The Effect of Instruction of Jump-Landing Motion Patterns And Impact Forces

Mary Elizabeth Joos
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THE EFFECT OF INSTRUCTION ON JUMP-LANDING MOTION PATTERNS

AND IMPACT FORCES

By

Mary Elizabeth Joos, ATC
B.A. May 2005, University of North Carolina at Chapel Hill

A Thesis Submitted to the faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE IN EDUCATION

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The use of visual instruction could be a valuable tool in prevention strategies for anterior cruciate ligament injuries, especially in large group settings, through the alterations of jump-landing motion patterns and impact forces. The purpose of this study was to determine the effectiveness of two visual modeling cues in altering jump-landing motion patterns, as measured by the Landing Error Scoring System (LESS), and impact forces, vertical ground reaction force (PVGRF) and peak posterior ground reaction force (PPGRF). Seventy-three physically active individuals (age = 20.89 ± 1.72 years; height = 172 ± 9.87 cm; mass = 68.43 ±15.97 kg) were baseline tested performing three trials of a box-drop landing task. Of these, 51 subjects (7 males; 44 females; age = 20.80 ± 1.70 years; height = 171.37 ± 9.10 cm; mass = 65.22 ± 13.44 kg), with poor landing mechanics (LESS scores ≥ 6) were randomly assigned to each modeling group (global modeling [G], specific modeling [S], and control[C]), 17 subjects per group. Data were collected during a box-drop landing task for a pretest [P] (3 trials). Subjects received modeling cues (global, specific, or no instructions), performed the same task during the immediate posttest [I] (3 trials), returned one-week later for a retention test [R] (3 trials) and a transfer test [T] of a running stop-jump task (3 trials), both with no additional instructions. Three separate 3 (instruction) x 4 (testing session) repeated measures ANOVA were conducted at a significance level of p<0.05 set a priori. Tukey Post Hoc HSD was used to analyze specific differences in the data. Effect size was determined
using Cohen’s d test. For PVGRF, we found a main effect for testing session, with [T] demonstrating higher values than [I] and [R]. A main effect was found for the higher [T] values compared to the [P], [I], [R] for PPGRF. Interactions were found for LESS scores, with [S] and [G] showing significant decreases for [I] and [R] compared to [P] and to the [C] for [I]; [G] demonstrated significant decreases in [R] compared to [C]. The global instructional cue may be effective in improving landing mechanics in individuals in need of intervention, but not for impact forces. Future research is needed to evaluate the long term effects of this instructional technique with varied age groups, along with utilizing the stop-jump task as a more athletically demanding task.
I would like to dedicate this work to all of those individuals in my life who have believed in me and helped me along my way to achieving my goals – Mom, Dad, Chris, Andie, Ava and all of my family; my friends, both near and far; and my mentors, many of whom are contributors to this thesis – Jimmy, Bonnie, Darin, and Nelson, among others.

Each of you have contributed significantly to the process of achieving this goal, to many aspects of this work and to many aspects of me. Thank you with all my heart.
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CHAPTER I

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are increasingly common in the athletic population, especially among females. ACL injuries are associated with a high rate of incidence (Malinzak, Colby, Kirkendall, Yu, and Garrett, 2001), large expense of the surgical repair, treatment, and rehabilitation (Griffin, Agel, Albohm, Arendt, Dick, Garrett, Garrick, Hewett, Huston, Ireland, Johnson, Kibler, Lephart, Lewis, Lindenfeld, Mandelbaum, Marchak, Teitz, and Wojtys, 2000), and long term potential side effects, such as joint osteoarthritis (Gelber, Hochberg, Mead, Wang, Wigley, and Klag, 2000). These problematic issues make ACL injury prevention an important topic in research as well as within clinical settings.

biomechanical alignment, neuromuscular factors) and extrinsic (playing or shoe surfaces, and equipment) (Griffin et al, 2000; Hewett et al, 2004). Clinical recognition of these risk factors, especially the biomechanical alignment and neuromuscular factors that can be influenced by the work of athletic trainers, physical therapists, and strength and conditioning coaches, is a critical first step in preventing ACL injuries (Ford et al, 2003). Ford et al (2003) reported that there is a current need to develop a tool to further identify athletes that may be at risk for ACL injury and that the use of video analysis should be considered for screening large numbers of athletes. The ability to screen large numbers of individuals, entire teams, physical education classes, or military units, is of utmost importance to clinicians as the need for ACL injury prevention and risk factor identification grows (Hewett, Myer, and Ford, 2001). The Landing Error Scoring System (LESS) is a reliable and valid clinical assessment tool that can be used to identify some of the biomechanical risk factors for ACL injuries that occur during jump-landings using video, therefore allowing for effective and efficient screening of a large number of individuals (Boling, Thigpen, Padua, and Marshall, 2005; Padua, Marshall, Beutler, DeMaio, Oñate, Yu, Guskiewicz, and Garrett, 2004; Padua, Marshall, Oñate, Beutler, Guskiewicz, Thigpen, Knowles, and Garrett, 2004).

The LESS has been used in previous research to screen for faulty biomechanical alignment that has been shown to predispose athletes to injury (Boling et al, 2005; Padua et al, 2004a; Padua et al, 2004b). With this identification tool at the clinician’s disposal, there is a need for an intervention device that can improve the jump-landing mechanics of a large number of individuals. A variety of strategies have been implemented to help reduce the number of ACL injuries including strength training, plyometric training, and
neuromuscular training (Griffin, 2001; Hewett et al, 1996; Hewett, Ford, and Myer, 2005; Hewett, Riccobene, and Lindenfeld, 2001; Mandelbaum, Silvers, Watanabe, Knarr, Thomas, Sampson, Knapp, Yinger, Kirkendall, Griffin, and Garrett, 2002; Myer, Ford, and Hewett, 2004). Several authors have started to focus on motor learning strategies, which are common in athletics, to assist in modifying jump-landing mechanics (Cowling, Steele, and McNair 2003; Janelle, Barba, Frehilch, Tennant, and Cauraugh, 1997; McNair, Prapavessis, and Callendar, 2000; Oñate, Guskiewicz, Marshall, Giuliani, Yu, and Garrett, 2005; Oñate, Guskiewicz, and Sullivan, 2001; Prapavessis and McNair, 1999).

While most of these authors have focused on verbal instructions, the use of visual modeling could also be a valuable tool for instruction (Lindahl, 1954; Scully and Carnegie, 1998; Sheffield, 1961; Simon and Bjork, 2002). There are many types of modeling, and choosing the most effective one could be paramount in developing a prevention program for large group instruction. Two such modeling techniques consist of specific modeling (where the focus of the instructions center on specifics of the body) and global modeling (where the focus is on a generalized global body position). These two techniques could effect the learning process quite differently, as some authors provide evidence that too much information can cloud the process for the individual (Annett, 1994; Janelle et al 1997), or that giving a goal outside of the body (like external focus and global modeling) can be more helpful to the individual in learning the skill (Shea and Wulf, 1999; Wulf, Mercer, McNevin, and Guadagnoli, 2004; Wulf, Weigelt, Poulter, and McNevin, 2003). In contrast, drawing attention to specific joint motions of a model has been shown to improve reproducibility of the joint motions and the overall
movement in the subject (Scully and Carnegie, 1998). The use of modeling could provide a means to best alter the motion patterns of large groups of individuals in order to possibly reduce the risk of ACL injury.

In addition to biomechanical alignment, ground reaction forces can have effects on ACL injury risk. High joint compressive forces and the high vertical ground reaction forces that can produce them have been shown as a mechanism of injury and a predictive factor for ACL injury (Meyer et al, 2005). Posterior ground reaction force is correlated with anterior tibial shear force (Sell, Ferris, Abt, Tsai, Myers, Fu, Leiphart, 2004), which has been shown to be a mechanism of ACL injury (Kirkendall and Garrett, 2000). One potential course of action to prevent ACL injury could be to reduce vertical and posterior ground reaction forces. By combining the reduction of ground reaction forces and the correction of biomechanical alignment upon landing, a course of action to potentially reduce ACL injury risk can be formulated. In order to reduce the total number of ACL injuries in athletic populations, it is of primary importance to find clinically applicable, easy to implement, and effective screening and intervention tools to be used on large numbers of individuals.

Statement of Problem

The purpose of this study was to determine the effect of two different forms of modeling and instruction (specific and global) on jump-landing mechanics as measured by use of the Landing Error Scoring System (LESS), peak vertical ground reaction forces, and peak posterior ground reaction forces. The effect of the instructions were measured in an immediate posttest with instruction, a one-week retention test sans instruction, and a transfer test of a different but similar jumping task.
Research Questions, Research Hypotheses, and Null Hypotheses

**Research Question 1:** Will instruction have any effect on landing technique?

**Research Hypothesis 1:** There will be a significant decrease in landing errors (a decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force for both experimental groups when comparing pretest and immediate posttest values (Oñate et al., 2005; Janelle, Barba, Frehlich, Tennant, Cauraugh, 1997; McNair et al., 2000; Oñate et al. 2001; Prapavessis and McNair, 1999; Ayalon and Ben-Sira, 1998; Wulf et al., 2004; Sell et al., 2004; Yu, Cheng-Feng, Garrett, 2006).

**Null Hypothesis 1:** There will be no significant difference in landing errors (a difference in LESS scores), in peak vertical ground reaction force, and in peak posterior ground reaction force for any group when comparing pretest and immediate posttest values.

**Research Question 2:** Will subjects be able to retain the knowledge to perform the task after instructions are removed from them?

**Research Hypothesis 2:** There will be a significant decrease in landing errors (a decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force for both experimental groups when comparing pretest and retention test values (Onate et al 2001; McNair et al, 2000; Onate et al 2001; Wulf et al, 2003; Shea and Wulf, 1997).

**Null Hypothesis 2:** There will be no significant difference in landing errors (a difference in LESS scores), in peak vertical ground reaction force, and
in peak posterior ground reaction force for any group when comparing pretest and retention test values.

**Research Question 3:** Will subjects’ performances degrade after instructions are removed?

**Research Hypothesis 3:** There will be no statistically significant difference in landing errors (no difference in LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force for any group when comparing the immediate posttest and the one-week retention test values (Onate et al, 2001; McNair et al, 2000; Onate et al, 2001; Wulf et al, 2003; Shea and Wulf, 1997).

**Null Hypothesis 3:** There will be a statistically significant difference in landing errors (a difference in LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force for any group when comparing the immediate posttest and the retention test values.

**Research Question 4:** Does instruction type effect landing technique over different testing times?

**Research Hypothesis 4a:** For immediate posttest values, both experimental groups will show a significant decrease in landing errors (a decrease in LESS scores), significant decrease in peak vertical ground reaction force, and significant decrease in peak posterior ground reaction force as compared to the control group (Oñate et al, 2005; Janelle et al, 1997; McNair et al, 2000; Oñate et al, 2001; Prapavessis and McNair, 1999; Ayalon and Ben-Sira, 1998; Wulf et al, 2004; Sell et al, 2004; Yu et al, 2006).
Null Hypothesis 4a: For immediate posttest values, neither experimental group will show a significant difference in landing errors (a difference in LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force as compared to the control group.

Research Hypothesis 4b: For immediate posttest values, the global modeling group will show a significant decrease in landing errors (a decrease in LESS scores), significant decrease in peak vertical ground reaction force, and significant decrease in peak posterior ground reaction force as compared to the specific modeling group and control group (Ofiate et al, 2005; Ofiate et al 2001; Yu et al, 2006; Wulf et al, 2004).

Null Hypothesis 4b: For immediate posttest values, neither experimental group will show a significant difference between instructional groups in landing errors (LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force.

Research Hypothesis 4c: For retention test values, both experimental groups will show a significant decrease in landing errors (a decrease in LESS scores), significant decrease in peak vertical ground reaction force, and a significant decrease peak posterior ground reaction force as compared to the control group (Onate et al 2001; McNair et al, 2000; Onate et al 2001; Wulf et al, 2003; Shea and Wulf, 1997).

Null Hypothesis 4c: For retention test values, neither experimental group will show a significant difference in landing errors (a difference in LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force as compared to the control group.
Research Hypothesis 4d: For retention test values, the global modeling group will show a significant decrease in landing errors (a decrease in LESS scores), a significant decrease in peak vertical ground reaction force, and a significant decrease peak posterior ground reaction force as compared to the specific modeling group and control group (Onate et al. 2001; McNair et al., 2000; Onate et al. 2001; Wulf et al., 2003; Shea and Wulf, 1997).

Null Hypothesis 4d: For retention test values, neither experimental group will show a significant difference in landing errors (LESS scores), peak vertical ground reaction force, and peak posterior ground reaction force.

Research Question 5: Will the modeling instructions have any effect on the performance of individuals on a novel landing task?

Research Hypothesis 5a: For transfer test values, both experimental groups will produce a decrease in landing errors (decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force as compared to the pretest values (Magill, 2001; Salmoni, Schmidt, Walter, 1984; Wulf and Schmidt, 1997; Park and Shea, 2005; Lai, Shea, Bruechert, Little, 2002; Choi, Meeuwsen, French, Sherrill, McCabe, 2001; Wulf et al., 2004).

Null Hypothesis 5a: For transfer test values, no group will produce differences in landing errors (differences in LESS scores), peak vertical ground reaction forces, and peak posterior ground reaction forces as compared to the pretest values.

Research Hypothesis 5b: For transfer test values, the global modeling group will produce a decrease in landing errors (decrease in LESS scores), a decrease in
peak vertical ground reaction force, and a decrease in peak posterior ground reaction force as compared to the control group and the specific group (Magill, 2001; Salmoni et al, 1984; Wulf and Schmidt, 1997; Park and Shea, 2005; Lai et al, 2002; Choi et al, 2001; Wulf et al, 2003; Shea and Wulf, 1997).

**Null Hypothesis 5b:** For transfer test values, no group will produce differences in landing errors (differences in LESS scores), peak vertical ground reaction forces, and peak posterior ground reaction forces.

**Research Question 6:** Will there be any learning effect in performing the jump-landing task as shown by the control group?

**Research Hypothesis 6a:** There will be no significant decrease in landing errors (decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force for the control group in the immediate posttest as compared to the pretest.

**Null Hypothesis 6a:** There will be a significant difference in landing errors (decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force for the control group in the immediate posttest as compared to the pretest.

**Research Hypothesis 6b:** There will be no significant decrease in landing errors (decrease in LESS scores), decrease in peak vertical ground reaction force, and decrease in peak posterior ground reaction force for the control group in the retention test as compared to the pretest.

**Null Hypothesis 6b:** There will be a significant difference in landing errors (decrease in LESS scores), decrease in peak vertical ground reaction force,
and decrease in peak posterior ground reaction force for the control group in the retention test as compared to the pretest.

