Y., Lee, S.Y., Shultz, S., Schmitz, R. (2009). The relationships among sagittal-plane lower extremity moments: implications for landing strategy in anterior cruciate ligament injury prevention. *Journal of Athletic Training, 44(1),* 33-38.

Shultz, S.J., Nguyen, A.D., Beynnon, B.D. (2007). Anatomical factors in ACL injury risk. In T.E. Hewett, S.J. Shultz & L.Y. Griffin (Eds.), *Understanding and preventing noncontact ACL injuries* (pp. 239-258). Champaign, IL: Human Kinetics.

Silvers, H.J., Giza, E., Mandelbaum, B.R. (2005). Anterior cruciate ligament tear prevention in the female athlete. *Current Sports Medicine Reports, 4,* 341-343.

Silvers, H.J., Mandelbaum, B.R. (2007). Prevention of anterior cruciate ligament injury in the female athlete. *British Journal of Sports Medicine, 41(suppl 1),* i52-i59.

Taylor, C. (2007). *A biomechanical comparison of the rotational shot put technique used by males and females.* Unpublished master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Thelen, D.G. Chumanov E.S., Hoerth, D.M., Best, T.M., Swanson, S.C., Li, L. Young, M., Heiderscheit, B.C. (2005). Hamstring muscle kinematics during treadmill sprinting. *Medicine and Science in Sports and Exercise, 37(1),* 108-114.

Tillman, M.D., Hass, C., Brunt, D., Bennett, G. (2004). Jumping and landing techniques in elite women's volleyball. *Journal of Sports Science and Medicine, 3,* 30-36.

Trowbridge, M.H., Cason, H. (1932). An experimental study of Thorndike's theory of learning. *Journal of General Psychology, 7,* 245-258.

van de Pol, J.G., Arnold, M.P., Verdonschot, N., van Kampen, A. (2009). Varus alignment leads to increased forces in the anterior cruciate ligament. *The American Journal of Sports Medicine, 37,* 481-487.

Vander, A. J., Sherman, J.H., Luciano, D. S. (2003). *Human Physiology; The Mechanisms of Body Function* (9th Edition). New York, NY; McGraw-Hill.

Van Wieringen, P.C.W., Emmen, H.H., Bootsma, R.J., Hoogesteger, M., Whiting, H.T.A. (1989). The effect of video-feedback on the learning of the tennis service by intermediate players. *Journal of Sports Sciences, 7*, 153-162.

Wallace, S.A., Hagler, R.W. (1979). Knowledge of performance and the learning of a closed motor skill. *Research Quarterly, 50,* 265-271.

Willson, J.D., Ireland, M.L., Davis, I. (2006). Core strength and lower extremity alignment during single leg squats. *Medicine and Science in Sports and Exercise, 38(5),* 945-952.

Winstein, C.J., Schmidt, R.A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 677-691.

Withrow, T.J., Huston, L.J., Wojtys, E.M., Ashton-Miller, J.A. (2006). The effect of an impulsive knee valgus moment on in vitro relative ACL strain during a simulated jump landing. *Clinical Biomechanics, 21,* 977-983.

Yde, J., Nielsen, A.B. (1988). Epidemiological and traumatological analyses of injuries in a Danish volleyball club. *Ugeskr Laeger, 150,* 1022-1023.

Appendix A

Ethics Approval

UNIVERSITY OF MANITOBA
OFFICE OF RESEARCH SERVICES
Office of the Vice-President (Research)

CTC Building
208 - 194 Dafoe Road
Winnipeg, MB R3T 2N2
Fax (204) 269-7173
www.umanitoba.ca/research

APPROVAL CERTIFICATE

20 October 2008

TO: **Joanne L. Parsons** (Advisor M. Alexander)
Principal Investigator

FROM: **Stan Straw, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2008:090**
"Modifying Spike Jump Landing Biomechanics in Female Adolescent Volleyball Athletes using Video and Verbal Feedback"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **if you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to Kathryn Bartmanovich, Research Grants & Contract Services (fax 261-0325), including the Sponsor name, before your account can be opened.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/ors/ethics/ors_ethics_human_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

Bringing Research to Life

Appendix B

Consent Forms

Intervention Group Consent Form

Research Project Title: Modifying Jump-Landing Biomechanics in Female Adolescent Volleyball Athletes using Video and Verbal Feedback.

Researcher: Joanne Parsons, BMR(PT), CAT(C); Dr. Marion Alexander, advisor

Sponsor: Manitoba Heath Research Council

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the Study:

The purpose of this study is to examine the technique of female volleyball players, in order to determine whether spike landing technique can be altered using video and verbal feedback.

Summary of Study:

The volleyball athlete will be filmed performing volleyball spikes on four separate occasions, during regular practice time at the athlete's home gymnasium, using filming equipment from the Biomechanics Laboratory in the Faculty of Kinesiology. Prior to filming, the athletes will go through their regular warm-up drills and then the filming procedures will be explained. The athletes will be asked to perform five spikes as normally would be undertaken in a practice situation, and the technique will be filmed. The athlete's coach will toss the volleyballs for the athlete to spike during the filming. Some verbal and video feedback will then be given to the athlete regarding how the landing from the spike can be altered. The athlete will then be asked to repeat five spikes and improve their technique while being filmed. The spike skill will be re-filmed every two weeks, for a six week time frame. During the two week, four week and six week follow-up filming sessions, the athletes will only perform five spike jumps while being filmed, with no instruction or feedback. The initial filming session will last approximately 1.5 hours, with each athlete taking about 10 minutes to complete the spikes and receive feedback. At subsequent filming sessions, each athlete will need about five minutes to complete their spikes, for a total of approximately one hour filming duration. Informed written consent for the study must be given by the athlete's parent or guardian prior to filming. All filming procedures will be organized and administered by the principal investigator (J.P.).

Four Canon video cameras will be used to film the athletes. The principal investigator will inform and guide them on what skills to perform at what time. The cameras will continue to film until all of the skills of interest have been performed

When all filming sessions are completed, the videos will be analyzed by the principal investigator working on the project. The types and ranges of motion during each filming session for each athlete, as well as selected distances and times will be described. Still images from the video may be used within the researcher's written Master's thesis as well as the oral thesis defense; however the identity of the athlete will be concealed.

Risk:

There is no additional risk involved in this study, as the athletes will perform the skills as would normally be performed in a practice situation. The cameras will be out of the way, and will not interfere with performance of the skills. As with any physical activity, there is a risk of injury with participation. Because the athletes will be performing skills as they normally would during a practice, it is felt that the risk to them is not any greater than during a regular volleyball practice. The equipment will be situated as far away as possible from the athlete as they perform their spikes. At least one additional graduate student will be present for the filming sessions, providing supervision along with the principal investigator.

Some people feel increased emotional stress when they know they are being videotaped. It will be explained to the subjects that they can withdraw from the study at any time, even if they have given consent to participate, with no penalty or repercussion.

Benefit:

By participating in this study, coaches and athletes may learn improved landing techniques that will decrease the athletes' risk of injury.

Confidentiality:

The film will be viewed only by the researchers involved in the study, the coaches, and by the athletes in the study. The data derived from the film will be available to the coaches and athletes after the study is completed in order to help to improve performance. The videotapes and all of the research data will be kept in a locked cabinet in the Biomechanics laboratory at the University of Manitoba. No one will have access to the films or data except the principal investigator and the graduate advisor. All forms containing the athlete's name or video clips taken from the videotape will be tagged with an identification number to protect identity. All video clips taken from the videotape will be stored on a laptop computer that is password protected, with only the principal investigator having access. All data from the study will be destroyed after the master's thesis has been successfully defended. Still images from the video may be used within the researcher's written master's thesis as well as the oral thesis defense; however the identity of the athlete will be concealed.
The name of the school, the volleyball team and the athlete will not be used in the master's thesis to further protect identity.

Signature:
Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

This research has been approved by the Education/Nursing Research Ethics Board at the University of Manitoba. If you have any concerns or complaints about this project you may contact any of the persons listed below or the Human Ethics Secretariat, Maggie Bowman, at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

<u>Principal Researcher</u>: Joanne Parsons, BMR(PT), CAT(C), Master's graduate student in the Faculty of Kinesiology and Recreation Management, University of Manitoba, Ph 255-1079, 474-6875, parsons_joanne@hotmail.com

<u>Advisor:</u> Dr. Marion J.L. Alexander, Professor, Faculty of Kinesiology and Recreation Management, Ph 474-8642

<u>Coach:</u> J.O., St. Mary's Academy

_______________ _______________ _______
Participant's name (print) Signature
Date

_______________ _______________ _______
Parent/Guardian Signature
Date
(if under 18 years of age)

_______________ _______________ _______
Researcher and/or Delegate Signature
Date

___ No, I do not wish to receive a copy of the study's results after all analysis has been performed.

___ Yes, I would like to receive a copy of the study's results after all analysis has been performed. Please mail the results to the following:

Address:______________________________

Control Group Consent Form

Research Project Title: Modifying Jump-Landing Biomechanics in Female Adolescent Volleyball Athletes using Video and Verbal Feedback.

Researcher: Joanne Parsons, BMR(PT), CAT(C); Dr. Marion Alexander, advisor

Sponsor: Manitoba Heath Research Council

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the Study:

The purpose of this study is to examine the technique of female volleyball players, in order to determine whether spike landing technique can be altered using video and verbal feedback.

Summary of Study:

Two groups of volleyball athletes will be filmed during the course of this study. One group is the intervention group, who will receive feedback about their technique during the filming sessions. Your group is the control group, who will not receive feedback during the filming sessions. The volleyball athletes in your control group will be filmed performing volleyball spikes on two separate occasions, during regular practice time at the athlete's home gymnasium, using filming equipment from the Biomechanics Laboratory in the Faculty of Kinesiology. Prior to filming, the athletes will go through their regular warm-up drills and then the filming procedures will be explained. The athletes will be asked to perform five spikes as normally would be undertaken in a practice situation, and the technique will be filmed. The athlete's coach will toss the volleyballs for the athlete to spike during the filming. The initial filming session will last approximately one hour, with each athlete taking about five minutes to complete the spikes. Six weeks later, the athletes will again be filmed performing five spikes. Again, each athlete will need about five minutes to complete their spikes, for a total of approximately one hour filming duration. Informed written consent for the study must be given by the athlete's parent or guardian prior to filming. All filming procedures will be organized and administered by the principal investigator (J.P.). Four Canon video cameras will be used to film the athletes. The principal investigator will inform and guide them on when to perform the spike skill. The cameras will continue to film until all of the spikes have been performed

When all filming sessions are completed, the videos will be analyzed by the principal investigator working on the project. The types and ranges of motion during each filming session for each athlete, as well as selected distances and times will be described. Still images from the video may be used within the researcher's written Master's thesis as well as the oral thesis defense; however the identity of the athlete will be concealed.

Risk:

There is no additional risk involved in this study, as the athletes will perform the skills as would normally be performed in a practice situation. The cameras will be out of the way, and will not interfere with performance of the skills. As with any physical activity, there is a risk of injury with participation. Because the athletes will be performing skills as they normally would during a practice, it is felt that the risk to them is not any greater than during a regular volleyball practice. The equipment will be situated as far away as possible from the athlete as they perform their spikes. At least one additional graduate student will be present for the filming sessions, providing supervision along with the principal investigator.

Some people feel increased emotional stress when they know they are being videotaped. It will be explained to the subjects that they can withdraw from the study at any time, even if they have given consent to participate, with no penalty or repercussion.

Benefit:

An incentive is being offered to the control group to participate in this study. The principal researcher will return to the school after completion of the study and perform a biomechanical analysis of volleyball skills for the team. The skills to be analyzed will be decided upon by the coach and researcher. The analysis will consist of filming the athletes and giving them instant video and verbal feedback on their performance, and advice on how to better improve their technique.

Confidentiality:

The film from the study will be viewed only by the researchers involved in the study, the coaches, and possibly by the athletes in the study. The data derived from the film will be available to the coaches and athletes after the study is completed in order to help to improve performance. The videotapes and all of the research data will be kept in a locked cabinet in the Biomechanics laboratory at the University of Manitoba. No one will have access to the films or data except the principal investigator and the graduate advisor. All forms containing the athlete's name or video clips taken from the videotape will be tagged with an identification number to protect identity. All video clips taken from the videotape will be stored on a laptop computer that is password protected, with only the principal investigator having access. All data from the study will be destroyed after the master's thesis has been successfully defended. Still images from the video may be used within the researcher's written master's thesis as well as the oral thesis defense; however the identity of the athlete will be concealed. The name of the school, the volleyball team and the athlete will not be used in the master's thesis to further protect identity.

Signature:
Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

This research has been approved by the Education/Nursing Research Ethics Board at the University of Manitoba. If you have any concerns or complaints about this project you may contact any of the persons listed below or the Human Ethics Secretariat, Maggie Bowman, at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

<u>Principal Researcher</u>: Joanne Parsons, BMR(PT), CAT(C), Master's graduate student in the Faculty of Kinesiology and Recreation Management, University of Manitoba, Ph 255-1079, 474-6875, parsons_joanne@hotmail.com

<u>Advisor:</u> Dr. Marion J.L. Alexander, Professor, Faculty of Kinesiology and Recreation Management, Ph 474-8642

<u>Coach:</u> L.M., Balmoral Hall

Participant's name (print)	Signature	Date
Parent/Guardian (if under 18 years of age)	Signature	Date
Researcher and/or Delegate	Signature	Date

___ No, I do not wish to receive a copy of the study's results after all analysis has been performed.

___ Yes, I would like to receive a copy of the study's results after all analysis has been performed. Please mail the results to the following:

Address:______________________________

Appendix C

Pilot Study

Pilot Study

INTRODUCTION

The purpose of this pilot study was to determine whether the kinematics of landing from a volleyball spike jump could be altered using video and verbal feedback and whether the study topic was viable for further research. The pilot study also served as a test for appropriate filming techniques for any subsequent studies.

METHODS

Subjects

Three female volleyball players from a local private school were filmed at the end of the school year, approximately one month after completing the club volleyball season. They were filmed in their home gymnasium on a familiar court, with their school volleyball coach acting as the ball tosser for the spikes. The subjects were thirteen or fourteen years of age and had all competed on their school volleyball team during the previous school year. All three girls had their parents sign informed consent forms (Appendix C). The athletes were filmed using University of Manitoba camera equipment, with all footage downloaded to a Toshiba laptop computer using Dartfish TeamPro software.

Test protocol

A general introduction describing the study was given to the subjects and the coach before filming commenced; however no specific information was given describing the purpose of the study to avoid influencing their jump landings. The girls completed a self-determined warm-up including light jogging and stretching, as well as practice spikes while their coach tossed the ball for them. Each athlete then completed three spikes in a row using their own technique, with no instruction. These trial spikes were filmed and concomitantly uploaded to the Toshiba laptop using the two way interface. The posterior frontal and left sagittal views were the two cameras that were directly linked to the computer for uploading. The anterior frontal and right sagittal views were downloaded after the filming session was complete, as it required manual transmission of the video clips from camera to computer.

After the athletes had completed their three trial spikes, they each viewed their own footage on the Toshiba laptop. The video clips of the left sagittal and posterior frontal views were observed by the athlete as the researcher made comments on their landing technique. They were specifically instructed to try to flex their knees and hips more upon landing from the jump, in order to absorb the landing forces. They were also instructed to land evenly on both feet, keeping their knees over their toes. They viewed their video clips twice, moving frame by frame through the footage as the researcher pointed out some key aspects of their technique and informed them where they could improve. They were then asked to complete three more spike jumps, keeping in mind the landing instructions discussed with them during the feedback session. The athletes demonstrated these spikes in the same order in which their trial spikes had been performed. The same school volleyball coach tossed the volleyballs for the girls during the trial and post-intervention spikes to maintain consistency. There were no timed rest periods between spikes in the trial session or intervention session.

The athletes were allowed to proceed at their own pace in order to complete the spike attempts.

Filming protocol

All spike jumps were filmed in position four on the volleyball court, which is the front left corner of the court by the net. The three athletes were filmed from four vantage points. All cameras were affixed to tripods to ensure they remained stationary for the duration of the filming session. A Canon GL2 camcorder captured the left sagittal view, while an additional Canon GL2 captured the anterior view. An additional two cameras, a Canon ZR500 and a Canon ZR700, captured the posterior and right sagittal views. The poster frontal view and the left sagittal views were directly linked with the laptop computer to allow immediate viewing of the video clips by the researcher and athlete.

The anterior camera was situated approximately two meters on the opposite side of the net from the athlete. It was located directly in line with the athletes' spike approach. The posterior camera was positioned two meters behind the start position of the athlete. It was also aligned with the athlete's spike approach to ensure accurate capture of frontal plane movements. The right and left sagittal view cameras were placed six meters laterally from the path of the spike approach, directly in line with the location on the floor where the athlete would be landing from her spike jump (Figure 1).