Independent Variables

The independent variables of this study are the modeling cues (control group, global modeling group, and specific modeling group) and the various testing times (pretest, immediate posttest, retention test, and transfer test).

Dependent Variables

The dependent variables of this study are the peak vertical ground reaction force (mbw), peak posterior ground reaction force (mbw), and the LESS scores.

Operational Definitions

1) Landing Error Scoring System (LESS) – The LESS is a qualitative assessment tool used for identifying potentially faulty movement patterns and poor technique during a jump-landing task, in which a sagittal plane camera and a frontal plane camera capture the jump-landing movement. An investigator then reviews the footage and scores the jump-landing based on the criteria of the LESS (Boling et al, 2005; Padua et al, 2004a; Padua et al, 2004b). High scores are considered poor (Appendix 7).

2) Poor Landing Mechanics – Poor landing mechanics is defined as a score of 6 or higher on the LESS (Padua et al, 2004b).

3) Specific Modeling Group – The specific modeling group receives written instructions as follows: “trunk, hips, knees are flexed to at least 30 degrees; feet are shoulder width apart; knees do not collapse in; toes are pointed straight ahead; and you are landing evenly on both legs.” Complimenting the
written instructions are frontal and sagittal plane pictures demonstrated by a model (Hewett et al, 1996). Subjects receive these instructions before completing each of their immediate posttest trials (Appendix 2).

4) Global Modeling Group – The global modeling group receives a set of pictures of models landing in an athletic “ready” position. This position is similar across athletic events and is taught at all levels as the proper starting position for numerous physical activities (Colvin, Egner, Markos, Walker, 2000; Joseph, 1998; Kravitz, Akalan, Nowicki, Kinzey, 2003; Shoemaker, 2001). This position is also similar to the proper landing strategy that should be employed by athletes (Myer, Ford, and Hewett, 2004; Shim, Carlton, Chow, and Chae, 2005). This correlation allows for a visual cue for subjects to be able to relate to as a demonstration of how their body should be positioned upon landing. Subjects receive these instructions before completing each of their immediate posttest trials (Appendix 3).

5) Control group – The control group receives no movement technique instruction.

6) Jump-landing Task – The jump-landing task consists of subjects dropping from a 30-cm high box, landing with one foot on each of two 40cm x 60cm force plates, and immediately jumping upward for maximal jump height. The subjects then land back on the force plates with one foot on each force plate (Appendix 4).

7) Maximal Jump Height – A subject will jump with a maximum effort as high as possible. This event does not use any equipment or goals to measure jump
height. The subjects are instructed to "land from the box and then immediately jump straight up in the air as high as they can possibly jump."

8) Peak Vertical Ground Reaction Force (multiples of body weight) – Peak vertical ground reaction force is the highest measurement of force produced in the vertical direction, as measured by a force plate, during the stop-jump phase of the jump-landing task.

9) Peak Posterior Ground Reaction Force (multiples of body weight) – Peak posterior ground reaction force is the highest measurement of force produced in the posterior direction, as measured by a force plate, during the stop-jump phase of the jump-landing task.

10) Stop-jump Phase - The stop-jump phase of the jump-landing task is the time between initial contact to take-off, defined as 300-msec after initial contact (Appendix 5). This definition is a variation of commonly used definitions that use kinematics as a guide, such as maximum knee flexion angle (Devita and Skelly, 1992). This working definition is based on time intervals in which maximal knee flexion would occur while eliminating kinetic forces that occur during the take-off (Lees, 1981; Huston et al, 2001). This time interval will encompass PVGRF and PPGRF.

11) Physically Active Individuals – Physically active individuals participate in exercise a minimum of 3 times per week for a minimum of 20 minutes for the past 2 months (Oñate et al, 2005).

Assumptions

The following is a list of basic assumptions that can be associated with this study:
1) All instrumentation [Two Bertec Force Plates, Model 4060-NC (Bertec Corporation, Columbus, OH, USA), two Sony DCR-HC40 digital mini-DV camcorders (Sony Electronics, INC., San Diego, CA, USA), and one Speed Trap I Timing System (Brower Timing Systems, Draper, UT, USA)] being used was reliable and valid.

2) All athletes complied with the guidelines set forth in the pre-participation agreement, specifically that they did not discuss their instructions and results with other subjects participating in this study and that they did not receive any outside jump-landing biomechanical instruction while participating in this study;

3) The results of the immediate posttest and the retention test were due strictly to the modeling cues given and no other external factors.

4) There was only a minimal practice effect from acclimatization sessions and previous testing sessions on subjects' scores for the LESS, vertical and posterior ground reaction forces.

5) The differences in clothing did not significantly alter the results of the study.

Limitations

Several limitations exist within this study.

1) The jump-landing task used in this study did not consist of many athletically functional tasks, during which most lower-extremity injuries and specifically those to the ACL occur. The jump-landing task in this study was selected due to its standardized nature and the previously tested reliability and validity of the LESS using this task (Padua et al, 2004b; Boling 2005).
2) The population of subjects in this study was not able to be randomly selected due to availability.

3) There was a presence of a practice effect present due to the acclimatization session and the similarity between testing sessions.

4) The maximum jump task did not use any objective measurement device, such as a Vertec, to determine if maximal effort was being achieved by the subjects. An objective measurement device was eliminated from the study in order to aide in the ease of set-up and implementation of the test to better allow for a large number of screenings to be performed in a relatively short amount of time.

Delimitations

1) This study was delimited to college-aged physically active individuals (18-25 years of age) that had no previous lower extremity injury in the past two months that limited activity for more than one day, no current self-reported history of lower extremity instability, or underwent any previous lower extremity surgery within the past two years (Oñate et al, 2005). Subjects did not have any previous history of ACL reconstruction surgery. Subjects also needed to exercise a minimum of twenty minutes a minimum of three times a week for the past two months to be eligible to participate in this study.
CHAPTER II

REVIEW OF LITERATURE

The following is a review of literature concerning the anterior cruciate ligament and subsequent issues associated with it; injury aspects, motor learning and its application with injury prevention strategies, and the use of jump-landing tasks to discover and screen for risk factors of anterior cruciate ligament injury. In combination, these topics can be vital portions of anterior cruciate ligament injury screening and prevention. While many studies have focused on the identification of risk factors of anterior cruciate ligament injury and injury prevention strategies, there is a need for research that will look at clinical tools for effective screening and prevention implementation for large numbers of individuals, such as athletic teams and the military. Identification of risk factors and subsequent correction of those risk factors is a primary goal of various disciplines within the medical community. The focus of future research must now be on clinical application of identification and prevention strategies.

Anatomy of the Anterior Cruciate Ligament

The anterior cruciate ligament (ACL) is a band of thick connective tissue that courses from the posteriomedial side of the lateral femoral condyle to the anterior portion of the medial tibial plateau on an oblique path through the intercondylar fossa (Zanthop, Petersen, and Fu, 2005). The width of the ACL ranges from 7mm to 12mm (Odenstern, Gillquist, 1985; Kennedy, Weinberg, and Wilson, 1974). The ACL is the primary restraint to anterior tibial translation in the knee (Fukubayashi, Torxilli, Sherman, and Warren, 1982; Butler, Noyes, and Grood, 1980) along with playing a role in controlling internal and external rotation (Fleming, Renstrom, Beynon, Engstrom, Perua, Badger,
and Johnson, 2001; Kanamori, Zeminski, Rudy, Li, Fu, and Woo, 2002; Markoff, Gorek, Kabo, and Shapiro, 1990) and varus and valgus forces (Marder, Raskind, and Carroll, 1991).

The ligament appears to turn upon itself due to its bony attachments – the femoral attachment being oriented to the femoral longitudinal axis and the tibial attachment being oriented in the tibial anterior-posterior axis (Zanthop, et al, 2005). This rotation creates two functional, though not physiological, bundles of the ACL – the anteriomedial and the posteriolateral (Odenstern et al, 1985; Girgis, Marshall, and Monajem, 1975). These two bundles function synergistically to create the optimal restraint over full knee flexion and extension ranges of motion (Xerogeanes, Takeda, Livesay, Ishibashi, Kim, Fu, and Woo, 1995). The range of motion of the knee dictates which bundle works as the primary restraint, with flexion moments causing the anteriomedial bundle to be taut and extension and rotary moments causing the posteriolateral bundle to be taut, while hyperextension creates the greatest strain in both bundles (Bach, Hull, and Patterson, 1997; Amis and Dawkins, 1991; Gabriel, Wong, Woo, Yagi, and Debski, 2004). In addition, the posteriolateral bundle, while still carrying less force than the anteriomedial bundle, increases its force load significantly from 30 degrees of flexion to 90 degrees of flexion (Xerogeanes et al, 1995).

The fibers of the ACL change length throughout knee motion through a crimping/straightening pattern inherent in the design of the ligament with the mean length being 32mm (Beynnon, Johnson, Abate, Fleming, and Nichols, 2005a; Amis et al,1991; Kennedy et al, 2001). Along the length and cross section of the ACL, the material properties of the ligament vary (Butler, Guan, Kay, Cummings, Feder, and Levy, 1992).
The average failure load and stiffness of the ACL has been measured to be $2160 \pm 157$ N and $242 \pm 28$ N/mm, respectively and these values has been shown to decrease with age (Woo, Hollis, Adams, Lyon, and Takai, 1991).

The ACL receives its blood supply from a variety of sources. The superior portion is supplied by the middle geniculate artery while the distal portion is supplied by branches of the inferior geniculate artery (Amoczky, Rubin, and Marshall, 1979; Petersen and Hansen, 1997). Within the ligament, the blood vessels are found in the loose connective tissue (Petersen and Hansen, 1997). Avascular areas exist at the insertion sites, where chondrocyte-like cells are found, and the anterior portion approximately 0.5cm proximal to the tibial insertion, perhaps due to the compressive stress located at this site due to the anterior end of the intercondylar notch (Petersen and Hansen, 1997). The nervous supply of the ACL is made up mainly of Ruffini receptors and free nerve endings that function as stretch receptors and nociceptors, respectively (Hogervorst and Brand, 1998).

Epidemiology/Etiology of Anterior Cruciate Ligament Injuries

The ACL is the most frequently totally disrupted ligament in the knee with over 95,000 new injuries each year and over 100,000 reconstructions performed every year in the United States (Frank and Jackson, 1997; Miyasaka, Daniel, and Stone, 1991; Muneta, Sekiya, Yagishita, Ogluchi, Yamanoto, and Shinomiya, 1999; Owings and Kozak, 1998). The incidence of ACL injury is 2.4 to 9.7 times higher in females than males, although more males undergo reconstruction due to the higher population of males in athletics in the United States, especially in the high risk sport of football (Owings and Kozak, 1998). Direct contact is only involved in 29% of the injuries (Kirkendall and Garrett, 2000).
Over 70% of ACL ruptures are non-contact injuries due to activities such as deceleration, pivoting, awkward landings, and “out of control play” (Griffin et al, 2000; McNair, Marshall, and Matheson, 1990). The highest incidence of ACL injury occurs in individuals, 15 to 25 years old, that are involved in pivoting and landing sports (Griffin et al, 2000).

ACL injuries are considered to have negative immediate and long term effects on the structure of the knee joint. The immediate problem of functional instability that a lack of an ACL creates is inevitably what can cause many of the long-term problematic effects (Beynnon et al, 2005a). These complications include meniscal tears, early onset of osteoarthritis, failure of secondary stabilizers, and lack of functionality due to sensations of “giving way” and feelings of weakness. (Beynnon et al, 2005a).

Attempting to limit these complications is the primary purpose of ACL reconstruction (Beynnon et al, 2005a); however surgery does not guarantee safety from these problems as the injury itself is a predisposing factor (Gelber et al, 2000). With the young age that most ACL injuries occur and the high risk for osteoarthritis, Gleber et al (2000) suggests that prevention may be the best route to reduce the incidence of early onset osteoarthritis.

Mechanisms of Injury of Anterior Cruciate Ligament Injuries

Several mechanisms of injury have been found to cause damage to and, in severe cases, rupture of the ACL. Noncontact ACL injuries usually involve a deceleration before a change in direction or landing from a jump on one or both legs with the knees between 20 degrees of flexion and full extension (Boden, Dean, Faegin, and Garrett, 2000). For the anterior cruciate ligament to tear, the patient must experience excessive anterior tibial translation or rotation of the femur (Kirkendall and Garrett, 2000). Ford et
al (2003) noted that an increased valgus motion at the knee is an indication of decreased joint control in the coronal plane and thus a predisposition to injury. A violent and strong quadriceps contraction, especially if in response to an uncontrolled movement, with the knee between 50 degrees of flexion and full extension, may also result in an ACL rupture by causing an excessive anterior tibial displacement (Markoff, 1990).

Meyer et al (2005) reported that excessive compression (5.1 ± 2.1 kN) between the tibia and the femur caused rupture of the ACL, resulting in the femur being displaced posteriomedially and the tibia rotated internally across all knee flexion angles; these values are not much higher than the 4.2 to 6.1 times body weight forces that are experienced in typical jump landings. Yet, several authors have found that compressive loading of the tibiofemoral joint actually increases the joint stiffness and thus decreases the anterior displacement of the tibia, taking stress off the ACL (Torzill, Deng, and Warren, 1994; Markolf, Bargar, Shoemaker, and Amstutz, 1981; Beynnon, Fleming, Labovitch, and Parsons, 2002).

Hyperextension, excessive tibial internal rotation, and excessive varus or valgus stresses after the collateral ligaments have been damaged can also contribute to an ACL tear (Lewis, Lew, and Markolf, 1993; Beynnon, Fleming, Pope, and Johnson, 1993). Chaudhari and Andriacchi (2006) found that altering the valgus and varus alignments of the knee as little as two degrees reduced the axial loading injury threshold for the ACL by as much as one factor of bodyweight; while Hewett et al (2004) found that increased valgus and external knee abduction moments can predict ACL injury in the female athlete with 73% specificity and 78% sensitivity. The knee flexed less than 30 degrees, valgus loading, and an externally rotated foot has also been implicated in ACL injury (Teitz,
McNair and colleagues (1990) found that over 53% of their 23 subjects' ACL injuries were aligned in internal tibial rotation and slight knee flexion. Not only does the ligament become stressed by the forceful movements into anterior tibial translation, hyperextension, and/or tibial rotation, but these positions also put the ACL in a position to become impinged in the intercondylar notch, adding to the threat of rupture or injury (Zhang, Fung, Ahn, Park, Ren, Koh, Hendrix, Liu, 2006).

Most patients describe their injury as occurring during planting to change directions, landing or stopping (Kirkendall and Garrett, 2000). These situations are problematic due to the stresses on the knee due to the forces listed previously. After reviewing video recordings of several confirmed ACL injuries, Teitz (2001) summarized that most injuries occurred when the center of gravity was behind the knees; and thus by focusing on landing on the toes or ball of the foot, this potentially injurious position can be eliminated.

Risk Factors of Anterior Cruciate Ligament Injuries

While in some ways very similar to the mechanisms of injury, risk factors for ACL tears have become prominent in the search to find a way to prevent the debilitating occurrence of ACL injury in the physically active population. Griffin et al (2000) broke down the multiple risk factors into four different categories – environmental, anatomic, hormonal, and biomechanical. Environmental risk factors are those that are imposed on the athlete from outside sources, such as surface and bracing issues. Anatomical risk factors usually concern the body’s inherent aspects, such as intercondylar notch size or Q-angle. The effects of hormones, especially progesterone, estrogen, and relaxin on the properties of the ACL are potential risk factors. Finally, biomechanical risk factors
encompass any problems that may be caused by strength, proprioceptive, neuromuscular, or technique deficits. This final category is where many prevention strategies are focused, since many of these issues may be correctable with training.

Recent literature has indicated mixed results concerning many of the environmental risk factors of ACL injury (Randall, Miller, and Shurr, 1983; Teitz, Hermanson, Kronmal, and Diehr, 1987; Rovere, Haupt, and Yates, 1987; Griffin et al, 2000; Myklebust, Maehlum, Engebretsen, Strand, and Solheim, 1997; Kirkendall and Garrett, 2000; Lambson, Barnhill, and Higgins, 1996; Orchard, Seward, McGivern, and Hood, 1998; Scranton, Whitseal, Powell, Dormer, Heidt Jr, Losse, and Cawley, 1997). The use of knee braces as a preventative measure early on had been found to be an effective tool (Randall et al, 1983); yet that has since been contradicted with statements of no definitive evidence (Teitz et al, 1987; Rover et al, 1987), most prominently by the American Academy of Orthopaedic Surgeons in 1984 (Griffin et al, 2000). The effect of shoe or playing surface has also been implicated in ACL injury rates. A high level of friction between the shoe and the playing surface in team handball players (Myklebust et al, 1997) and a greater number of cleats creating greater torsional forces have all been implicated in higher ACL injury rates (Kirkendall and Garrett, 2000; Lambson et al, 1996). A dry playing surface, especially where weather conditions consist of high evaporation and low rainfall before competition can predispose an individual to ACL injury (Orchard et al, 2001; Scranton et al, 1997).

Anatomical risk factors are implicated in ACL injuries due to the impact that they have on the ligament itself, whether through stretching, stressing, or impinging. Sourayl and Freeman (1993) found that high school athletes with small intercondylar notch width
indices (the ratio of the width of the anterior outlet of the intercondylar femoral notch divided by the total condylar width at the level of the popliteal groove) had an increased risk of ACL injury. Zhang et al (2006) described two patterns for ACL impingement due to intercondylar notch width based on 3-D knee geometry and computer simulation models. Individuals with "narrow" notches can experience impingement of the ACL on the lateral wall during tibial external rotation and abduction in flexed knees, while those with "normal" or "wide" intercondylar notches did not experience impingement forces with various tibial movements except in extreme hyperextension, where there was impingement on the medial corner of the notch roof. Anderson et al (1987) demonstrated a significant narrowing of the intercondylar notch outlet in patients with unilateral and bilateral ACL tears. In contrast, Lombardo et al (2005) found no correlation between intercondylar notch width and ACL injury in male professional basketball players. They state this may be due to the fact that males have larger intercondylar notch indices and that there was no difference between injured and noninjured males. Other research has indicated that there is no statistically significant difference in the notch width between sexes (Anderson et al, 2001). Related to intercondylar notch width is the actual size of the ACL, which has been shown to differ in males and females, with males having larger anterior cruciate ligaments (Anderson et al, 2001). Uhorchak et al (2003) not only found a correlation between smaller notch width and ACL injury, but that generalized joint laxity, an increased arthrometric measurement of laxity on a KT-2000 of one standard deviation or more, and a higher body mass index in females all predicted ACL injury in military academy cadets. Hutchinson and Ireland (1995) also found several risk factors that could result in failure of the ACL in female athletes including excessive pathological
laxity, tibial rotation, the Q-angle and other foot-pelvis alignments. Body Mass Index (BMI) may also explain the female/male differences in ACL injury rates, with higher BMIs correlating to increased ACL injury risk (Anderson et al, 2001).

With the increased risk of ACL injury for females, many researchers have investigated the natural hormonal differences between genders for answers. Estrogen and progesterone receptor sites have been found in ACL cells showing a correspondence between these hormones and the ACL (Liu et al, 1996). These female hormones can weaken the composition and reduce the tensile strength of the ACL in rabbits (Liu et al, 1996; Slauterbeck et al, 1997). Wojtys et al (1998) found more injuries during the ovulatory phase of the menstrual cycle (when hormones surge) than in the follicular phase (when hormones are low). Consensus in this arena is lacking currently, as Van Lunen et al (2003) found no correlation between phases of the menstrual cycle and the arthorometric measurements of laxity of the ACL.

The final category of risk factors, biomechanical, involves many aspects that have become the focus of ACL injury prevention strategies. While attempting to distinguish between males and females and their incidence of ACL injuries, increased focus has been given to muscle imbalances of the hip and knee. The relative weakness of females’ hip extensors, forcing them to use their illiopsoas muscles for trunk control over the hips, most likely causes them to land from a jump in a more upright hip position, allowing for improper knee alignment (Putnam, 1993). A decrease in the function of the hip extensors (monoarticulate muscles), decreases the activation of the quadriceps and the hamstrings (biarticulate muscles) altering the optimal load-bearing capacity of the knee joint (van Ingen Schenau et al, 1987; Bobbert and van Zandwijk, 1999). Medina et al (2007)
discovered that male athletes and female athletes recruited the rectus femoris significantly earlier when landing from a jump as compared to female nonathletes. Female athletes demonstrated faster time to initial contraction of the vastus medialis compared to male athletes, which may support the male versus female differences in knee stabilization strategies. There were no difference in hamstring activation among the three groups, exhibiting that basketball training alone does not target the hamstrings directly and that some hamstring-focused exercises should be implemented (Medina et al, 2007). Male athletes have been shown to have greater quadriceps and hamstring muscle strength than female athletes, possibly contributing to ACL injury rates (Anderson et al, 2001). Large hip internal rotation and flexion was found to correspond with knee valgus angles in NCAA athletes during a sidestepping task, which has implications to ACL injury risk (McLean et al, 2005).

Along these lines, women have been shown to cut and land during athletic activities in a more erect posture with less knee and hip flexion and thus putting the ACL at greater risk for injury (Griffin et al, 2000). Being off balance or experiencing a sudden change in a movement or a perturbation causes an athlete to activate their quadriceps in order to steady themselves, causing greater strain on the ACL while the knee is in an abnormal alignment due to the unexpected motion (Griffin et al, 2000). This abnormal alignment, usually a valgus or varus condition, has been shown by Chaudhari and Andriachhi (2006) to increase the injury threshold of the ACL during a jump landing type activity (increased joint compressive forces).

Chaudhari and Andriachhi (2006) also stated that dynamic stabilization of the hip abductors and adductors improves the alignment and stability of the knee, limiting valgus
and varus motion, as they act like a link to use the rest of the body to control the motion of the hip, and thus the motion of the knee. Decreased strength in the hip abductors and adductors could predispose individuals to misalignment of the knee and thus predispose them to ACL injury. A phenomenon known as ligament dominance, in which an athlete cannot control the torque on the joints of the lower extremity using their musculature during athletic activities has been shown to be present in female high school basketball players (Ford et al, 2003). This ligament dominance is characteristic of excessive knee valgus motion during several different athletic tasks, predisposing the ACL to greater risk of injury (Ford et al, 2003). Recently, Hewett et al (2005) and McLean et al (2005) determined that knee valgus loads and motion during a jump-landing task and sidestepping task, respectively, can predict ACL injury in females.

Along with knee valgus and varus alignment, small knee flexion angles upon landing from a jump or other athletic maneuvers have been shown to be a risk factor for ACL injury (Mesfar and Sirazi-Adl, 2005), especially concerning the increased risk of ACL injury in women (Arendt and Dick, 1995; Huston et al, 2001; Malinzak et al, 2001). Females have significantly less knee flexion angular displacement, lower leg internal rotation maximal angular displacement, and time to knee flexion maximum angular displacement than males in a single leg hop and a single leg land (Lephart, Ferris, Riemann, Myers, and Fu, 2001) and a double leg jump landing task (Padua, Marshall, Beutler, DeMaio, Oñate, Bing, Guskiewicz, and Garett, 2004) which may increase ACL load deformation. Yu et al (2005) also found that youth female soccer players begin to demonstrate decreased knee and hip flexion angles at initial ground contact and throughout landing from a stop-jump task compared to males beginning after the average
age of twelve; whereas before this age, the two sexes display similar mechanics.

Conversely, Faugenbaum and Darling (2003) reported that female collegiate basketball players did not land in a more extended position at their knee joints as compared to male collegiate basketball players; and thus, the greater incidence of ACL injury in women cannot be attributed to knee flexion angles.

The findings of Meyer et al (2005) concerning the increased risk of ACL injury with high joint compressive forces demonstrate a mechanism of injury for ACL injury. They also indicate that high vertical ground reaction forces in jump-landing tasks could be a predictive factor of ACL injuries. Along with vertical ground reaction force, high posterior ground reaction forces could indicate a risk of ACL injury, due to their correlation with anterior tibial shear force, a mechanism for ACL injury (Sell et al, 2004).

Yu et al (2006) determined that PPGRF correlated to PVGRF, peak anterior tibial shear force, and peak knee extension moments during the landing phase of a jump, indicating the potential for PPGRF to relate to improper kinetic and kinematic factors.

### Prevention of Anterior Cruciate Ligament Injuries

With the identification of many risk factors for ACL injuries, there has been an increase in the strategies of prevention that address a variety of different risk factors. Prevention strategies encompass many different techniques and approaches to achieve their goals, usually of decreasing landing forces and increasing joint stability. The use of plyometric, jump technique, strength, proprioceptive, and instructional training have all been used alone or, more commonly, in combination to achieve ACL injury prevention.

Hewett and his colleagues (1996) proposed a jump-training program to alter the mechanics of landing and increase the strength of female athletes’ lower extremity
musculature. The purpose of the program was to reduce landing forces through neuromuscular control and increase the stability of the knee joint through strength gains in the musculature surrounding the knee. The Hewett program incorporated weight training for both the upper and lower extremities to supplement a jump-training program consisting of a variety of different plyometric jumps in both double and single leg stances that followed a three phase strategy (two weeks each). The first phase focused on technique, with emphasis on proper body alignment, posture, and imagery of landing softly. The second phase focused on fundamentals, increasing strength, power and agility while using the proper technique, and the third phase was based on performance to achieve maximal jump height. They found that ten of eleven female jumping athletes reduced their vertical ground reaction forces and that abduction (varus) and adduction (valgus) were significantly reduced in the subject population (Hewett et al, 1996). Valgus motion is a predictor to peak landing forces (Hewett et al, 1996) and a mechanism of injury for ACL injuries (Ford et al, 2003).

Similar to Hewett et al, a variety of plyometric jumping tasks were compiled from literature and incorporated by Myer et al (2004) into a variety of neuromuscular training protocols to address the different neuromuscular imbalances that are often displayed in female athletes, leg dominance, quadriceps dominance, and ligament dominances. While the authors did not produce any data showing the effectiveness of the programs, through their review of literature, they concluded that the specific strengthening and neuromuscular training, based on the athlete’s specific dominance issue, could result in lower ACL injury rates if training sessions were implemented.
Over three seasons, female team handball players were monitored for ACL injuries (Myklebust, Engebresten, Braekken, Skjolber, Olsen, Bahr, 2003). The first season was used as a control season with the subsequent two seasons acting as the intervention timeframe. Fifty-two total teams (850 players) were enrolled in a five-phase program that incorporated balance exercises, neuromuscular control, and planting/landing skills. The received exercise equipment and video and poster visual aides while reporting back to physiotherapists. The number of ACL injuries significantly reduced over the two intervention seasons compared to the control season. The authors concluded that their neuromuscular training program could be implemented to reduce ACL injuries.

Combining neuromuscular and proprioceptive training proved effective for Mandelbaum and colleagues (2002) and Hewett et al (2001) in decreasing ACL injury. Mandelbaum et al (2002) reduced ACL risk by 88% in female soccer players over the course of a season by incorporating avoidance techniques, strengthening, plyometrics, and agility drills over the course of twelve weeks, two to three times per week. Hewett et al (2001) reported zero injuries in the training group compared to five injuries in the control group of female soccer players over the course of one season. They used thirty minutes of plyometrics and thirty minutes of progressive resistance exercises three times a week for six weeks. Both of these programs incorporated informing the athlete as to proper mechanics with the goal to "land as softly as possible".

While the previous studies have incorporated some corrective elements (proper mechanics instruction), the Henning Program is based mainly on altering athletic maneuvers that have been implicated with ACL injuries by previous publications (Griffin, 2001). Henning’s focus was to change the way an athlete planted and cut into
an accelerated round turn, modify an athlete’s landing into a more flexed knee position, and to transform a one-step stop with a straight knee into a three step stop with a flexed knee. The Henning Program was not scientifically tested before Dr. Henning’s untimely death. While Griffin does not specify the methods of providing the instruction, the Henning Program is an example of using motor learning to alter an athlete’s motor skills, in order to reduce injury rates.

Two lower extremity training programs, one consisting of stretching, strengthening, and balance; and the other involving plyometric and agility exercises in addition to the previous three components, were measured kinetically and kinematically and resulted in improvements in neuromuscular control needed for proper movement patterns to prevent ACL injury (Sell, Lephart, Ferris, Abt, Irrgang, Fu, 2003). The program that included plyometric and agility drills also improved muscle firing patterns which may improve dynamic joint stability, important to reducing noncontact ACL injury.