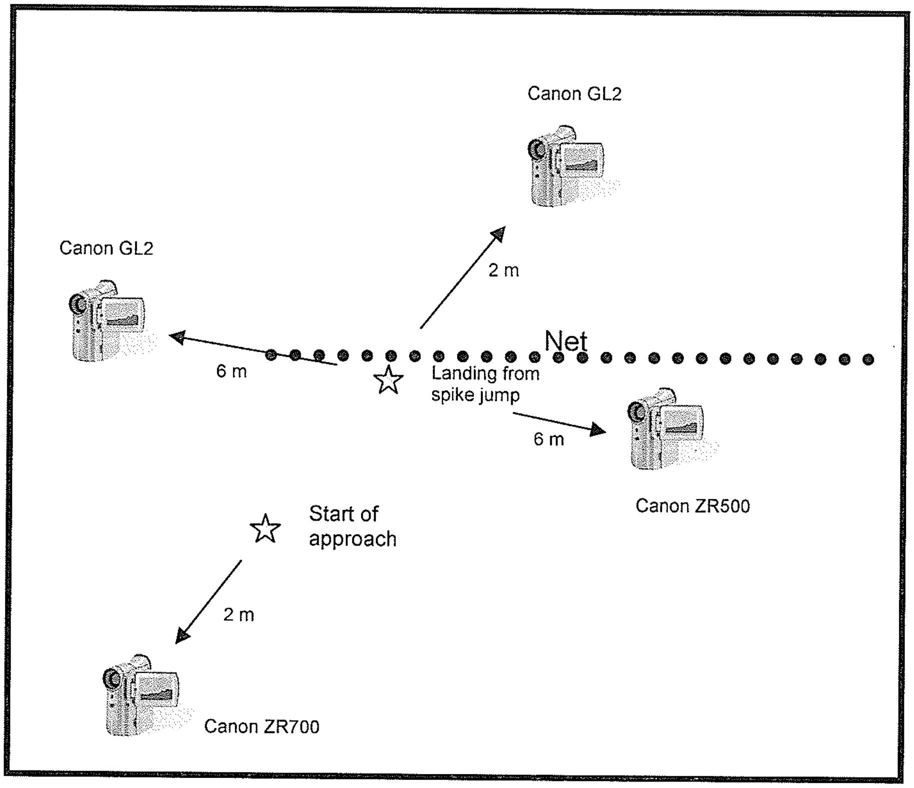


Figure 1: Camera setup and location of spike approach.

VIDEO ANALYSIS OF THE VOLLEYBALL SPIKE LANDING

After filming, the video from the camcorders to the right and in front of the athlete was manually downloaded into Dartfish TeamPro 4.5.2 software. The video from the left and posterior views had been directly downloaded during the filming session via the "In the Action" tool in Dartfish. The appropriate video clips were viewed and the following variables measured:

Table 1: Table of measured variables

Phase of Landing Skill	**Variable Measured (units)**
Initial touchdown	Right and left knee valgus (degrees) Right and left knee flexion (degrees) Right and left hip flexion (degrees) Right and left ankle position (degrees) Toe versus heel landing bilaterally Two-foot versus one-foot landing Trunk flexion (degrees)
Position of maximum flexion	Right and left knee valgus (degrees) Right and left knee flexion (degrees) Right and left hip flexion (degrees) Right and left ankle position (degrees) Trunk flexion (degrees)
End of force absorption	Length of stance phase from initial touchdown to end of force absorption bilaterally (seconds)

The angular variables were measured using the angle tool in Dartfish and included knee, hip, ankle and trunk flexion. The length of stance phase was measured using the time tool. Landing on one versus two feet was determined by observation from all camera angles.

RESULTS

The results from this pilot study indicate that landing biomechanics after a volleyball spike can indeed be altered using verbal and visual feedback. The three adolescent female subjects in this study had received no previous jump landing training, or education on the reasons why proper landing technique is important for injury prevention. All subjects showed a marked improvement in some flexion angles following the video analysis and instruction, which more closely resembled the desired landing pattern for avoiding injury.

Individual results

Subjects one and three improved in eight out of eleven variables during the initial touchdown phase of the landing skill. Subject two improved in only five out of the eleven variables. However, the improvement in technique was especially notable in the position of maximum flexion, with subjects one and two improving in seven out of nine variables, and subject three improving her performance in six out of nine variables. Appendix B contains all raw data from the pilot study. All three subjects increased their length of stance phase.

Averaged results

When averages from the three subjects were combined, 15 of the 21 variables showed a positive change from pre-intervention to post-intervention. At initial touchdown, right knee flexion angle was 28.15 degrees pre-intervention compared to 35.01 degrees post-intervention. Similarly, left knee flexion increased to 35.31 degrees from 20.74 degrees after verbal and video feedback. Right hip flexion improved to 57.58 degrees from 44.37 degrees, and left hip flexion increased to 49.42 degrees from 37.10 degrees post-intervention. Trunk flexion also increased, from 12.60 degrees to 18.99 degrees.

DISCUSSION

The increased flexion position of the hip, knee and trunk post-feedback is a positive adaptation, as landing in a more upright, erect position has been suggested to be a contributing factor to ACL injury (Decker et al., 2003; Salci et al., 2004). By landing in a position of increased knee flexion, the hamstring muscle group is more mechanically effective, with a longer moment arm, and is able to counteract the anterior tibial translation occurring because of the quadriceps contraction when landing from a jump (Ireland, 2002; Renstrom et al., 2008). As well, in a moderately flexed position, the length of the muscle is in a position with optimal overlap of sarcomeres, the contractile unit of the muscle. In this position, the muscle has the greatest ability to produce tension compared to a more shortened position (See Figure 2).

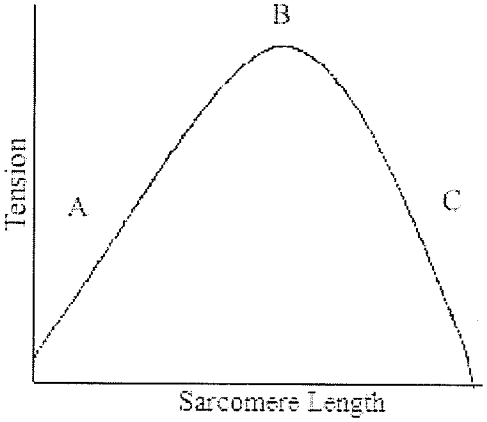


Figure 2: Length-tension relationship of the hamstring muscle. "A" represents a shortened position of the muscle, "B" the optimal length with maximal tension output, and "C" the stretched position of the muscle. (Retrieved on August 21, 2008 from www.exrx.net/Images/SacromereLength.gif).

Increased hip flexion upon landing increases the ability of the gluteal muscles to stabilize the femur because of greater stretch on the muscle, preventing it from falling into adduction and internal rotation, another position that puts the female athlete at risk for ACL injury (Ireland, 2002).

In a study by Blackburn and Padua (2008), increased trunk flexion upon landing caused an increase in knee and hip flexion. It is not the trunk flexion itself that is desirable in order to decrease ACL injury risk. It is the fact that increased trunk flexion can increase knee and hip flexion; both of which have been shown to decrease ACL injury risk (Dugan, 2005; Ireland, 2002; Renstrom et al., 2008). However, one direct benefit of trunk flexion is that as the trunk accelerates downwards, vertical ground reaction forces decrease. This is related to Newton's Second Law, which states that force is proportional to mass times acceleration (Hall, 2007). If an athlete accelerates her trunk upwards, the acceleration is in a positive direction, so the ground reaction forces increase. Conversely, when an athlete accelerates her trunk downwards in a negative direction, the ground reaction forces are decreased.

Both right and left ankle plantarflexion decreased from pre-intervention to post-intervention at initial touchdown. This is not an advantageous adaptation on the part of the athlete, as increased plantarflexion at initial touchdown from a jump has shown to be the most effective way to absorb shock and results in the largest reduction of vertical ground reaction forces (Self & Paine, 2001). Decreased vertical ground reaction forces have been linked with a decrease in ACL injury risk (Hewett et al., 2005).

The subjects' foot landing pattern did not improve with intervention, and in fact worsened after verbal and video feedback. The athletes landed on one foot more often post-intervention and were more likely to land heel to toe rather than toe to heel. This may have occurred due to the fact that foot position was not enforced as much as trunk, knee and hip position within the feedback session.

At the position of maximum flexion, all variables improved except for left ankle dorsiflexion and left knee valgus. Right and left knee and hip flexion, trunk flexion, right knee valgus and right ankle dorsiflexion all increased. This increased range of motion allows the athlete to absorb the forces of landing over a larger period of time. The distribution of forces over a larger time frame requires less force production by the athlete's muscles, tendons and ligaments to arrest downward movement during landing from a jump. Correspondingly, the length of stance phase in the post-intervention video increased to 0.271 seconds from 0.178 seconds.

One variable that did not improve at the position of maximum flexion with verbal and video feedback was left ankle dorsiflexion. This value actually decreased from 9.11 degrees to 3.53 degrees. This may be because the subjects had a tendency to finish their landings early with their left leg, to allow them to quickly clear the test area and prepare for another trial. All subjects exited the filming area to their right, toward the middle of the court. They did not seem to take the time to complete their landings before starting to move to the right to exit the filming area. Left knee valgus may not have decreased due to the same reason. In order to exit the filming area to the left, the subjects tended to pivot on their left foot, causing a left knee valgus. See Table 2 for all averaged values for pre-intervention and post-intervention variables.

Table 2: Averaged variables from all three subjects.