Recent research indicates that prevention should be implemented to reduce the risk of ACL injury in females, especially on those who demonstrate poor dynamic knee stability, as they will benefit most from training. Hewett et al in their meta-analysis of prevention strategies (2006) determined that neuromuscular training potentially changes active knee joint stability which may reduce ACL injury risk in female athletes. The three effective studies (reduced ACL injury risk) they reviewed all included plyometric training in combination with biomechanical analysis and technique training, while straight balance training and plyometric training did not prove effective. These findings demonstrate a need for multivariate prevention programs that should especially include
biomechanical analysis and instruction/feedback (Hewett, Ford, Myer, 2006). However, when utilizing multivariate programs, it is difficult to know which program components are the keys to prevention strategies for knee injuries (Bahr, Krosshaug, 2007). Padua and Marshall (2006) reviewed the current literature for research that involved proprioceptive balance-training and plyometric agility training. The majority (all but one) of the reviewed literature was considered an evidence level 2 which is middle of the three levels, denoting limited quality patient-oriented evidence, lower quality clinical trials, cohort studies, and case-control studies. The pooled level of evidence for exercise programs to prevent ACL injuries was moderate, signified by inconsistent or limited-quality of patient-oriented evidence. From the research reviewed, the authors determined individuals should be encouraged to participate in these types of exercise programs due to the moderate supportive evidence and no indication that these programs cause any harm.

However, it is important to not only consider the level of evidence in the current research, but to observe the actual numbers of subjects, exposure hours to both the interventions and to the risky environment, and the number of injuries in order to obtain a more objective viewpoint of the results. Grindstaff and colleagues (2006) examined all of these variables in their meta-analysis involving number-needed-to-treat (NNT) and relative risk ratios (RRR) to prevent ACL injuries with neuromuscular control training programs. Five studies were utilized, all of which were from peer-reviewed journals where the training programs were compared to controls. The authors determined that to prevent one ACL injury over the course of one competitive season, 89 individuals must participate in the intervention program and these programs collectively had a RRR of 70%.
When decided whether to incorporate an intervention program, one must consider the results of studies, the NNT and RRR of such programs, as well as logistics, such as time involved, number of personnel needed to implement the training, and how these issues weigh in compared to the projected results. Another matter to consider is who needs the intervention and how to reach that number of individuals, small or large. There are indications that identifying athletes in need of training should be a focus of future research and prevention strategies (Hewett et al., 2001). Hewett et al (2001) call for a need to screen large number of individuals, using valid and reliable tools, as the best means to prevent and lower ACL injury risk.

Anatomy/Physiology of Motor Learning

The process of learning a new skill involves complex brain activity to both acquire and retain the information. Much of the anatomical and physiological affects of learning have been performed on lab mice as a means of visualizing changes in the brain. In mice, there are stages of learning, an initial phase of fast improvement and a slow phase of improvement across many sessions of training (Costa, Cohen, and Nicolelis, 2004). These sessions are indicated by differences in neuron firing rates and plastic changes in the motor cortex and/or striatum. The fast improvement phase is characterized by the majority of plastic changes corresponding with an increase in task-related neural circuitry in both the striatum and the motor cortex. During the subsequent learning sessions, the ratio of recruited and dismissed neurons equalizes. Within the slow improvement phase, the plastic changes develop slowly throughout the learning sessions and are distinct from the fast motor skill learning and correspond with the refinement of the motor skill. Costa and associates (2004) have also found that there are ongoing
changes that occur within these areas for days after the training has expired, indicating a continuous process of learning even in the absence of direction, especially during the next sleep cycle.

Using positron emission tomography (PET) to track cerebral blood flow, investigators determined that, in humans, different stages of motor learning cause activation of different areas of the brain (Matsumura, Sadato, Kochiyama, Nakamura, Naito, Matsunami, Kawashima, Fukuda, Yonekura). Matsumura et al (2004) found that all changes in activation patterns during learning were found exclusively in the cerebellum, while implicit motor learning was most prevalent in the left-side of the cerebellum. They used a unimanual two-ball rotation task to evaluate the cognitive processes of motor skill learning. Task performance activated the left lateral cerebellum, and the right inferior frontal gyms closest to the ventral portion of the premotor cortex were used exclusively regardless of the side of the body being used. Activity in the left lateral cerebellum was highest while the task was being performed for the first time. As task performance improved (suggesting learning gains), the neuronal activity of the left Qua close to the dentate nucleus (the left parasagittal cerebellum) decreased, demonstrating that this area is used mostly in initial learning stages.

Learning seems to follow a top-down pattern in the temporal domain, with easy tasks (those with larger signal-to-noise ratios) are learned at higher cortical levels of the visual pathways while difficult tasks (where better/smaller signal-to-noise ratios are needed) are learned at lower-levels (Ahissar and Hochstein, 2004). This top-down pattern is essentially demonstrating that learning is attention driven, in that attention is the mechanism in place to choose the correct neuronal population. According to Ahissar
and Hochstein (2004), there is a specific neurological process to becoming an expert performer. Beginners (Naïve performers) are controlled by representations at the “top” of the visual hierarchy no matter the complexity of the task. Mildly trained performers with previous exposure to the task and its context demonstrate high-level modifications and marked general improvement. Highly trained performers (those with a lot of training experience) can “decide” which level they access when performing the task depending on the conditions and context surrounding the task. Finally, experts (with ample amounts of training) can use higher levels again, even in difficult cases as the task is second nature to them.

The storage of motor skills is a separate sequence than the acquiring of a skill. Humans have been found to store ballistic movements and novel dynamic tasks in different portions of the brain (Baraduc, Lang, Rothwell, and Wolpert, 2004). Ballistic, repeated movements, such as a simple index finger task, are stored within the primary motor cortex, while the new motor skill, a dynamic overcoming of an external force to the index finger, was found to be undisturbed by interference to the motor cortex. This conclusion led the investigators to assume that novel tasks are stored outside the motor cortex, perhaps distributed in many areas.

Theories/Definitions of Motor Learning

In order to be able to retain any motor skill, a method of motor learning must be implemented. To acquire any motor skill, one has to identify and learn the most effective techniques of performing the tasks of the skill (Annett, 1993). Two main theories have been established to explain how humans acquire skills. Open-looped systems have no feedback or means of error regulation. In this system, if an error occurs it is because of a
characteristic of the input and/or the transformations imposed by the system (Adams, 1971). The example that Adams uses is a traffic light that changes the lights based on a pre-programmed timing regardless of traffic flow. Adams (1971) also proposed a closed-loop system in which there is feedback, error detection, and error correction. For a closed-loop system, a reference must be present that dictates the desired value for the system. The results or output of the system are fed back into the system to be compared with the reference to detect errors that can then be corrected. This self-regulating system thrives on the ability to detect and alter any deviations from the standard reference. Two traces are used to alter the action – the perceptual trace and the memory trace. The perceptual trace is the reference of the closed-loop system and it is based on the memory of past movements/actions. The memory trace commences the response when it is cued to begin.

Most modern day motor learning theories are based on the closed-loop system. Inherent in this theory is the use of Knowledge of Results (KR) or Knowledge of Performance (KP). KR involves an individual knowing whether or not they completed a task correctly based on the results of the task by receiving a “right” or “wrong” from an instructor with or without directional focus (Adams, 1971). KR was supported by Newell (1974) when he determined that the primary role of KR is in providing information to reduce error and assiting in developing the reference for future comparisons of the same action/movement. While KR is based on the results of the completion of a movement, KP focuses on providing feedback to the subject about the particular kinematics used to perform the action/movement (Salmoni et al, 1984). Janelle et al (1997) found that the use of KP in trying to improve throwing form was more successful than KR. English
(1942) found that the rapid improvement of military shooters in their marksmanship skills had to be attributed more so to KP than to KR since they gained a local kinesthetic insight into what they had to do in order to perform the task correctly.

Knowledge of Performance and Knowledge of Result can be found in most forms of motor learning, especially instruction and feedback, where KP is seen in feedback and KR is seen in instructions and modeling. Using both instruction and feedback, the subject can compare back to the original cue to gain KR. In order for KR to be effective in training sessions, especially those in real-life situations, the student must be directed to those points of the skill which are most essential and critical to the overall goal of the motor task (Annett, 1993).

There is debate on how much feedback is most effective in skill acquisition. While it seems logical that the more information a subject receives during the learning process, the better equipped that subject is to learn the skill accurately (Adams, 1971), there is evidence that too much information degrades the ability of the subject to retain the learned information over time (Schmidt, 1991). The positive and negative effects of frequent feedback must be weighed in any learning process to provide the most effective learning environment. Additionally, discovery learning and directive learning (given instructions/analogies) seem to have the same effect on the accuracy of a performance on a balance task (Orrell, Eves, and Masters, 2006). The amount and timing of KR appears to affect acquisition and retention of motor skills. Delaying KR to after every other trial allowed subjects to report using a larger number and variety of intrinsic feedback sources (sources available to them through their senses) and found to have better retention than those who received KR after every trial (Anderson, Magill, Seikya, and Ryan, 2005).
However, this same delayed KR group had lower acquisition scores than the immediate KR group. So it seems that while given ample instruction may facilitate immediate performance. However, in order to attain retention of a skill, individuals must have some time to sort the skill out for themselves.

**Transfer Tests in Motor Learning Research**

Within motor learning research, there is a need to provide indication that a skill has been acquired and retained in order to deem a teaching technique successful. To assess acquisition of skill, skills are usually measured immediately after interventions or instructions are given to a subject. To determine how well a subject retains knowledge of a skill, most research uses a retention test. Retention tests involve subjects performing the same skill as they performed earlier (days, weeks, months, or years) with instruction, KR, KP, or other such intervention with the exception that this time they receive no intervention.

Transfer tests are important in motor learning research when dealing with tasks that can translate to other movements that are similar in concept but different in execution. Magill (2001) defines what transfer tests infer as “the adaptability aspects of performance changes related to learning.” A novel situation is used so that subjects must adapt their newly acquired skill (Magill, 2001). Transfer tests involve testing a subject who has gained knowledge of one task being asked to perform a variation of the task. In means of KR research, a transfer test usually involves subjects who receive KR in the acquisition phase and then have the KR removed to perform a similar but different task or the same task with varied parameters (Salmoni et al, 1984). Transfer tests usually occur without KR or KP in order to make the most powerful statements about learning
Essentially, the research indicates that the group that performs best on the transfer test has learned the most from the acquisition phase (Salmoni et al, 1984).

Some examples of transfer tests in research involve subjects performing tracking patterns where the amplitude or pattern vary from the acquisition phase (Wulf and Schmidt, 1997), produce waveform patterns using the contralateral limb (Park and Shea, 2005), and type a new sequence or type a sequence using a single hand or finger in the same timeframe as the acquisition phase (Lai et al, 2002), all without the use of KR.

Motor skill learning and transfer tests can be exemplified in a throwing task by Choi et al (2001) in which subjects with profound mental retardation practiced throwing bean bags at targets at designated distances during the acquisition phase. To test learning gains, a transfer test was implemented where subjects had to throw the bean bags to different distances and then throw a horseshoe at the original targets. Subjects were able to transfer knowledge gained in the acquisition phase to both novel distances and a novel instrument.

Verbal and Visual Instructions in Motor Learning

In order to teach a skill, most instructors resort to verbally directing the subjects in the task. Annett (1996) provided an explanation as to how verbal instructions are translated into human action and vice versa. The action, language, imagination (ALI) model shows two channels, one for human action and one for verbal instructions. The two channels are linked by the Action-Language Bridge, which utilizes visual imagery. Imagery is a common occurrence in athletic skill learning and has both a cognitive and motivational component to it for the athlete (Hall, Buckolz, and Fishburne, 1992). In order to perform a task, the subject needs the ability to take verbal instructions and
visualize what the instructor is explaining to them. According to this same theory (Annett, 1996), visual instructions are a simple way of initiating and controlling the learning process, as the visual image would travel along the same path directly to human action without having to be converted unlike verbal instruction.

The basic theory behind acquiring knowledge from a visual demonstration or instruction has been summed up by Sheffield (1961) when he compares motor responses with perceptual responses in “passive” learning from demonstrations. He provides a model of learning a complex motor skill, in which the skill is broken down into a chain of sequences that are learned separately, yet tied together utilizing the previous point as the cue for the next portion. The more the individual portions are observed and subsequently practiced together, the stronger the cues will be hinged together. The individual that observes a demonstration can then commit the correct overt sequence to memory and then reproduce the sequence in action. The memory image is continually manipulated by the learner until his or her recall is a perfect match to the actions that they can reproduce.

When processing afferent information, one determines which source is most likely to result in the best performance and will use this piece of information above all other sources of afferent information available (Robin, Toussant, Blandin, and Proteau, 2005). Many times this form of afferent information is visual cuing. However, effective visual cuing may be to immediate performance, the reliance on any one form of afferent information can inhibit retention and reproduction of the task, especially tasks that involve proprioception or other feedback forms.

Providing instructions to individuals in some form may benefit the learning process of a motor skill. External instruction provided to a subject is better for learning
than overt self-instruction or covert self-instruction in a tracing task for both speed and standardized compound score (Nedate, Toyokawa, Shirakawa, 1993). When providing instructions, there is a need to understand what specifics and how many specifics to draw the attention of the subject to while performing the task. Del Rey (1971) looked at the effectiveness of an outside individual choosing to put emphasis on certain aspects of a motor skill for a subject. He found that subjects just learning a task must be directed to pick out relevant information in assessing their performance. When the scene of the skill was closed (the environment was controlled), he found that the best focus for individuals to learn the skill was to reproduce preplanned standard movement patterns that had been given to them in the learning process. In contrast, researchers have found that too much instruction can be detrimental to the learning process, especially when subjects try to reproduce the task in a stressful situation, like an athletic event (Wulf, Weigelt, 1997).

**Modeling as a Form of Motor Learning**

Modeling is a form of visual instruction in which an individual is given a cue on which to base their actions or positioning. Like demonstration, modeling is a necessary part of the learning process, allowing the individual to know what must be practiced, especially in complex motor tasks (Sheffield, 1961). Modeling has a tradition of being used with training programs where large number of individuals must learn the skill in a timely manner, such as with manufacturing (Lindahl, 1945). Trainees who were learning to cut tungsten rods, learned the quickest and most accurately from a standard model in which their progress was constantly compared to the standard (Lindahl, 1945). Lindahl saw the potential for modeling in other areas following the success of this study.
Individuals tend to perform and retain a skill significantly better when they focus on an external function (outside themselves) versus an internal function (within their own body) (Wulf, Weigelt, Poulter, and McNevin, 2003; Wulf, Mercer, McNevin, and Guadagnoli, 2004). Wulf and Weigelt (1997) showed that giving body-related instruction degraded the learning process. This concept may have some correlation with modeling. An individual focusing on their own body, or instructions linked specifically to the body, may have similar ends to those of an internal focus; while individuals modeling a system that does not draw attention to specifics, may be similar to those who use an external focus. It is theorized that external foci allow unconscious or automatic processes to control movement and internal foci cause individuals to consciously intervene in the control process, which can actually disturb the whole learning and performing process (Shea and Wulf, 1999; Wulf et al, 2004).