	Preintervention	Postintervention
Initial Touchdown		
Right knee valgus(deg)	10.37	6.63
Left knee valgus (deg)	10.93	6.08
Right knee flexion (deg)	28.15	35.04
Left knee flexion (deg)	20.74	35.31
Right hip flexion (deg)	44.37	57.58
Left hip flexion (deg)	37.10	49.42
Right ankle (deg)	28.73 plantarflexion	16.13 plantarflexion
Left ankle (deg)	43.9 plantarflexion	30.17 plantarflexion
Trunk flexion (deg)	12.60	18.99
Toe vs. heel landing	8 – toe, 1 – heel	6 – toe, 3 – heel
1 vs. 2 foot landing	5 – 1 foot, 4 – 2 foot	6 – 1 foot, 3 – 2 foot

Position of Maximum Flexion		
Right knee valgus (deg)	27.87	24.53
Left knee valgus (deg)	9.5	12.08
Right knee flexion (deg)	79.77	96.87
Left knee flexion (deg)	78.98	94.98
Right hip flexion (deg)	68.51	109.6
Left hip flexion (deg)	68.02	94.97
Right ankle (deg)	2.66 dorsiflexion	18.36 dorsiflexion
Left ankle (deg)	9.11 dorsiflexion	3.53 dorsiflexion
Trunk flexion (deg)	18.43	39.63
Duration of stance (sec)	0.178	0.271

SUMMARY OF PILOT STUDY

The results of this study suggest that adolescent female volleyball players can be positively influenced by using video and verbal feedback to modify their landing biomechanics. All subjects in this study (n=3) demonstrated improved technique in at least 13 of the 21 variables following one session of intervention consisting of verbal feedback of their performance and viewing themselves performing the skill. Changes were evident during both the initial touchdown phase of the skill and the peak flexion position of the landing skill. The length of time taken from initial touchdown to peak flexion to halt the downward movement of the athlete's body also increased substantially when comparing post-intervention values to pre-intervention values. The duration of this stance phase increased by almost two-thirds, allowing the athlete's body to decrease the amount of force it had to produce to decelerate downward movement.

Each subject showed some variability in their kinematics between trials, both pre-intervention and post-intervention. It appeared that subject number two, who was determined by the coach to be the more skilled athlete, possessed the least variability among trials as well as some of the largest joint flexion values.

CONCLUSION

It is clear that using video and verbal feedback may cause a change in the landing biomechanics of adolescent female volleyball players who have not had exposure to jump landing training. What remains to be determined is whether this change can be sustained over time and reproduced. Further studies are recommended, with a larger number of subjects in order to increase the power of the findings. Future studies should also examine whether the kinematic changes seen immediately after verbal and video feedback are reproducible after a length of time, such as several weeks. Only if changes are sustained over time will the injury prevention aspect of modifying jump landing biomechanics be valid. If the athlete reverts to her old movement patterns the day after instruction, the injury prevention effects of landing in a more flexed position will be null and void.

The intervention methods used in this study were relatively straightforward, simple and can be accessed with relative ease and low cost. Coaches working with this at-risk population of young female athletes must be educated on the benefits of jump landing modification, and at the least, provided with a checklist with which to instruct their athletes on proper technique. Dartfish biomechanical software can be purchased by teams or sport organizations for independent use, or biomechanists with Dartfish training can be hired to work with the athletes on a regular basis. Many coaches and organizations are not aware of these beneficial tools that exist to improve their athletes' performance and prevent injury. There is a need for educators and personnel involved with athletes' health such as strength and conditioning specialists, physiotherapists and athletic therapists to become aware of biomechanical analysis and introduce it to coaches and team management as a regular part of their season preparation.

Variables to record during future studies are the position that the athlete normally plays on the volleyball court, the number of years of experience playing volleyball, and the skill level of the athlete. The position that the athlete normally plays will influence their spike approach and subsequently, their landing. If an athlete normally plays on the right side of the court, they may struggle with the spike when performing it from the left side of the court. Their concentration on just hitting the ball may take their mind off the skill of interest, the jump landing, and therefore limit the extent to which the jump landing can be modified.

The number of years of experience that the athlete has played volleyball may influence the findings of the study for similar reasons. Someone with many years of experience will find the spike skill much easier to perform than a novice player, therefore making it less difficult for the more experienced player to concentrate on improving their landing technique. By studying adolescent females of 13 and 14 years of age, the number of years of experience playing should not be a significant contributing factor to any differences noted between subjects. Competitive volleyball typically begins in grade six or seven, meaning that at the most, these athletes will have had two years of playing experience.

The athleticism and innate ability of the athlete may affect their ability to comprehend and demonstrate a change in their spike jump landing technique. A less skilled player has to concentrate more on the movements involved in the execution of the spike, which decreases the time and energy they have to think about their jump landing.

This pilot study suggested that a measurable change can be elucidated in spike jump landing kinematics after verbal and video feedback. This suggests that this protocol can be used in further studies, using larger numbers of subjects, to determine if the observed change is significant and sustainable.

Raw Data - Subject 1

	Pre Trial 1	**Pre Trial 2**	**Pre Trial 3**	**Post Trial 1**	**Post Trial 2**	**Post Trial 3**
Initial Touchdown						
Right knee valgus (deg)	0	15.3	n/a	0	4.9	n/a
Left knee valgus (deg)	9.5	11.5	n/a	4.6	9.3	n/a
Right knee flexion (deg)	47.7	32.2	21.9	59.2	15.3	56.2
Left knee flexion (deg)	14.6	11.6	3.7	30.7	21.1	31.6
Right hip flexion (deg)	71.9	28.9	22.2	59.4	37.3	91.7
Left hip flexion (deg)	21.5	18.2	27.7	58.7	42.6	18.7
Right ankle(deg)	15.9 PF	36.5 PF	28.1 PF	9.8 PF	35.3 PF	11.0 PF
Left ankle (deg)	42.0 PF	53.5 PF	47.5 PF	44.7 PF	44.0 PF	n/a
Toe vs. heel landing	Toe	Toe	Toe	Toe	Toe	Left – toe Right – heel
Trunk flexion (deg)	3.2	0	5.9	12.8	15.5	19.3
1 vs. 2 foot landing	1; left first	2	2	1; left first	2	1 left first
Peak Value						
Right knee valgus (deg)	n/a	30.4	n/a	15.0	14.0	n/a
Left knee valgus (deg)	n/a	n/a	n/a	18.5	19.6	n/a
Right knee flexion (deg)	60.3	76.2	89.1	96.9	82.6	105.5
Left knee flexion (deg)	88.5	62.6	52.6	109.2	64.0	89.6
Right hip flexion (deg)	70.7	58.8	62.3	94.2	81.1	129.2
Left hip flexion (deg)	66.5	57.1	61.8	101.7	71.7	94.1
Right ankle(deg)	0	15 DF	6.5 PF	20 DF	0	13.3 DF
Left ankle(deg)	27.6 DF	11.9 DF	7.6 PF	28.4 DF	4.2 PF	n/a
Trunk flexion (deg)	11.3	18	16.1	18	27.4	48.6
Duration of stance (sec)	0.316	0.200	0.200	0.266	0.200	0.333

Raw Data - Subject 2

	Pre Trial 1	**Pre Trial 2**	**Pre Trial 3**	**Post Trial 1**	**Post Trial 2**	**Post Trial 3**
Initial Touchdown						
Right knee valgus (deg)	0	n/a	7.6	11.2	0	0
Left knee valgus (deg)	3.2	n/a	0	0	n/a	5.2
Right knee flexion (deg)	35.4	20.1	40.2	n/a	30.3	31.6
Left knee flexion (deg)	35.4	36.5	28.7	37.1	52.9	37.3
Right hip flexion (deg)	60.1	50.3	38.8	n/a	46.0	58.2
Left hip flexion (deg)	60.1	64.5	38.5	47.8	64.2	73.5
Right ankle (deg)	40 PF	39 PF	37.4 PF	n/a	22.3 PF	32.3 PF
Left ankle (deg)	40 PF	51.5 PF	49.7 PF	37.8 PF	37.9 PF	42.8 PF
Toe vs. heel landing	Toe	Toe	Toe	Toe	Toe to heel	Toe to heel
Trunk flexion (deg)	23.4	25.0	4.5	17.2	21.1	27.0
1 vs. 2 foot landing	2	1; left by 1 frame	2	1; left by 1 frame	1; right by 1 frame	2
Peak Value						
Right knee valgus (deg)	n/a	n/a	8.6	28.5	n/a	n/a
Left knee valgus (deg)	n/a	n/a	n/a	n/a	n/a	n/a
Right knee flexion (deg)	85.8	71.5	95.9	71.7	101.9	135.3
Left knee flexion (deg)	85.8	84.9	99.1	92.5	108.7	136.2
Right hip flexion (deg)	94.5	77.7	112.0	64.4	116.8	127.7
Left hip flexion (deg)	94.5	88.6	105.7	78.0	122.1	127.1
Right ankle(deg)	n/a	8.2 PF	67.3 DF	n/a	27.5 DF	1.0 PF
Left ankle (deg)	5.7 DF	3.1 DF	28.0 DF	16.2 DF	26.8 DF	37.0 DF
Trunk flexion (deg)	36.5	26.2	37.2	26.9	52.4	36.2
Duration of stance (sec)	0.150	0.133	0.316	0.166	0.300	0.333

Raw Data - Subject 3

	Pre Trial 1	**Pre Trial 2**	**Pre Trial 3**	**Post Trial 1**	**Post Trial 2**	**Post Trial 3**
Initial Touchdown						
Right knee valgus (deg)	8.2	n/a	n/a	0	3.8	n/a
Left knee valgus (deg)	19.1	n/a	n/a	0	n/a	n/a
Right knee flexion(deg)	19.5	21.6	32.9	27.2	20.7	29.0
Left knee flexion (deg)	18.6	11.9	61.8	17.3	0	15.2
Right hip flexion (deg)	33.2	40.4	60.1	37.1	53.1	73.6
Left hip flexion (deg)	46.2	26.1	94.4	21.8	5.0	49.2
Right ankle(deg)	23.5 PF	10.6 PF	47.3 PF	25.5 PF	19.0 DF	25.4 DF
Left ankle (deg)	44.6 PF	32.4 PF	n/a	45.8 PF	32.0 DF	37.4 PF
Toe vs. heel landing	Toe to heel	Toe to heel	Left-toe Right-flat	Left-toe Right-heel	Toe to heel	Left-toe Right-heel
Trunk flexion (deg)	10.2	18.4	21.2	5.5	14.3	3502
1 vs. 2 foot landing	1; right by 2 frames	1; left by 3 frames	1; right by 9 frames	1; left by 2 frames	2	1; left by 2 frames
Peak Value						
Right knee valgus (deg)	44.6	n/a	n/a	0	30.6	n/a
Left knee valgus (deg)	9.5	n/a	n/a	0	5.1	n/a
Right knee flexion (deg)	104.6	65.5	122.0	93.2	67.0	64.7
Left knee flexion (deg)	60.7	90.0	80.2	93.2	72.5	95.3
Right hip flexion (deg)	73.0	62.9	122.0	52.3	87.0	116.4
Left hip flexion(deg)	68.9	44.5	122.5	52.3	34.1	75.7
Right ankle(deg)	9.4 DF	13.2 DF	1.6 DF	13.2 DF	18.7 DF	1.2 DF
Left ankle(deg)	2.8 DF	7.3 DF	n/a	15.0 DF	3.1 DF	11.0 PF
Trunk flexion (deg)	12.9	11.4	45.4	6.6	35.6	56.0
Duration of stance (sec)	0.133	0.166	0.300	0.133	0.150	0.233

Guidelines for Informed Consent

Research Project Title: Pilot Study: Modifying Jump-Landing Biomechanics in Female Adolescent Volleyball Athletes using Video Feedback.

Researcher: Joanne Parsons, BMR(PT), CAT(C), Dr. Marion Alexander, advisor

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Outline of the Study:

The purpose of this study is to examine the techniques of members of the St. Mary's Girls' Volleyball Team, in order to determine whether spike technique can be altered using video feedback. You are either currently a member of this team, or are considered to be a prospect for membership in this program.

Methodology:

You will be filmed, on one occasion only, while practicing at the St. Mary's gymnasium, using filming equipment from the Biomechanics Laboratory in the Faculty of Kinesiology. All practices are organized and administered by the coach, who will instruct you regarding the skills to perform. Prior to filming you, the filming procedures will be explained. You will be asked to perform the skills as you normally would in a competitive situation, and your techniques will be filmed. You must provide informed consent for the study prior to filming. All filming procedures will be organized and administered by Joanne Parsons.

Video cameras will be used to film the athletes. The coach will instruct you regarding which skills are to be performed while the cameras are filming. The cameras will continue to film you until all of the skills of interest have been performed

When filming is completed, the videos will be analyzed by the principal investigator working on the project. The types and ranges of motion in each of the skills, as well as selected linear and angular velocities in each of the skills will be described. Still images from the video may be used within the researcher's written Master's thesis as well as the oral thesis proposal; however the identity of the athlete will be concealed. It is possible that some of the technique descriptions developed from this analysis may eventually be published in a technical journal in the sport being examined.

Risk:

There is no additional risk involved in this study, as you will perform the skills as you would normally perform them in a practice situation. The cameras will be out of the way, and will not interfere in any way with your performance of the skills.

Confidentiality:

The film will be viewed only by the researchers involved in the study, the coaches, and by the athletes in the study. The amount of data available to the athletes will be determined by the coaches. The data derived from the film will be available to the coaches and athletes in order to help to improve performance. The video films and all of the research data will be kept in a locked cabinet in the Biomechanics laboratory. No one will have access to the films or data except the principal investigator and the research assistants. It is possible that the technique analysis data will be published in a technical journal, however the identity of all subjects in the study will be kept confidential.

Signature:

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Principal Researcher: Joanne Parsons, BMR(PT), CAT(C), Master's graduate student, Ph 255-1079
Dr. Marion J.L. Alexander, Professor, Faculty of Physical Education and Recreation Studies, graduate advisor, Ph 474 8642

Participant's name (print)	Signature	Date
Parent/Guardian (if under 18 years of age)	Signature	Date
Researcher and/or Delegate	Signature	Date

Appendix D

Jump Landing Variables Linked to a Decrease in Injury

Phase of jump landing	Variable
Initial touchdown	Increased knee flexion
	Increased hip flexion
	Decreased knee valgus
	Two-foot landing vs. one-foot landing
	Forefoot/toe landing
Position of maximum flexion	Increased knee flexion
	Increased hip flexion
	Increased trunk flexion
Overall landing	Increased time from initial touchdown to position of maximum flexion

Appendix E

Verbal Checklist for Intervention Group

Verbal checklist for intervention group

Keep your knees in line with your toes when landing from a jump; don't go into a "knock-kneed" position

Bend your knees and hips closer to 90 degrees when landing from a jump.

Land evenly on two feet, with a toe to heel landing.

Try to land softly, not stiffly.

*Allowed time for questions from the athletes in order to clarify the instructions.

Appendix F

Jump Landing Checklist for Coaches and Physical Education Teachers

When instructing children and adolescents in sports and activities that involve landing from a jump, proper instruction is imperative for injury prevention. This is especially true in young female athletes, who have an increased risk of injury compared to males. Take the time to not only teach the sport specific skills, but also the basics of landing safely from a jump. Here is an outline of the aspects of jump landing that should be covered with young athletes.

1. Allow enough time for the athlete to complete the sport specific skill and the jump landing. In many practices (ex. volleyball), after hitting the ball, the athlete gets out of the way quickly in order for the next hitter to hit, or to retrieve the ball. A good jump landing requires the athletes to bend their knees, hips and trunk fully, which takes time. When first learning the skill, the athlete may need time immediately after landing to do a "self-check". This allows the athlete time to evaluate their performance and learn from the experience.

2. Encourage the athletes to bend their knees and hips as close to 90 degrees (Figure 1) as they can when landing from a jump. This can be observed by the coach or teacher from the side view of the athlete.

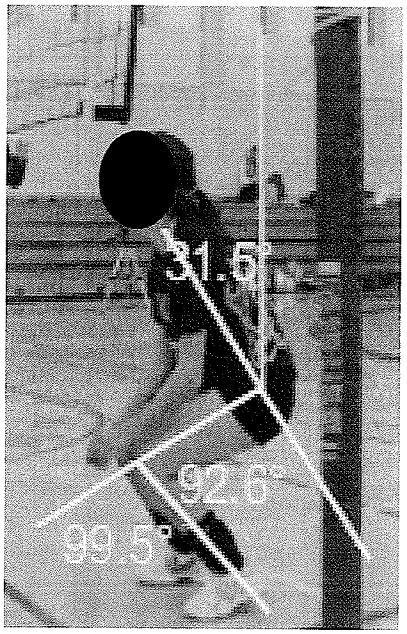


Figure 1: Knees and hips flexed to 90 degrees.

3. The trunk should be bent forward when the athlete lands.

4. The athletes should be instructed to land with their knees in line over their toes (Figure 2A) in order to avoid the dangerous "knock-kneed" position (Figure 2B). This can be observed by the coach or teacher when standing in front of their athlete performing the skill.