In contrast to these findings, Scully and Carnegie (1998) discovered that verbally directing the attention of observers to a specific joint (knees or ankles) of a model dancer resulted in the ability of the observers to more accurately replicate the model’s movements and timing than those using point of light displays or simply watching the model in real time. Not only did these observers more accurately replicate the specific joint motions of the model (as recorded by kinematic measures), they were able to better execute the entire motion, incorporating all the joints of the body. This finding was especially important as it depicted that demonstrations can not only be effective in acquiring the coordination pattern of skill acquisition, but during the control phase as well.
The ability to extract information from model displays can be based upon the original level of skill the observer has in the area and the type of motion being depicted. Shim et al (2005) found that both experts and novice tennis players were able to use the visual information of a hitter’s movement to anticipate the hitter’s shot. As the investigators increased the information on the display (from point of light, to two-dimensional, to live action), experts and novices diverged in their learning attempts. Increasing the information caused an increased accuracy in anticipation of shots in expert players and a decreased accuracy in novice players. The additional information may have been distracting or overloading to novices. The researchers also found that skilled players can react significantly faster when the information is available to them.

In addition to the original skill of the observer, the skill level of the model may also affect the learning process for the observer. Pollock and Lee (1992) examined this theory but found that simply observing a model produced learning effects. Observing a poor model was just as effective in promoting learning as observing a skilled model.

When observing a model in an attempt to acquire a skill, there is a variety of modes by which the model can be presented to the observer. Use of live models, animations, recordings, computer layouts, and pictures are all viable options for presenting information. The use of a live model recorded on VHS replayed at two different speeds and still pictures were contrasted by Scully and Carnegie (1998). They compared the ability of an observer to kinematically reproduce joint angles, kinetically reproduce forces, timing, and movement accuracy of landing placement on jumps with the original model’s measures. They found that slow motion analysis was the most effective tool with observers reproducing the model’s joint motions and movement
accuracy 75.3% of the time. Real-time speed and still pictures were less accurate with 62.5% and 55.3%, respectively. However, timing was significantly worse for slow motion analysis and there was an insignificant trend for the efficacy of slow motion analysis on force production.

Motion analysis as a means of modeling for skill acquisition has also been demonstrated in point of light techniques, in which a model is filmed in dark clothes in a dark room with points of light all over their body so that observers can witness motion and no other factors. Point of light display has shown that observing motion can accurately impart knowledge of a skill in as much as observers can reproduce the skill (Scully and Carnegie, 1998). Observers have been shown to be able to reproduce movement accuracy of a model dancer 75-100% of the time along with the ability to replicate action patterns and kinetic forces (Scully and Carnegie, 1998). However, when a more complex skill, especially one that is rotary in nature, is used, point of light display may become ambiguous as lights rotate on top of each other and thus does not allow for accurate interpretation (Shim, Carlton, Chow, and Chae, 2005).

Along with the type of display used, the way in which the modeled information is presented to the observer can also effect learning acquisition and retention. When having to learn more than one task, an observer best acquires the skill immediately when the task trials are blocked together as compared to when they are randomized (Simon and Bjork, 2002). Also, matching models (presenting a model of the task that the observer must then attempt to duplicate) result in better performance for the observer in immediate subsequent trials. However, in retention tests, in which observers are not presented with any additional modeling, those subjects that received training with randomized trials and
mismatched models (presenting a model of one of the other tasks before the subject must perform the remaining task) were able to most effectively reproduce the tasks. Thus, retaining knowledge may require a more active learning process than the immediate skill acquisition phase. The skill level of the learner may dictate how he or she can learn, with more skilled subjects being able to learn from randomized trials and mismatched models. Along with the skill of the learner, the similarity of the model can also affect the ability of the observer to acquire and retain motor skills. Gould and Weiss (1981) found that subjects responded better in a leg endurance test when they observed a live model of similar sex and athletic ability.

As Sheffield (1961) noted, a perceptual response can be elicited in absence of the actual object or stimulus if the sequence can be tied to a recognizable symbol. This means that if someone can tie the sequence of actions to a neutral image or a title of an image, similar to the theory of external focus, that person could perform the proper motor sequence when instructed to only perform the overarching neutral cue in the complete absence of the original motor cues and sequences. The connection between the neutral cue and the motor skill is strengthened by repetition over time. This neutral cue, when the memory of the motion is committed properly and the motor sequence has been perfected, can often be the "final product" or final positioning of the sequence. Use of the "final product" of a motor sequence as the model for learning could elicit the proper movement in an athlete or subject.

*The Use of "Athletic Ready Position" as a Modeling Cue in Motor Learning*

In light of Sheffield's findings (1961), the use of a final stage of a motion as the cue to elicit the learned sequence is a possibility in modeling. In ACL jump landing
prevention, this means presenting a subject with an image of the final landing position. This position is a combination of previous research that indicates the proper biomechanical alignments to reduce the risk of ACL injuries based on risk factors (Myer et al, 2004). There are several ways to describe this positioning, however the image of the “athletic ready position,” also known in some sports as the “defensive position,” is one known to a large population, especially those being targeted by ACL injury prevention. This position involves all of the same positioning as a proper biomechanical alignment for jump landing, such as knees comfortably flexed, shoulders back, eyes up, feet shoulder-width apart, a balanced stance, and knees over the toes (Meyer et al, 2004).

The “athletic ready position” spans most sports at the most basic levels, and thus most athletes (one of the targets of ACL injury prevention) will have a common knowledge of this positioning, no matter the skill level or the sport (Shim et al, 2005). Coaching and physical education teaching manuals and textbooks have described “ready position” for the starting position of athletic tasks, all using similar terminology of “knees bent, feet shoulder width apart” among others (Colvin et al, 2000; Joseph, 1998). These manuals target teaching of individuals of all ages, especially younger children just developing athletic motor skills, and all skill levels of individual sports (Joseph, 1998; Colvin et al, 2000). From getting in position for advanced softball drills (Joseph, 1998), to breaking down to throw, catch, or kick a ball (Colvin et al, 2000), to preparing for a power squat (Kravitz et al, 2003), to proper positioning to begin a dodgeball game (Shoemaker, 2001), common vocabulary and descriptions of the athletic ready position exist.
The “athletic ready position” is also essentially an analogy for the proper landing position. Orrell et al (2006) found that use of an analogy for a balance task produced equal learning results as an errorless group and a discovery group. These findings further indicating the potential use of an analogy to help teach jump-landing mechanics.

Applications of Motor Learning in ACL Research

When trying to prevent ACL injuries, teaching proper strategy, whether for jump landing or other athletic maneuvers, has become a major focus of current research. In order to implement any changes in the motor skills of an individual, some sort of motor learning concept needs to be applied. Instructions and augmented feedback have been used previously by researchers to try and modify jump-landing technique in an attempt to reduce the risk for ACL injury (Ayalon and Ben-Sira, 1988; Cowling et al, 2003; Lees, 1981; McNair et al, 2000; Oñate et al, 2005; Oñate et al, 2001; Prapavessis and McNair, 1999; Ettlinger et al, 1995).

Some studies have examined potential prevention of knee injuries through the use video-based awareness programs (Ettlinger, Johnson, Shealy, 1995; Arnason, Engebretsen, Bahr, 2005). Within these intervention programs, individuals are given video of common mechanisms of injuries and vulnerable postions within their respective sport (e.g skiing [Ettlinger et al, 1995] and soccer [Arnason et al 2005]) and are asked to brainstorm means of avoiding these positions during activity. This guided, self-discovery is thought to involve the individual in the process and make them responsible for their own movement patterns. Ettlinger et al (1995) discovered a significant reduction on the risk of ACL injuries during the intervention while no significant difference was ascertained during a similar intervention with soccer players (Arnason et al, 2005).
Differences in results may be due to the demands of the specific sports and the ability to change motions. Also, the specifics of the intervention sessions are not known, as to how much guidance was given how much emphasis was placed on subsequent application of these prevention strategies during activity.

Oñate et al (2001) investigated the use of augmented feedback, verbal (instructions from the investigator as to how to change their technique) and visual (videotape of the subject’s jump trials) feedback, and sensory feedback (use of the subject’s recall of the sensory input they received from their jump) in order to decrease the vertical ground reaction forces of a jump landing task. Both feedbacks were individualized to the subject. The visual and verbal feedback was focused on specific joint movements. Their results showed that recreational athletes receiving augmented video and visual feedback were able to significantly reduce their peak vertical ground reaction forces as compared to the sensory and control groups both immediately after the instructional sessions and one week later without any additional feedback. Similarly, Ayalon and Ben-Sira (1988) evaluated the effects of various feedback methods on peak vertical ground reaction force and time to peak vertical ground reaction force. They used a verbal feedback group (individual instruction of mistakes), a verbal and visual feedback group (individual instruction of mistakes along with a visual representation of the ground reaction force), and a control group. Feedback proved to significantly lower the mean peak vertical ground reaction force, though there was no indicated difference between the two feedback groups. There was no significant difference between groups in time to peak vertical ground reaction force, however. Prapavessis and McNair (1999) compared the use of verbal augmented feedback, concerning the hip and knee joint motions and
forefoot landings, and sensory feedback, in which the subject used their experiences with the land to decrease their vertical ground reaction forces. The augmented feedback group of recreational athletes was able to significantly decrease their vertical ground reaction forces during a jump-landing task as compared to the sensory and control groups.

Mandelbaum and his colleagues (2002) conducted an ACL prevention strategy study in youth soccer players. They chose to stress proper landing technique along with strengthening, plyometric activities, and agility work. The use of visual examples of correct and incorrect biomechanical activity performances, in itself an example of modeling, in combination with the neuromuscular training program was found to reduce the rate of ACL injury in a soccer league (52 teams) by 88% over one season. However, it could be possible that these results were due to the combination of all the training program components, or by a singular component other than technique instruction.

Investigating vertical ground reaction forces and joint motions with the use of a kinematic analysis system, Ofiate et al (2005) used three different augmented videotape feedback strategies for recreational athletes. Subjects in the three different groups were shown videotape of either their own jump-landing trials, an expert landing with “proper” technique to reduce ACL injury, or a combination of self and expert video. The investigators hypothesized a reduction of vertical ground reaction forces, an increase in knee angular displacement flexion angles, and an increase in maximal knee flexion angles as an indication of improving jump-landing technique in an attempt to lower the potential risk of ACL injury. Complementing the videotape sessions was a written form with cues to direct the attention of the subject to certain proper motions patterns, such as landing with both feet at the same time, in neutral knee valgus/varus position, with feet
shoulder width apart, on forefoot and rolling toward rearfoot, and with optimal knee and hip flexion at initial contact to be greater than 20 degrees and estimated to be a total of approximately 90 degrees, respectively. They found that all three feedback groups significantly decreased their vertical ground reaction forces, increased their knee angular displacement flexion angles, and increased in maximal knee flexion angles both immediately after the instructional sessions and one week later after no additional instruction. The self and combination groups improved their technique to greater extents than the expert or control groups. The investigators determined that augmented video feedback is a more potent teaching tool when it incorporates the viewing of the individual's own landings with or without demonstrations by an expert. However, these instructions were not able to increase the knee flexion angles at initial contact, which may be problematic since small knee flexion angles at initial ground contact is considered a predictive factor for ACL injury.

Lees (1981) gave the verbal instructions of producing hard or soft landings to his subjects. These instructions were aimed at, and proved to be effective, in creating high and low vertical ground reaction forces upon completion of a jump-landing task. He went on to expound upon segmental actions that are produced in order to absorb the force of hard and soft landings, concluding that soft landings are produced by controlled and phased deceleration of the body segments. The instructions given to the subject were able to produce a change in segment movement and acceleration/deceleration.

McNair et al (2000) also found that peak vertical ground reaction forces were reduced in individuals that received instruction on their limb position. Athletes using the auditory cues from their land (listening to impact sounds), as compared to those who used
imagery, also demonstrated a decrease in peak vertical ground reaction forces. The authors postulated that these decreases in vertical ground reaction forces would potentially decrease the risk of ACL injury in individuals who incorporate these instructions into their training.

Muscle activity and its role in ACL injury prevention has also been targeted by motor learning based strategies. Cowling, Steele, and McNair (2003) examined the effect of two different instructions, “land with your knee bending” and “activate your hamstrings earlier and more before landing,” on hamstring muscle activation during a sudden landing task. They found that giving the generic “knee bending” instruction significantly diminished landing forces and incited a larger burst of quadriceps activity associated with the eccentric contraction of the quadriceps to control the knee flexion. Instructions focusing on hamstring activation created a larger vertical ground reaction force and earlier onset times of the quadriceps which would actually increase the risk of ACL injury during landing. Overall, they concluded that asking someone to alter their muscle contraction patterns without actually training them in the task is not useful.

**Jump Landing Mechanics and ACL Research**

As stated previously in this review of literature, biomechanical risk factors associated with ACL injury often revolve around misalignment of the lower extremity during athletic maneuvers, such as jump landing. Research using jump landing tasks has been used to both identify and correct biomechanical risk factors for ACL injury. Findings from previous research have painted a picture of both correct and incorrect motion patterns of jump landing.
The type of athlete and the type of jump performed can have an effect on the findings of jump landing research. Recreational athletes tend to implement greater hip flexion and adjust to increases in impact velocities by increasing the time to absorb the forces than gymnasts (McNitt-Gray, 1991). In order to complete a soft landing (potentially decreasing the likelihood of injury), the segments of the body produce a phased and controlled deceleration that is motor program controlled (Lees, 1981); while soft landings involve greater joint flexion in order to place the entire body in a more flexed position upon impact along with overall greater joint range of motion (Devita and Skelly, 1992). The height of the landing causes an increase in maximum knee flexion angles (Huston et al, 2001).

When landing from a jump, subjects have demonstrated many key motions and alignments. Lees (1981) determined that most absorption techniques must be initiated before contact as the length of time of the impact impulse is much less than the time it takes to place the muscles in absorptive positions. Active hamstring stiffness is positively correlated with landing functionality (McNair and Marshall, 1994). Hewett et al (2004) found that decreased valgus control and high abduction moments upon landing can predict ACL injury in female athletes.

There have been gender connections found in research concerning jump landing mechanics. Females demonstrate significantly less total knee flexion range of motion and more knee valgus at initial contact and less peak knee flexion in both double and single leg stances (Ford et al, 2004; Lephart et al, 2002; Padua et al, 2004a). The issue of lower leg internal rotation has produced mixed findings as Padua et al (2005a) found greater peak tibial internal rotation in females and Lephart et al (2002) demonstrated less
lower leg internal rotation. This discrepancy could be attributed to the difference between single (LePhart et al, 2002) and double leg landings (Padua et al, 2004a). Females also present with greater hip internal rotation and time to maximum angular displacement of hip internal rotation (LePhart et al, 2002). Many of these gender differences are apparent upon higher height drops, such as 40 or 60-cm, but disappear with heights around 20-cm, due to lack of time to produce changes in motion for absorption (Huston et al, 2001). Jones and Watt (1971) found that falls around 13-cm are associated with uncomfortable jolts from lack of time to activate muscle protection. In contrast to most research in the field, Fagenbaum and Darling (2003) found that females and males do not differ in muscle activation patterns and that females land with greater knee flexion angles.

Teaching landing technique does not only occur in laboratory settings or other controlled settings to reduce only ACL injuries. Sease et al (2006) studied the efficacy of a training program to reduce the rate of injuries due to landing and falling in Australian football competitors. Through an eight session intervention program that taught players six different falling, landing, and recovery skills, the authors discovered that the subjects demonstrated an overall improvement in landing skills (as measured by two expert assessors on a scale of one to five) and a reduction in overall injury levels, especially in landing injuries. This study indicates that motor learning techniques, specifically teaching proper landing mechanics, could be incorporated into athletic situations effectively and could produce injury rate reduction results.

*Phases of the Jump-Landing Task*
A jump-landing task has a variety of components that can be classified into phases. The different phases of the jump-landing task can offer different information to be analyzed depending on the researchers’ goals. These phases need to be defined in order to provide accurate and applicable data. The flight or decent phase is from initial takeoff to initial contact (Devita and Skelly, 1992). Initial contact can be defined by a variety of means, videography, piezoelectric triggers, or force plate reaction forces.

The stop-jump phase, also known as the landing phase or floor contact phase, is the major phase of analysis for jump landing research. This phase has had many discrepancies in its definition. McNitt-Gray (1991) defines the landing phase as the time from initial contact to the minimum vertical position of the total body center of gravity, while Lees (1981) calls for the establishment of the body in a balanced and stationary position as the ending point of the phase. Using joint motions as a guide, Devita and Skelly (1992) defined the floor contact phase as the time from initial contact to the maximum knee flexion. Lees (1981) explains that in order to evaluate impact reduction techniques, one must look at the first 200-ms after initial contact. Huston et al (2001) supported this finding when they discovered that maximum knee flexion (a major force absorption method) occurred an average of 200 to 300-ms after impact. With all this in mind, it is apparent that initial vertical ground reaction force impulse only lasts 30-ms (Huston et al, 2001).

Finally, the take-off phase is the time of the post-landing activity. The take-off phase is initiated when the subject begins the force generation to produce the subsequent motions, a max jump, pivot, etc... The take-off phase ends with the conclusion of the subsequent motion. The take-off phase is usually not analyzed during jump landing
research focused on landing patterns, but has been evaluated for performance effects for
sport tasks (e.g. measurements of vertical jump height, power) (Hewett et al 1996;
Hoffman, Ratamess, Cooper, Kang, Chilakos, Faigenbaum, 2005; Woolstenhulme,
Griffiths, Woolstenhulme, Parcell, 2006).

Types of Jump-Landing Tasks

As is true in real athletic situations, there are many types of jump-landing tasks in
research. These jump-landing tasks usually fall into two major categories, standardized
and realistic. Standardized jumps are often times used in laboratory settings in order to
allow for more control over the experimental procedures and limit individual difference
among subjects’ techniques.

One commonly used standardized jump is the box-drop. The box-drop usually
consists of a subject beginning on a box, stepping off the box (not jumping up or out),
landing in the designated area with single leg (Cowling et al, 2001; Cowling et al, 2003;
Fagenbaum and Darling, 2003; McNair and Marshall, 1994; Lephart et al, 2002) or
double legs (Boling et al, 2005, Devita and Skelly, 1992; Dufek and Bates, 1990; Hewett
et al, 2004; Huston et al, 2001; McNair et al, 2005; McNitt-Gray, 1991; Padua et al,
2004a; Padua et al, 2004b; Ford et al, 2003; Prapavessis and McNair, 1999) and then
either ending the task (Devita and Skelly, 1992; Dufek and Bates, 1990; Fagenbaum and
Darling, 2003; Huston et al, 2001; McNair and Marshall, 1994; McNair et al, 2005;
McNitt-Gray, 1991; Prapavessis and McNair, 1999) or producing a subsequent motion
(Boling et al, 2005; Cowling et al, 2001; Ford et al, 2003; Padua et al, 2004a; Padua et al,
2004b). The objective measurements are typically taken during the landing phase. There
are some variations of this task. The box can be a standard height, such as 30-cm (Boling
et al, 2005; Fagenbaum and Darling, 2003; Ford et al, 2003; Padua et al, 2004a; Padua et al, 2004b; McNair and Marshall, 1994; McNair et al, 2000; Prapavessis and McNair, 1999), 20-cm (Lephart et al, 2002), or 60-cm (Devita and Skelly, 1992; Fagenbaum and Darling, 2003); or multiple heights, such as 32, 72, and 128-cm (McNitt-Gray, 1991), 40, 60, 100-cm (Dufek and Bates, 1990) or 20, 40, and 60-cm (Huston et al, 2001) for a multiple height experiment. The height of the box can also be a varying height based on the height of the subject (Huston et al, 2001). The distance of the box from the landing zone can be standardized or varied by the height of the subject (Boling et al, 2005). Standardized distances include 11-cm (Devita and Skelly, 1992; Lephart et al, 2002), 40-cm (Dufek and Bates, 1990; Huston et al, 2001), 70-cm, and 100-cm (Dufek and Bates, 1990).

The subsequent motion usually consists of a maximum height jump, either measured using an overhead goal, such as a basketball (Oñate et al, 2005; Padua et al, 2004a) or Vertec jumping instrument (Oñate et al, 2001). It can also be to simply direct the subjects to jump as high as they possibly can (Boling et al, 2005; Ford et al, 2004; Padua et al, 2004b).

Functional jump-landing tasks vary as much as athletic maneuvers do. They can include a level ground forward hop over an obstacle (Lephart et al, 2002), a level ground leap from nondominant leg onto the dominant leg while catching or not catching a ball (Cowling et al, 2001, Cowling et al 2003), a volleyball spike jump or a volleyball block jump (Richards et al, 1996).

*The Landing Error Scoring System as a Jump Landing Screening Tool*
As researchers determine more risk factors for ACL injury, there is a greater need for protocols and instruments that can screen individuals for these risk factors prior to participation. Ford et al (2003) noted that no system for accurate and practical screening and identification of individuals who may be at risk of ACL injury is currently available. They believe such an identification tool, especially a two-dimensional video tool that would allow mass screening, would be beneficial because it would be able to pick out at-risk individuals (those with excessive valgus) before they begin sports participation to allow for intervention. It is believed that these individuals would benefit more so than those whose faults may not be visible on camera. McLean et al (2005) agrees that being able to identify specifically at-risk individuals during their initial ground contact would allow greater opportunities to intervene with these individuals versus interventions in which some people may not need the training. Padua et al (2004b) called for a tool that would be more clinically-friendly than the expensive and time intensive three dimensional motion analysis systems.

The Landing Error Scoring System (LESS) is a relatively new clinical qualitative assessment tool for jump-landing technique, identifying potentially faulty movement patterns and poor technique as two cameras videotape the sagittal and frontal planes (Padua et al, 2004a; Padua et al, 2004b; Boling et al, 2005). An investigator watches the tape and records the error on a standard LESS scoring sheet that involves scoring individual joint motions at various moments in the landing sequence [Appendix 7] (Boling et al, 2005).

Through a variety of studies, the LESS has been proven both reliable and valid in identifying specific biomechanical movements that may put an individual at risk for an
ACL injury. Padua et al (2004b) showed the intra-session and intra-rater reliability, examined through ICC, to be excellent for both areas (ICC = 0.9, SEM = 1.05 and ICC = 0.9, SEM = 1.08, respectively). The item specific inter-rater reliability of the LESS was assessed by calculating the percent agreement between two investigators scores for each LESS item and ranged from good to excellent for each item (75-100% agreement) and was excellent for total LESS score (ICC = 0.83, SEM = 0.95) (Boling et al, 2005). The intra-rater reliability was assessed by calculating the percent agreement between days for each LESS item as scored by one of the investigators and was excellent for each item (90-100% agreement range) and the total LESS score (ICC = 0.98, SEM = 0.3) (Boling et al, 2005). Concurrent validity of the LESS has been examined using the "known groups" method by comparing sexes (Padua et al, 2004a). LESS scores were significantly higher in females demonstrating that the LESS has good concurrent validity to differentiate between males and females (Padua et al, 2004a). In this study, the LESS scores were shown to be able to differentiate between the sexes, with scores being significantly higher for females. The LESS scores have also been divided into percentiles by Padua et al (2004b) to present a tool to separate individuals with proper and poor landing mechanics. The 25\textsuperscript{th} percentile (best landing technique) was scores between 0-4.66. The 50\textsuperscript{th} percentile (good landing technique) was scores between 4.67-7.65. The 75\textsuperscript{th} percentile (poor landing technique) was scores between 7.66 - 8.99. The 100\textsuperscript{th} percentile (worse landing technique) was scores greater than 9. The highest percentile (high scores) was found to have less maximal knee flexion, knee and hip flexion displacement, time to peak vertical ground reaction force, and time to maximal knee and hip flexion, greater peak vertical ground reaction forces, anterior shear force, knee valgus
torque, and anterior shear ground reaction force when compared with common kinetic and kinematic data collection techniques. This last study displays the LESS's ability to subjectively match the data of common objective three-dimensional analysis techniques in identifying biomechanical and neuromuscular risk factors of ACL injuries.

**Vertical Ground Reaction Forces in Jump-Landing Tasks**

As previous ACL research has shown, vertical ground reaction forces and subsequent joint reaction forces have a correlation with ACL injury (Meyer et al, 2005). In most jump-landing studies, vertical ground reaction forces, the times to peak vertical ground reaction forces, and impulses are usually measured by landing on force plates. Force plates can measure forces in 3 orthogonal vectors (2 horizontal, 1 vertical) and the moments around each vector (Riemann, Myers, and Lephart, 2002).

Many authors use force plates as a means of measuring vertical ground reaction forces in jump landing studies. Most use one or two 40cm x 60cm force plates embedded into the ground, running at between 1000 and 1200Hz for jump landing tasks (McNair, Prapavessis, and Callender, 2000; Ford et al, 2003; Oñate et al, 2005; Devita and Skelly, 1992; Lephart et al, 2001; Richards, Ajemian, Wiley, and Zernicke, 1996; Yu et al, 2005). Oñate et al (2001) and Dufek and Bates (1990) also used between 500 and 540Hz for data collection, mainly to match with kinematic data.

The reliability and validity of force plates and vertical ground reaction forces have not been extensively examined in research, especially concerning jump-landing tasks. However, research has shown that vertical ground reaction forces (sampled at 1000Hz) have a high intraclass correlation coefficient (ICC average of 0.87) during running gait (Karamanidis, Arampatzis, and Bruggemann, 2004). However, this study used pressure
measuring insoles, not force plates. Using dogs as subjects in a running task, Bockstahler and colleagues (2005) found that force plates sampling at 300Hz were able to provide comparable and repeatable measures. The intraday reliability of running vertical ground reaction forces (using force plates) range from 74 to 93% based on sample sizes of three to twenty-five trials (DeVita and Bates, 1988). High interday reliability for a 10-trial mean GRF measurements over a one-week period and low (less than 10% of the mean) standard error has been shown during running tasks (Bennell, Crossley, Wrigley, Nitschke, 1999). A sample size of 25 trials is found to be minimum number of trials needed to see reliable results in a running task (DeVita and Bates, 1988).

Similar to running, walking ground reaction forces have intraday reliability, especially between day 2 and day 3, and need approximately 10 trials to stabilize the mean of the data (Hamill, McNiven, 1990). However, a discrete, single event, such as jumping, would require significantly less trials to see the reliability than a continuous event, like running or walking (DeVita and Bates, 1988). Concerning jumping tasks, peak vertical ground reaction force (measured using a force plate) is very reliable for a single leg jump (ICC [2,1] \( r_{xx} = .94; \) SEM = 0.003% BW) (Cordova, Armstrong, 1996) and for a double leg jump (ICC \( r_{xx} = 0.97 \)) (Harman, Rosenstein, Frykman, and Rosenstein, 1990). Finally, the minimum differences in ground reaction force data that are considered significant are estimated at 1N/kg (DeVita and Bates, 1988).

*Posterior Ground Reaction Forces in Jump-Landing Tasks*

Posterior ground reaction force (PGRF) is a kinetic measurement used to analyze the anterior and posterior forces acting on the lower extremity during jump-landing tasks. The forces, while acting upon the whole lower extremity, will have some kind of effect
on the ACL, as a component of the lower extremity. PGRF is a significant predictor of anterior shear force during jump-landing tasks (Sell et al, 2004). High anterior shear force (also known as anterior tibial shear force) has been linked to potentially increased risk for ACL injury (Kirkendall and Garrett, 2000). Yu et al (2006) determined that peak PGRF (PPGRF) is correlated with peak vertical ground reaction force (p<0.001), peak proximal tibial anterior shear force (p<0.001), and peak knee extension moment (p<0.001) during the landing phase of stop-jump tasks. These four events were also found to occur at essentially the same moment, during the initial 25ms of the landing phase of a stop-jump task (Yu et al, 2006). Increased PGRF occurs with reactive jump-landings (used to simulate athletic or daily-life activities that more commonly cause ACL injury) (Sell, Ferris, Abt, Tsai, Myers, Fu, Lephart, 2006). PPGRF also has been shown to vary with jump direction, with jumps to the nondominant side (left) resulting in significantly higher PPGRF followed by vertical jumps and then right-sided jumps during a stop-jump task (Sell et al, 2006). These two points of interest make a case that increased PPGRF is an indication of uncertainty in movement, and thus a potential indicator for ACL injury. Hip joint motion verses joint position seem to have greater effects on PPGRF while knee motion verses joint position impacts PVGRF greater (Yu et al, 2006), possibly inferring that hip mechanics react to the anterior/posterior forces while the knee is where the body reacts to vertical stresses.

Summary

Numerous studies have described biomechanical risk factors for anterior cruciate ligament injury (Arendt and Dick, 1995; Chaudhari and Andriachhi, 2006; Faugenbaum and Dariling, 2003; Ford et al 2003; Griffin et al, 2000; Hewett et al, 2005; Huston et al,
2001; Lephart, 2001; Malinzak et al. 2001; McLean et al, 2005; Mesfar and Sirazi-Adl, 2005; Meyer et al, 2005; Padua et al, 2004; Putnam, 1993; van Ingen Schenau et al, 1999; Yu et al, 2005). With the discovery of these risk factors, researchers and clinicians have started to develop valid and reliable clinical screening tools. The LESS has been shown to be valid and reliable in identifying biomechanical risk factors for anterior cruciate ligament injury and is also a relatively simple clinical tool that can be employed on large numbers relatively quickly (Boling et al, 2005; Padua et al 2004a; Padua et al, 2004b).