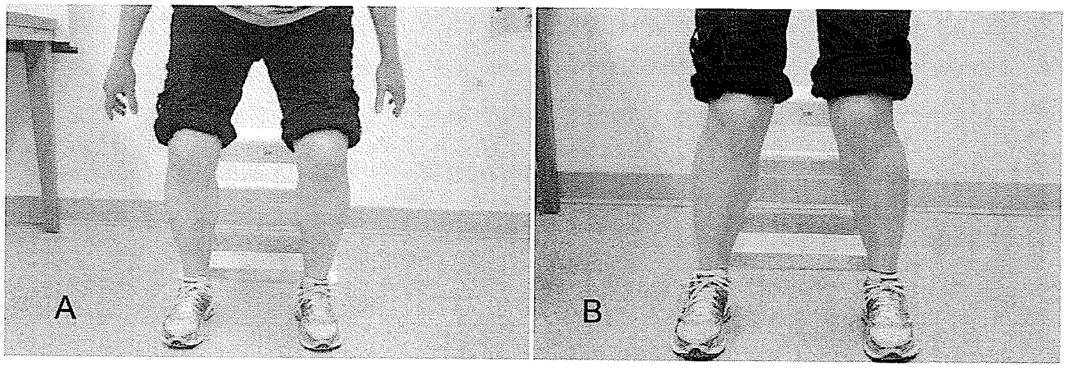


Figure 2: Good and bad landing technique.

5. A two foot landing (Figure 3A) should be encouraged over a one foot landing (Figure 3B), in order to decrease landing forces. The landing should be a toe to heel landing, **NOT** a heel to toe landing or on a flat foot.

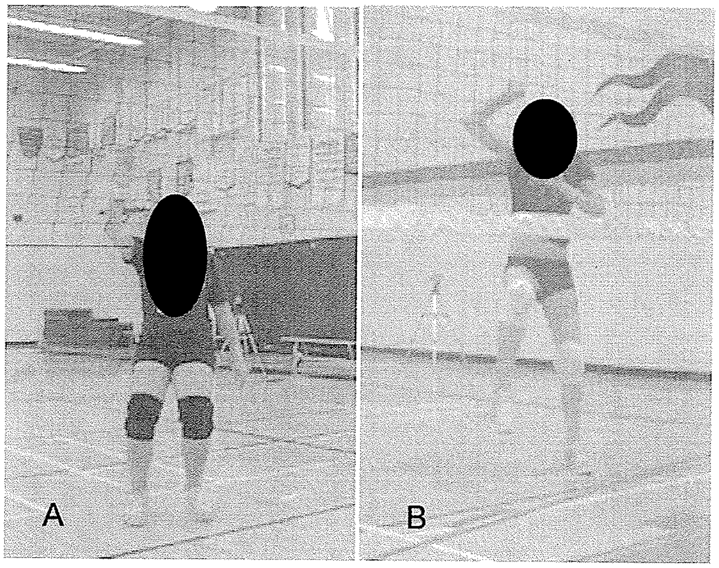


Figure 3: Two foot and one foot landing technique.

6. To further decrease landing forces, the athletes should be taught to swing their arms down and back as they land.

7. Athletes would be greatly aided in their ability to avoid unsafe landing techniques if they participated in strengthening exercises for their legs, hips and trunk. Sample exercises could include lunges, squats, and abdominal crunches. They would also benefit from balance exercises, learning to maintain control of their body when it is off balance. The use of wobble boards could be integrated for that purpose.

Landing safely from a jump is a skill that needs to be taught and practiced just like any other sport skill. But instead of improved performance, the goal is injury prevention. The skill can be learned with minimal instruction, however frequent feedback would be of benefit to further instill the proper technique in young athletes. Video feedback can also be used to demonstrate visually to the athletes which aspects of their jump landing needs to be improved.

Appendix G

Control Group Raw Data

Control Group at Time One – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	5.83	-39.43	24.23	33.23	-4.40	6.07	5.80	25.77	-11.57
2	-12.10	-36.73	23.20	22.00	-13.40	-0.97	51.00	20.87	8.83
3	-18.80	-39.63	37.37	25.77	-1.33	2.03	-5.17	9.37	-16.33
4	-32.40	-30.07	17.40	19.77	-0.90	0.00	9.10	5.20	-9.67
5	n/a	-40.83	n/a	12.50	n/a	-2.00	n/a	22.23	3.07
6	-28.63	-32.90	21.20	43.27	-6.37	15.03	19.17	29.93	-0.20
7	-49.50	-40.57	12.87	14.77	0.00	-2.53	10.77	14.03	-1.80
8	-37.19	-39.25	17.24	24.68	-3.03	4.55	12.17	20.45	-2.65
9	-42.13	-47.77	19.77	21.27	0.00	0.00	31.07	37.20	4.53

Control Group at Time One – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg)	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	32.00	10.90	69.20	66.43	-17.97	0.07	23.27	33.33	-4.43
2	-14.40	28.07	29.10	53.93	-15.40	2.00	59.40	39.80	8.30
3	14.67	9.33	70.03	65.00	-16.90	9.37	4.57	25.23	-15.83
4	4.60	25.70	59.60	52.53	2.05	6.13	16.70	20.60	-3.17
5	n/a	22.33	n/a	50.73	n/a	1.90	n/a	35.23	1.87
6	20.57	8.37	81.90	96.10	-15.73	17.03	68.73	71.77	20.83
7	15.53	22.10	54.37	56.43	2.47	-6.90	30.73	32.40	4.57
8	16.26	18.02	63.42	72.56	-8.58	4.90	42.05	45.62	7.11
9	15.47	12.17	73.57	76.97	0.40	-2.10	91.60	104.57	40.63

Control Group at Time One – Other Variables

Subject	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)
1	0.12	0.17	0.47	0.00	1.00	1.00
2	0.18	0.74	0.30	0.00	0.00	1.00
3	0.15	0.28	0.52	0.33	1.00	1.00
4	0.18	0.22	0.23	0.67	1.00	1.00
5	0.14	n/a	n/a	0.00	n/a	1.00
6	0.30	0.27	0.24	0.67	1.00	1.00
7	0.15	0.11	0.23	0.67	1.00	1.00
8	0.20	0.18	0.32	0.00	1.00	1.00
9	0.35	0.11	0.45	0.67	1.00	1.00

Control Group at Time Two – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	-43.60	-44.03	14.70	16.13	3.37	1.47	-7.00	4.70	-10.00
2	-42.00	-31.60	13.10	16.37	-2.30	0.43	22.70	5.17	-4.43
3	-0.23	-34.97	35.60	55.23	2.17	2.57	3.50	15.73	-7.90
4	-34.53	-33.77	17.60	20.90	-4.63	7.07	13.93	25.17	-7.80
5	n/a	-27.37	n/a	16.50	n/a	-0.97	n/a	15.20	-15.70
6	-46.55	-34.77	17.30	13.13	-4.90	1.40	12.05	14.80	-10.63
7	-43.97	-36.73	11.33	17.93	-3.50	0.13	14.10	14.23	-3.83
8	-33.70	-30.07	13.53	22.70	-4.50	1.43	3.53	12.00	-9.50
9	-38.23	-35.73	14.63	22.10	-3.30	2.70	16.83	20.83	-4.67

Control Group at Time Two – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg0	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	16.67	22.53	68.30	79.40	4.97	7.77	34.17	45.53	9.40
2	9.80	27.10	49.00	53.83	-5.70	4.93	45.10	25.00	2.17
3	31.67	25.57	58.67	72.30	-9.60	8.50	17.63	36.93	-3.17
4	20.77	29.07	56.47	82.17	-26.80	30.67	46.97	45.47	5.17
5	n/a	13.33	n/a	49.07	n/a	6.63	n/a	23.53	-13.10
6	9.10	21.63	72.25	75.97	-16.45	17.13	49.05	42.57	0.33
7	15.50	20.23	57.97	58.53	-10.97	5.77	33.27	28.70	-4.43
8	0.50	14.13	52.73	54.67	-17.20	9.13	21.53	22.47	-6.43
9	21.23	15.97	68.33	69.43	-13.77	16.03	59.57	51.57	14.80

Control Group at Time Two – Other Variables

Subject	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)
1	0.67	1.00	1.00	0.21	0.12	0.56
2	0.33	1.00	1.00	0.15	0.30	0.32
3	0.33	1.00	1.00	0.14	0.12	0.52
4	0.67	1.00	1.00	0.16	0.19	0.18
5	0.00	n/a	1.00	0.13	n/a	n/a
6	0.33	1.00	1.00	0.22	0.17	0.30
7	0.33	1.00	1.00	0.21	0.06	0.19
8	0.33	1.00	1.00	0.14	0.11	0.36
9	1.00	1.00	1.00	0.24	0.09	0.32