The determination of risk factors has also led to numerous prevention strategies to reduce the risk of ACL injury (Griffin, 2001; Hewett, 1996; Madelbaum et al. 2002; Myer, 2004). Several of these prevention strategies have incorporated motor learning techniques as a means of correcting biomechanical risk factors during at-risk maneuvers, such as landing (Ayalon and Ben-Sira, 1988; Cowling et al, 2003; Lees, 1981; McNair et al, 2000; Oñate et al, 2005; Oñate et al, 2001; Prapavessis and McNair, 1999). Motor learning, especially simple instruction or modeling, could provide a clinical-friendly intervention strategy to match the clinical screening tools. It is not known, however, if simplistic modeling and instruction have enough learning power to improve jump landing mechanics, specifically those identified by the LESS.
CHAPTER III

METHODOLOGY

An experimental design consisting of a pretest, an immediate posttest, a one-week retention test, and a transfer test of subjects performing a jump-landing task was conducted. Subjects were divided into three groups receiving written instruction and a visual cue on knee and hip positioning (specific modeling), a visual cue of landing in an athletic ready position (global modeling), and a control group receiving no instruction. Each trial was video-taped and then analyzed using the Landing Error Scoring System (LESS) for changes in landing mechanics along with examining the vertical and posterior ground reaction forces. The dependent variables were LESS scores, vertical ground reaction forces (N), and posterior ground reaction forces (N). The independent variables were the instructions received (control, specific and global modeling) and the testing times (pretest, immediate posttest, one-week retention, one-week transfer test). Three repeated measures 3 (instruction) x 4 (test) ANOVAs for LESS scores, peak vertical ground reaction force (mbw) and posterior ground reaction force (mbw) were used to assess the effects of the instructions on the LESS scores as well as on the vertical ground reaction forces. A Tukey Post Hoc Honestly Significant Difference (HSD) analysis was used to identify directional group differences within the data sets. Effect size was measured using Cohen’s d test (Thalheimer and Cook, 2002). Follow-up testing was conducted using Pearson’s Product Moment correlation between the retention test and transfer test for all three variables as well as a one-way ANOVA to determine between-group differences in the transfer test for all three variables.

Subject Characteristics
Seventy-three physically active individuals (mean age = 20.89 ± 1.72 years; height = 172 ± 9.87 cm; mass = 68.43 ±15.97 kg) volunteered as participants in the study. These subjects were baseline tested performing three trials of a jump landing task using the LESS. Of these 51 subjects (7 males; 44 females; age = 20.80 ± 1.70 years; height = 171.37 ± 9.10 cm; mass = 65.22 ± 13.44 kg), those who demonstrated poor landing mechanics, defined as a score of 6 or higher on the LESS, were selected to continue in the study. Of these subjects, 17 were counter-balanced and assigned to each modeling group (global modeling, specific modeling, and control); additionally, criteria for inclusion involved that the subjects participate in exercise a minimum of three times per week for a minimum of twenty minutes for the past two months and had not sustained a previous lower extremity injury within the past two months that limited activity for more than one day, had no reported lower extremity instability, had no surgical procedures performed on the lower extremity in the last two years, or any history of ACL reconstruction surgery (Oñate et al, 2005). Each subject signed the informed consent form approved by the University Investigational Review Board (Appendix 1).

Instrumentation

Two Bertec series 4060 nonconductive force plates (Bertec Six Component Force plate Model –4060-NC, Columbus, OH) were used to collect ground reaction force data. The two force plates were secured in a wooden runway platform for a combined area of 60cm x 80cm. The force plates were calibrated and set to collect at 1000 Hz. The analog signal was amplified and sent to an A to D board. The measurements were obtained by the MotionMonitor computer-based software acquisition program (Ascension Technology, Burlington, VT). The landing trials were captured using two Sony DCR-HC40 digital
mini-DV camcorders (Sony Electronics, INC. San Diego, CA, USA), located 184 cm away from the landing area to capture the frontal and sagittal views of the landing. These videotaped trials were analyzed using the LESS at a later time by a single investigator.

*The Landing Error Scoring System*

The LESS is a qualitative assessment tool for identifying potentially faulty movement patterns and poor technique during a jump-landing task, in which a sagittal plane camera and a frontal plane camera capture the jump-landing movement. An investigator then reviews the footage and scores the jump-landing based on the criteria of the LESS. The LESS is a 15 point criteria for grading landing technique in which each criteria can receive a score of 0 or 1 depending on the presence or absence of the criterion. The final two criteria have a possibility of 0, 1, or 2 depending on the degree that the individual criterion is present (Appendix 7).

A single investigator watched each video-taped trial of each subject and scored the trial according to the LESS grading sheet. Initial contact was defined as the first frame that shows any foot contact with the floor. The scores for each criterion of each trial were summed to give the total score for each trial. The total scores of each trial were then averaged to give the total score for each subject. In order to be a participant in the study, the subject’s baseline score had to be a 6 or higher, indicating poor landing mechanics (Padua et al, 2004b). The LESS has been determined to have excellent intra-session reliability ($ICC_{2,1} = .90$, $SEM = 1.05$) and intra-rater reliability ($ICC_{2,k} = .90$, $SEM = 1.08$) (Padua et al, 2004b). It has also been shown to have an excellent item specific intra-rater reliability for each item (percent agreement range = 90%-100%) and total LESS score ($ICC = .98$, $SEM = .30$) (Boling, 2005).
Testing Procedure

Subjects reported to the Sports Medicine Research Lab wearing athletic attire (athletic shorts). They were given standardized shoes to wear in their size (Nike Air Max Glide; Nike USA, Inc, Beaverton OR, USA). They read and signed the informed consent form (Appendix 1). In order to select subjects for the study, each volunteer was pretested on the jump landing task to assess for LESS scores of 6 or higher. Each subject was given an ID number that was used to identify them on the videotape and the scoring sheet.

Pretest (Criteria for inclusion in the test)

Each subject was familiarized with the jump landing task. The jump landing task consisted of the subject standing on a 30 cm high box placed 30 cm back from the force plate landing area. Subjects were instructed to lean forward on both feet at the edge of the box and fall forward off the box, focusing on not jumping out or up into the air, and land with one foot on each of the force plates. The subject immediately jumped straight up in the air “as high as they can” to achieve a maximal jump height. The subjects then landed back on the force plate area, with one foot on each force plate. The subjects were allowed two practice trials to allow for familiarization.

Each subject then performed three separate trials of the jump landing task. The subject’s ID number was recorded on the cameras for identification purposes. After this was completed, the subject was instructed to jump when ready and stay on the force plate after the task until instructed to return to the box. The force plates collected for one second before initial contact and four seconds after. Following completion of the task and the end of data collection, the cameras were stopped and the subject was allowed to
return to the box and rest for thirty seconds. After three trials, the subjects were informed that the investigators would contact them at a later date if their services were to be needed for follow-up testing. The subjects were not informed concerning what criterion made them eligible for further inclusion in the study to reduce any threats to validity. They were instructed that if they were to return, they would need to be in similar clothing as they wore during the pretest session and to not receive any jump landing instruction.

Assignment to Instructional Groups

Using the grading sheet of the LESS, a single investigator viewed the recorded pretest trials and analyzed the landing technique. Those individuals with average scores from the three trials of 6 or higher were considered potential subjects for the study. These identified subjects were counter-balanced and assigned to one of the three instructional groups and contacted to return to the research lab for subsequent testing. The investigator viewing the recorded trials was blinded to which instructional group subjects were placed in. The investigator was blinded via the use of marked envelopes. The instructional sheets were placed randomly into three envelopes labeled A, B, and C and the subjects received and viewed these sheets without informing the investigator of the contents of the envelopes. The investigator did not find out which instructions were in which labeled envelope until all testing and video-tape analysis review of the LESS test was completed.

Immediate Posttest

Subjects reported back to the Sports Medicine Research Laboratory wearing similar athletic attire and were given the same standardized shoes for the immediate posttest session (mean days from pretest to immediate posttest=12.4±6.9days). Each
group received their set of instructions (global/specific modeling groups) or no
instructions (control group). They were given two minutes to go over their information.

The three instructional groups received a different form of visual instructions
concerning their jump-landing technique. The specific modeling group received a set of
written instructions outlining the proper biomechanical alignment (Hewett et al 1996) for
jump landing form. The written instructions were “trunk, hips, knees are flexed to at
least 30 degrees; feet are shoulder width apart; knees do not collapse in; toes are pointed
straight ahead; and you are landing evenly on both legs.” Complimenting the written
instructions was a picture of this proper alignment demonstrated by a model (Appendix
2). The global modeling group received a picture of a model landing in an athletic
“ready” position (Appendix 3). This position is similar across athletic events and is
taught at all levels as the proper position for activity (Myer et al 2004; Shim et al, 2005).
This position is also similar to the proper landing strategy that should be employed by
athletes (Myer et al, 2004). This correlation allowed for a visual cue for subjects to be
able to relate to as to how their body should be positioned upon landing without focusing
on specifics of their bodies. The control group did not receive any landing mechanic
instructions, but instead received an irrelevant reading to look over during the two-minute
instruction time.

As in the baseline trials, each subject was instructed to lean forward on both feet
at the edge of the box and fall forward off the box, focusing on not jumping out or up into
the air, and land with one foot on each of the force plates. The subject then immediately
jumped straight up in the air “as high as possible” to achieve a maximal jump height.
The subjects then landed back on the force plate area, with one foot on each force plate.
After the first trial, they received another two minutes to review their instructions (experimental groups) or the irrelevant reading (control group). They completed the second trial and received their instruction time again. No additional feedback was provided to the subjects beyond the standardized written instructions. After the third trial, they were informed that they would need to report back to the testing facility in one week for a follow up test. They would report in their similar attire and should not receive any jump landing training or practice jump landing during the time.

**One-week Retention Test**

Subjects returned in one week (mean=6.8±0.9 days) for a retention test. They did not receive any further instructional time. They performed the three trials in the same manner as the two previous tests. They received a thirty second rest between trials, similar to the pretest.

**Transfer Test**

On the same day, following the one-week retention test, subjects performed a transfer test. The transfer test involves similar characteristics of the task but in a different context. The test consisted of the subjects running along a runway at maximal speed, taking off on one leg at a line that was set at 30% of the subjects’ standing arm reach, and landing with one foot on each force plate. The subjects then performed a maximum jump (the same procedure as the original box-drop task) and landed with one foot on each force plate. The maximal standing arm reach was measured by having the subject standing relaxed facing the wall and reaching the arm into full flexion and measuring the height of the finger tips on a tape measure. The investigator then calculated 30% of the standing arm reach to use as the take-off line for the task (Oñate et al, 2005). Subjects’ maximum
speed was measured using a Speed Trap I timing system (Brower Timing Systems, Draper, UT, USA). The subjects stood at the end of the runway on the starting pad of the timing system. They took off at full speed to approach the take-off line where the finish sensor of the timing system was located. The subjects practiced the task three times before performing the trial and the investigator measured their time down the runway during these practice trials. In the testing trials, subjects had to attain this same time ± 10% of their maximum speed for the trial to count as a maximum speed run. Subjects ran down the runway with an average velocity of 3.19±0.42m/s (maximum: 4.24±0.46m/s; minimum: 2.36±0.89m/s). The subjects performed the task for three trials with a 30 second rest in between trials and gained no further instruction during the testing session, but were informed to recall the instructions they received previously.

Data Analysis

The average LESS scores of the three trials for each testing session for each subject were used to compare with the pretest scores to determine any differences. The average peak vertical ground reaction force (N) and peak posterior ground reaction force (N) of the three trials for each testing session for each subject was used to compare with the pretest values to determine any differences. Statistical significance was set a priori at p < 0.05. Three 3 (instruction) x 4 (test) repeated measures ANOVAs were performed for the dependent variable of LESS total scores, peak vertical ground reaction force (mbw) and peak posterior ground reaction force (mbw). A separate Pearson’s Product Moment was conducted to compare the retention test and the transfer test for correlation for all three variables. A follow-up one-way ANOVA was also utilized to evaluate the differences between the three instructional groups during the transfer test in order to
assess transferability of the knowledge. A Tukey Post Hoc HSD was performed to determine group differences within the data sets. Effect size was determined using Cohen’s d for t-test (Thalheimer and Cook, 2002). The data were analyzed with SPSS for Windows (Version 13.0; SPSS Inc. Chicago, IL).
CHAPTER IV
RESULTS AND DISCUSSION

Results

The mean LESS scores, PVGRF, and PPGRF for each instructional group (Control [C], Specific [S], and Global [G]) for each condition (Pretest[P], Immediate Posttest[I], Retention Test[R], and Transfer Test[T]) with standard deviations are presented in Tables 1-3. LESS scores results are presented in Figures 1 and 2. PVGRF data are presented in Figures 3 and 4 and PPGRF outcomes are depicted in Figures 5 and 6. The change scores and effect size for each of the dependent variables are presented in Tables 4-9 and depicted in Figures 7-15.

Pretest Values

There was no significant difference found between any of the instructional groups for LESS scores for the pretest condition. Also, no significant difference was observed for the pretest PVGRF and PPGRF data when compared to the other three testing conditions.

Research Question 1: Will instruction have any effect on landing technique?

There was a significant main effect indicating a decrease in mean total LESS scores between the pretest (8.35±1.46) and the immediate posttest condition (5.23±2.26) (F=103.579,df=3, p<0.001). The effect size for mean total LESS scores between the pretest and the immediate posttest was 1.66. Tukey HSD Post-Hoc revealed that the control group demonstrated no significant difference between the immediate posttest condition and the pretest. The specific group demonstrated significantly lower LESS scores in the immediate posttest condition (4.62±2.47) than in the pretest (8.08±1.64), as
did the global group (I=4.08±1.32; P=8.96±1.56) (F=7.492, df=6, p<0.001), effect sizes were 1.7 and 3.48, respectively. There were no significant differences noted in PVGRF (mbw) (P: C=3.11±0.45, S=3.18±0.64, G=3.32±0.56; IP: C=2.95±0.63, S=3.00±0.70, G=3.02±0.45) or PPGRF (mbw) (P: C=0.58±0.09, S=0.58±0.08, G=0.59±0.12; IP: C=0.51±0.27; S=0.55±0.16; G=0.62±0.08) between the pretest and the immediate posttest conditions (Tables 2 and 3).