Appendix H

Intervention Group Raw Data

Intervention Group at Time One – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	-29.20	-44.93	21.00	1.60	1.05	-4.60	14.95	13.27	-3.40
2	-51.23	-47.53	19.47	20.30	-0.70	-0.73	20.17	17.10	-4.93
3	-60.33	-54.57	21.20	19.90	1.10	-0.53	30.43	36.27	1.50
4	-35.23	-41.40	9.40	19.27	-0.80	3.30	9.20	14.90	-4.17
5	-29.93	-46.90	15.30	14.60	-0.53	2.73	19.70	17.70	0.93
6	-38.73	-46.57	12.93	12.20	0.00	0.73	15.97	15.33	-4.23
7	-22.80	-43.70	48.50	12.20	-2.70	-1.77	32.20	9.13	-17.00
8	-36.90	-41.03	17.90	22.77	0.00	-0.87	21.35	18.97	-4.63
9	-48.77	-52.37	19.33	15.23	-2.17	0.37	30.10	30.20	4.30
10	-43.23	-43.90	18.80	21.70	0.87	2.07	4.73	8.80	-13.40

Intervention Group at Time One – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg)	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	3.65	17.90	73.95	59.70	5.20	-13.20	39.65	39.17	2.00
2	19.50	19.67	68.47	75.27	-7.97	-0.43	43.13	38.43	-2.17
3	11.70	20.60	73.20	75.00	4.23	-0.17	49.60	53.00	1.93
4	17.57	12.23	66.53	62.33	-13.87	10.13	34.43	32.83	-7.53
5	22.10	7.80	67.93	77.00	-5.67	8.00	43.57	46.70	5.73
6	6.87	3.17	57.17	79.20	-0.37	1.20	36.00	41.50	-2.50
7	-0.30	2.97	63.60	58.60	-8.20	-5.53	49.10	41.57	-8.30
8	13.05	25.47	77.60	92.17	-6.10	3.60	64.15	71.20	9.47
9	18.00	20.97	61.50	66.90	-8.50	7.37	45.30	50.77	4.43
10	18.17	12.87	56.00	72.70	-2.70	8.90	17.40	25.87	-15.13

Intervention Group at Time One – Other Variables

Subject	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)
1	0.33	1.00	1.00	0.19	0.33	0.23
2	0.67	1.00	1.00	0.17	0.06	0.25
3	1.00	1.00	1.00	0.17	0.07	0.28
4	0.67	1.00	1.00	0.16	0.08	0.17
5	0.67	1.00	1.00	0.16	0.06	0.16
6	1.00	1.00	1.00	0.17	0.12	0.23
7	0.00	1.00	1.00	0.14	0.01	0.32
8	0.33	1.00	1.00	0.25	0.08	0.36
9	1.00	1.00	1.00	0.13	0.01	0.19
10	0.67	1.00	1.00	0.14	0.20	0.27

Intervention Group at Time Two – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	-15.27	-41.93	23.83	13.53	7.20	-2.17	32.33	28.00	7.77
2	-45.43	-45.37	36.07	29.20	-3.57	0.87	37.80	31.10	2.40
3	-52.10	-48.63	25.43	30.47	2.30	3.97	41.73	46.67	7.03
4	-53.13	-36.40	19.70	16.07	1.33	-2.00	24.10	28.57	4.07
5	-38.90	-44.93	24.27	19.17	-1.33	2.87	10.30	11.67	-7.67
6	-50.37	-37.93	20.20	21.67	-0.80	-0.17	18.27	18.43	-5.27
7	-20.77	-30.10	27.77	25.60	-4.37	4.73	14.37	15.20	-8.83
8	-23.37	-43.50	38.07	24.73	-1.17	0.40	44.77	28.87	7.27
9	-43.90	-51.23	16.73	14.13	-3.03	0.63	17.83	20.10	-0.27
10	-52.03	-42.17	24.07	24.67	-0.13	1.73	6.50	4.53	-18.17

Intervention Group at Time Two – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg)	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	15.67	20.37	69.73	72.37	8.40	-6.07	50.60	53.80	4.23
2	27.83	26.53	95.20	100.73	-15.90	14.50	86.50	84.17	27.10
3	9.87	18.00	78.37	80.00	-5.07	1.67	63.77	68.23	9.40
4	22.27	17.43	106.23	97.97	14.17	-13.90	102.77	100.43	27.40
5	26.87	28.00	75.37	79.27	-10.60	6.73	34.20	34.40	-6.37
6	13.83	28.93	94.33	108.70	3.63	2.80	88.20	87.73	25.13
7	7.40	11.97	76.97	83.93	-14.07	8.10	33.90	36.83	-11.27
8	26.23	34.87	96.27	105.47	-9.07	5.83	87.00	92.37	21.00
9	29.63	26.33	79.43	84.47	-11.77	13.87	51.93	63.00	2.77
10	28.80	29.37	77.17	77.43	-9.47	5.07	35.00	35.33	-10.10

Intervention Group at Time Two – Other Variables

Subject	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)
1	0.33	1.00	1.00	0.16	0.17	0.35
2	0.67	1.00	1.00	0.24	0.09	0.31
3	0.00	1.00	1.00	0.17	0.07	0.37
4	0.33	1.00	1.00	0.37	0.19	0.22
5	1.00	1.00	1.00	0.19	0.03	0.12
6	1.00	1.00	1.00	0.31	0.05	0.24
7	0.00	1.00	1.00	0.16	0.04	0.24
8	0.33	1.00	1.00	0.29	0.10	0.43
9	1.00	1.00	1.00	0.20	0.04	0.19
10	0.00	1.00	1.00	0.19	0.13	0.28

Intervention Group at Time Three – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	-46.73	-37.53	8.80	13.73	-2.30	1.93	22.17	22.17	1.53
2	-43.97	-54.30	18.47	20.23	-0.90	0.00	29.53	24.87	8.37
3	-49.87	-52.13	20.77	19.10	-0.53	-0.63	22.67	26.13	-3.57
4	-21.83	-23.97	34.83	26.03	-0.63	-1.37	36.67	39.53	5.97
5	-29.67	-30.70	18.07	13.07	1.10	2.10	27.63	21.93	3.23
6	-26.63	-36.70	19.13	21.80	-1.40	3.37	10.70	14.60	-8.73
7	-42.70	-39.73	19.20	41.50	-3.87	17.67	23.77	33.17	-1.63
8	-51.87	-41.23	26.13	20.80	3.83	-0.60	25.63	27.83	5.60
9	-38.87	-52.83	18.13	20.57	-3.90	2.63	30.47	31.20	8.07
10	-38.73	-39.33	23.57	31.83	2.93	5.50	9.27	12.33	-10.03

Intervention Group at Time Three – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg)	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	15.03	20.00	76.00	79.07	-13.90	15.40	55.43	51.33	7.40
2	9.07	1.03	90.67	87.70	-19.93	24.70	83.40	73.53	28.63
3	15.27	18.97	73.20	75.73	-3.90	1.50	51.07	48.70	3.63
4	10.90	26.53	133.00	137.20	4.33	-7.67	133.37	134.10	34.30
5	3.77	-2.27	68.33	80.20	6.00	7.10	53.20	54.77	8.10
6	8.20	0.90	74.00	79.70	-3.27	9.43	53.43	53.27	6.07
7	21.30	23.73	101.23	99.70	-9.00	32.27	77.33	68.80	10.70
8	5.33	14.00	90.37	76.63	17.20	-10.87	48.13	51.23	5.23
9	23.63	7.73	78.00	82.67	-19.67	14.80	67.17	66.63	18.03
10	13.93	24.43	69.97	68.53	2.73	8.73	30.33	30.20	-7.93

Intervention Group at Time Three – Other Variables

Subject	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)
1	1.00	1.00	1.00	0.18	0.05	0.29
2	0.33	1.00	1.00	0.27	0.14	0.31
3	1.00	1.00	1.00	0.17	0.05	0.26
4	0.67	1.00	1.00	0.34	0.14	0.29
5	1.00	1.00	1.00	0.12	0.10	0.21
6	1.00	1.00	1.00	0.17	0.04	0.25
7	0.67	1.00	1.00	0.25	0.13	0.45
8	0.33	1.00	1.00	0.17	0.20	-0.03
9	1.00	1.00	1.00	0.31	0.05	0.15
10	1.00	1.00	1.00	0.16	0.06	0.27

Intervention Group at Time Four – Initial Touchdown

Subject	Right ankle at IT (deg)	Left ankle at IT (deg)	Right knee flexion at IT (deg)	Left knee flexion at IT (deg)	Right knee valgus at IT (deg)	Left knee valgus at IT (deg)	Right hip flexion at IT (deg)	Left hip flexion at IT (deg)	Trunk flexion at IT (deg)
1	-42.20	-39.63	16.47	16.20	-1.17	1.87	37.20	34.03	10.37
2	-21.77	-55.20	47.30	18.33	-0.97	-0.77	50.03	18.73	9.13
3	-53.87	-55.30	24.43	25.47	-0.77	-1.57	22.83	19.03	-1.90
4	-8.60	-16.10	29.03	51.23	3.57	-0.60	48.47	66.97	14.70
5	-31.00	-39.57	28.33	18.97	0.83	0.03	24.40	14.70	-2.13
6	-46.30	-47.20	19.87	18.27	-1.30	0.93	4.70	5.87	-15.50
7	-31.40	-33.87	24.70	25.10	0.87	0.37	24.17	22.10	11.13
8	-27.07	-42.87	33.00	17.17	-2.77	-1.00	36.87	13.83	1.33
9	-39.37	-50.37	12.83	22.03	-1.80	1.20	19.93	25.70	2.17
10	-1.63	-28.07	49.57	36.17	-5.77	6.40	41.30	26.47	8.47

Intervention Group at Time Four – Position of Maximum Flexion

Subject	Right ankle at max flexion (deg)	Left ankle at max flexion (deg)	Right knee flexion at max flexion (deg)	Left knee flexion at max flexion (deg)	Right knee max valgus (deg)	Left knee max valgus (deg)	Right hip flexion at max flexion (deg)	Left hip flexion at max flexion (deg)	Trunk flexion at max flexion (deg)
1	21.83	21.00	79.60	81.80	-7.30	16.20	62.57	54.07	10.50
2	26.97	4.97	93.70	86.47	-10.87	16.47	91.50	80.67	31.17
3	13.53	20.37	68.10	70.00	-3.27	-1.23	42.40	36.87	-2.53
4	17.40	29.17	147.47	152.67	14.73	-9.33	136.10	150.90	25.00
5	12.50	16.57	76.90	74.77	-6.83	1.60	50.13	49.67	5.37
6	10.03	1.07	73.10	78.43	-5.37	8.17	38.33	39.10	-3.97
7	11.63	13.13	73.50	68.47	-8.43	-0.97	55.27	55.10	18.87
8	8.70	20.60	76.63	87.77	-11.33	-2.80	67.00	69.47	9.83
9	24.70	4.13	74.30	76.40	-12.97	11.47	56.60	52.30	10.37
10	25.37	22.40	89.33	87.13	-16.90	18.60	96.13	98.20	38.93

Intervention Group at Time Four – Other Variables

Subject	2 foot landing (Y=1, N=0)	Toe landing (right) (Y=1, N=0)	Toe landing (left) (Y=1, N=0)	Stance phase time (sec)	Anterior/posterior stance (m)	Medial/ lateral stance (m)
1	0.67	1.00	1.00	0.18	0.07	0.36
2	0.00	1.00	1.00	0.37	0.07	0.41
3	1.00	1.00	1.00	0.15	0.04	0.29
4	0.33	0.50	1.00	0.31	0.13	0.29
5	0.67	1.00	1.00	0.16	0.05	0.22
6	0.67	1.00	1.00	0.17	0.05	0.27
7	0.00	1.00	1.00	0.15	0.13	0.28
8	0.00	1.00	1.00	0.32	0.07	0.42
9	1.00	1.00	1.00	0.18	0.05	0.18
10	0.33	1.00	1.00	0.26	0.11	0.45

Appendix I

Written Permission for use of Copyrighted Material

Re: permission for thesis

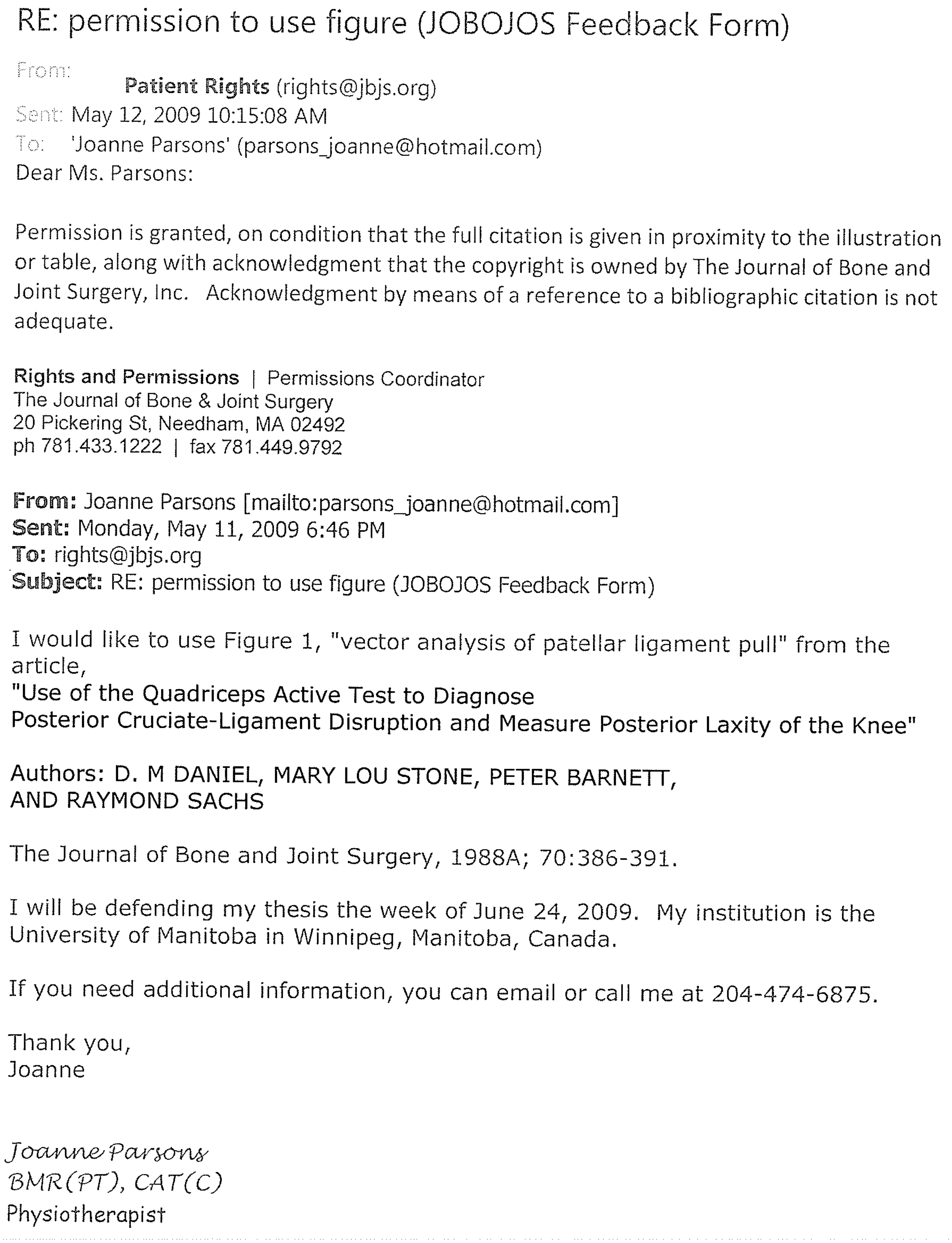
From: **ksm** (ksm@kysportsmed.com)
Sent: September 10, 2008 1:37:06 PM
To: Joanne Parsons (parsons_joanne@hotmail.com)
RE: Permission for reprint of figures

Dear Ms. Parsons:

Permission is hereby granted for reprint of Position of No Return figure and Figs. 5 & 6 on pages 640 and 641 in the article "The female ACL: Why is it more prone to injury?"
Please use credit line with reprint of figures.

Sincerely yours,

Mary Lloyd Ireland, M.D.
Associate Professor
University of Kentucky
Dept. of Orthopaedic Surgery &
Sports Medicine



RE: permission to use figure (JOBOJOS Feedback Form)

From: **Patient Rights** (rights@jbjs.org)
Sent: May 12, 2009 10:15:08 AM
To: 'Joanne Parsons' (parsons_joanne@hotmail.com)

Dear Ms. Parsons:

Permission is granted, on condition that the full citation is given in proximity to the illustration or table, along with acknowledgment that the copyright is owned by The Journal of Bone and Joint Surgery, Inc. Acknowledgment by means of a reference to a bibliographic citation is not adequate.

Rights and Permissions | Permissions Coordinator
The Journal of Bone & Joint Surgery
20 Pickering St, Needham, MA 02492
ph 781.433.1222 | fax 781.449.9792

From: Joanne Parsons [mailto:parsons_joanne@hotmail.com]
Sent: Monday, May 11, 2009 6:46 PM
To: rights@jbjs.org
Subject: RE: permission to use figure (JOBOJOS Feedback Form)

I would like to use Figure 1, "vector analysis of patellar ligament pull" from the article,
"Use of the Quadriceps Active Test to Diagnose
Posterior Cruciate-Ligament Disruption and Measure Posterior Laxity of the Knee"

Authors: D. M DANIEL, MARY LOU STONE, PETER BARNETT,
AND RAYMOND SACHS

The Journal of Bone and Joint Surgery, 1988A; 70:386-391.

I will be defending my thesis the week of June 24, 2009. My institution is the University of Manitoba in Winnipeg, Manitoba, Canada.

If you need additional information, you can email or call me at 204-474-6875.

Thank you,
Joanne

Joanne Parsons
BMR(PT), CAT(C)
Physiotherapist