**Research Question 2: Will subjects be able to retain the knowledge to perform the task after instructions are removed from them?**

There was a significant main effect indicating a decrease in LESS scores from the pretest mean value (8.35±1.46) to the retention test mean value (4.65±2.15) (F=103.579,df=3, p<0.001), with an effect size of 2.03. All three instructional groups showed a significant decrease in LESS scores from their respective pretest scores (C=8.02±0.95; S=8.08±1.64; G=8.96±1.46) for the retention test (C=5.77±2.36; S=4.61±2.09; G=3.59±1.41), effect sizes ranged from 1.29 - 3.72. There were no significant differences between the pretest and retention test conditions for any instructional group or across all instructional groups for either PVGRF (mbw) (P: C=3.11±0.45, S=3.18±0.64, G=3.32±0.56; R: C=3.07±0.52; S=3.03±0.65; G=3.04±0.48) and PPGRF (mbw) (P: C=0.58±0.09, S=0.58±0.08, G=0.59±0.12; R: C=0.59±0.10, S=0.56±0.10, G=0.63±0.11) (Tables 2 and 3).

**Research Question 3: Will subjects' performances degrade after instructions are removed?**
There were no significant differences between the immediate posttest and the retention test for any instructional group or across all instructional groups for LESS scores, PVGRF (mbw), or PPGRF (mbw) (Tables 1, 2, and 3).

Research Question 4: Does instruction type effect landing technique over different testing times?

For the LESS, the specific group demonstrated significantly lower scores in the immediate posttest condition (4.62±2.47) in comparison to the control’s immediate posttest scores (6.98±1.74) (F=7.492, df=6, p<0.001). The effect size for this interaction was 1.13. The global group also displayed significantly lower LESS scores in the immediate posttest condition (4.08±1.32) when compared to the control group’s immediate posttest scores (6.98±1.74) (F=7.492, df=6, p<0.001), effect size reported as 1.94. There was no significant difference found between the global group and the specific group for the immediate posttest condition. There were no interactions or main effects found between the instructional groups for either ground reaction force variables (Tables 5 and 6).

For the retention test across instructional groups, only the global group showed significantly lower LESS scores (3.59±1.41) as compared to the control group (5.77±2.36) (F=7.492, df=6, p<0.001) with an effect size of 1.15. No other interactions occurred for LESS scores during the retention test. Ground reaction force data revealed no significant interaction or main effects for the retention test across instructional group (Tables 5 and 6).

Research Question 5: Will the modeling instructions have any effect on the performance of individuals on a novel task?
Main effect increases were observed in total mean LESS scores (F=103.579, df=3, p<0.001) for the transfer test (8.05±1.94) compared to the immediate posttest (5.23±2.26) and the retention test (4.65±2.15). The effect sizes were 1.36 and 1.68, respectively. The transfer test LESS scores showed no significant difference from pretest scores for any of the instructional groups. Similarly, there was no significant difference between the transfer test LESS scores of any one group as compared to any other group. Both the specific and global groups demonstrated significantly higher LESS scores (F=103.579, df=3, p<0.001) for the transfer test (S=7.88±2.11; G=7.88±2.02) as compared to the immediate posttest (S=4.62±2.47; G=4.08±1.32) with effect sizes of 1.46 and 2.29, respectively. All three groups showed a significant increase from the retention test LESS scores (C=5.767±2.36; S=4.61±2.09; G=3.59±1.41) to the transfer test scores (C=8.39±1.72; S=7.88±2.11; G=7.88±2.02) for their respective groups (F=103.579, df=3, p<0.001). Effect sizes ranged from 1.31 to 2.53.

For PVGRF data, post hoc analysis determined that the significant difference was found between the transfer test (3.32±0.69mbw) and both the immediate posttest (2.99±0.59mbw) and the retention test (3.05±0.54mbw) (F=6.640, df=2.645, p=0.001), effect sizes of 0.52 and 0.44, respectively. Post hoc analysis of PPGRF data revealed significant differences between the transfer test (1.01±0.19mbw) and all of the other conditions (P=0.58±0.10; I=0.56±0.19; R=0.59±0.11) (F=152.822, df=2.191, p<0.001). Effect sizes ranged from 2.35-2.80.

Follow-up testing was conducted to determine both the correlation between LESS scores and ground reaction force values for the retention test and the transfer test. Weak (low Pearson correlation values) but significant (p<0.05) correlations were found for each
variable between the retention test and the transfer test. The LESS scores were
determined to have a correlation of $r=0.425$ (p=0.002), PVGRF was $r=0.571$ (p<0.001),
and PPGRF was $r=0.280$ (p=0.046). A follow-up one-way ANOVA revealed no
significant differences between any of the groups for any of the three variables (LESS
scores: $F=0.382$, df=2, p=0.684; PVGRF: $F=1.557$, df=2, p=0.221; PPGRF: $F=0.103$,
df=2, p=0.902).

Research Question 6: Will there be any learning effect in performing the jump­
landing task as shown by the control group?

As stated earlier, the retention test for the control group (5.76±2.36) was
significantly lower than the control group’s pretest LESS scores (8.02±0.95) ($F=7.492$,
df=6, p<0.001) with an effect size of 1.29. However, the control group showed no
significant difference between immediate posttest LESS scores and retention test scores.
There were no interactions found for PPGRF and PVGRF between the retention test and
the pretest or immediate posttest for the control group (Tables 2 and 3).
### Table 1: Instructional Group Mean (SD) LESS Scores across Testing Conditions

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Pretest</th>
<th>Immediate Posttest</th>
<th>Retention</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8.02(0.95)</td>
<td>6.98(1.74)</td>
<td>5.76(2.36)</td>
<td>8.39(1.72)</td>
</tr>
<tr>
<td>Specific</td>
<td>8.08(1.64)</td>
<td>4.63(2.47)</td>
<td>4.61(2.09)</td>
<td>7.88(2.12)</td>
</tr>
<tr>
<td>Global</td>
<td>8.96(1.56)</td>
<td>4.08(1.32)</td>
<td>3.59(1.41)</td>
<td>7.88(2.03)</td>
</tr>
<tr>
<td>Total</td>
<td>8.35(1.46)</td>
<td>5.23(2.26)</td>
<td>4.65(2.15)</td>
<td>8.05(1.94)</td>
</tr>
</tbody>
</table>
Table 2: Instructional Group Mean (SD) PVGRF (mbw) across Testing Condition

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Pretest</th>
<th>Immediate Posttest</th>
<th>Retention</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.11(0.45)</td>
<td>2.95(0.63)</td>
<td>3.07(0.52)</td>
<td>3.53(0.67)</td>
</tr>
<tr>
<td>Specific</td>
<td>3.18(0.64)</td>
<td>3.00(0.70)</td>
<td>3.03(0.65)</td>
<td>3.11(0.68)</td>
</tr>
<tr>
<td>Global</td>
<td>3.32(0.56)</td>
<td>3.02(0.45)</td>
<td>3.04(0.48)</td>
<td>3.31(0.69)</td>
</tr>
<tr>
<td>Total</td>
<td>3.20(0.56)</td>
<td>2.99(0.59)</td>
<td>3.05(0.54)</td>
<td>3.32(0.69)</td>
</tr>
</tbody>
</table>

All of the following are statistically significant at the p<0.05 level:

Total Values:

a Retention Test to Transfer Test
b Immediate Posttest to Transfer Test
Table 3: Instructional Group Mean (SD) PPGRF (mbw) across Testing Condition

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Pretest</th>
<th>Immediate Posttest</th>
<th>Retention</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.58(0.09)</td>
<td>0.51(0.27)</td>
<td>0.59(0.10)</td>
<td>1.02(0.22)</td>
</tr>
<tr>
<td>Specific</td>
<td>0.58(0.08)</td>
<td>0.55(0.16)</td>
<td>0.56(0.10)</td>
<td>1.00(0.20)</td>
</tr>
<tr>
<td>Global</td>
<td>0.59(0.12)</td>
<td>0.62(0.08)</td>
<td>0.63(0.11)</td>
<td>0.99(0.17)</td>
</tr>
</tbody>
</table>

Total 0.58(0.10)^a 0.56(0.19)^b 0.59(0.11)^c 1.00(0.19)^a,b,c

All of the following are statistically significant at the p<0.05 level:

Total Values:

^a Pretest to Transfer Test
^b Immediate Posttest to Transfer Test
^c Retention Test to Transfer Test
Table 4: Within-Subjects Change Scores (Effect Size) for LESS Scores.

<table>
<thead>
<tr>
<th>Instruction</th>
<th>P-I</th>
<th>P-R</th>
<th>P-T</th>
<th>I-R</th>
<th>I-T</th>
<th>R-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.04</td>
<td>2.26*</td>
<td>0.37</td>
<td>1.22</td>
<td>1.41</td>
<td>2.63*b</td>
</tr>
<tr>
<td></td>
<td>(0.76)</td>
<td>(1.29)</td>
<td>(0.27)</td>
<td>(0.61)</td>
<td>(0.84)</td>
<td>(1.31)</td>
</tr>
<tr>
<td>Specific</td>
<td>3.45*c</td>
<td>3.47*d</td>
<td>0.20</td>
<td>0.02</td>
<td>3.26*e</td>
<td>3.27*f</td>
</tr>
<tr>
<td></td>
<td>(1.70)</td>
<td>(1.90)</td>
<td>(0.11)</td>
<td>(0.01)</td>
<td>(1.60)</td>
<td>(1.46)</td>
</tr>
<tr>
<td>Global</td>
<td>4.00*</td>
<td>4.45*b</td>
<td>0.20</td>
<td>0.49</td>
<td>3.80*i</td>
<td>4.29*j</td>
</tr>
<tr>
<td></td>
<td>(3.48)</td>
<td>(3.72)</td>
<td>(0.61)</td>
<td>(0.37)</td>
<td>(2.53)</td>
<td>(2.29)</td>
</tr>
<tr>
<td>Total</td>
<td>3.12*k</td>
<td>3.70*l</td>
<td>0.30</td>
<td>0.58</td>
<td>2.82*m</td>
<td>3.40*n</td>
</tr>
<tr>
<td></td>
<td>(1.66)</td>
<td>(2.03)</td>
<td>(0.18)</td>
<td>(0.26)</td>
<td>(1.36)</td>
<td>(1.68)</td>
</tr>
</tbody>
</table>

P=Pretest, I=Immediate Posttest, R=Retention Test, T=Transfer Test
All of the following are statistically significant at the p< 0.05 level:

- Control Group:
  - a Pretest to Retention Test
  - b Retention Test to Transfer Test

- Specific Group:
  - c Pretest to Immediate Posttest
  - d Pretest and the Retention Test
  - e Immediate Posttest to Transfer Test
  - f Retention Test to Transfer Test

- Global Group:
  - g Pretest to Immediate Posttest
  - h Pretest to Retention Test
  - i Immediate Posttest to Transfer Test
  - j Retention Test to Transfer Test

- Total Scores:
  - k Pretest to Immediate Posttest
  - l Pretest to Retention test
  - m Immediate Posttest to Transfer test
  - n Retention test to Transfer test
Table 5: Between-Subjects Change Scores (Effect Size) for LESS Scores.

<table>
<thead>
<tr>
<th>Condition</th>
<th>C-S</th>
<th>C-G</th>
<th>S-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>0.06(0.05)</td>
<td>0.94(0.75)</td>
<td>0.88(0.57)</td>
</tr>
<tr>
<td>Immediate Posttest</td>
<td>2.35(1.13)\textsuperscript{a}</td>
<td>2.90(1.94)\textsuperscript{b}</td>
<td>0.55(0.29)</td>
</tr>
<tr>
<td>Retention Test</td>
<td>1.16(0.53)</td>
<td>2.18(1.15)\textsuperscript{c}</td>
<td>1.02(0.59)</td>
</tr>
<tr>
<td>Transfer Test</td>
<td>0.51(0.27)</td>
<td>0.51(0.28)</td>
<td>0.00(0.00)</td>
</tr>
</tbody>
</table>

C=Control, S=Specific, G=Global

All of the following are statistically significant at the p<0.05 level:

\textsuperscript{a} Control group and the Specific group for the Immediate Posttest
\textsuperscript{b} Control group and the Global group for the Immediate Posttest
\textsuperscript{c} Control group and the Global group for the Retention Test
Table 6: Within-Subjects Change Scores (Effect Size) for PVGRF (mbw).

<table>
<thead>
<tr>
<th>Instruction</th>
<th>P-I</th>
<th>P-R</th>
<th>P-T</th>
<th>I-R</th>
<th>I-T</th>
<th>R-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.17</td>
<td>0.04</td>
<td>0.42</td>
<td>0.13</td>
<td>0.58</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.08)</td>
<td>(0.76)</td>
<td>(0.21)</td>
<td>(0.92)</td>
<td>(0.79)</td>
</tr>
<tr>
<td>Specific</td>
<td>0.18</td>
<td>0.15</td>
<td>0.07</td>
<td>0.03</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td>(0.24)</td>
<td>(0.11)</td>
<td>(0.05)</td>
<td>(0.16)</td>
<td>(0.12)</td>
</tr>
<tr>
<td>Global</td>
<td>0.50</td>
<td>0.28</td>
<td>0.01</td>
<td>0.02</td>
<td>0.29</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>(0.61)</td>
<td>(0.55)</td>
<td>(0.02)</td>
<td>(0.04)</td>
<td>(0.51)</td>
<td>(0.47)</td>
</tr>
<tr>
<td>Total</td>
<td>0.22</td>
<td>0.16</td>
<td>0.11</td>
<td>0.06</td>
<td>0.33</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
<td>(0.29)</td>
<td>(0.18)</td>
<td>(0.11)</td>
<td>(0.52)</td>
<td>(0.44)</td>
</tr>
</tbody>
</table>

P=Pretest, I=Immediate Posttest, R=Retention Test, T=Transfer Test
Table 7: Between-Subjects Change Scores (Effect Size) for PVGRF (mbw).

<table>
<thead>
<tr>
<th>Condition</th>
<th>C-S</th>
<th>C-G</th>
<th>S-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>0.07(0.13)</td>
<td>0.21(0.43)</td>
<td>0.14(0.24)</td>
</tr>
<tr>
<td>Immediate Posttest</td>
<td>0.05(0.08)</td>
<td>0.08(0.13)</td>
<td>0.02(0.04)</td>
</tr>
<tr>
<td>Retention Test</td>
<td>0.04(0.07)</td>
<td>0.03(0.06)</td>
<td>0.01(0.02)</td>
</tr>
<tr>
<td>Transfer Test</td>
<td>0.41(0.64)</td>
<td>0.22(0.33)</td>
<td>0.20(0.30)</td>
</tr>
</tbody>
</table>

C=Control, S=Specific, G=Global
Table 8: Within-Subjects Change Scores (Effect Size) for PPGRF (mbw).

<table>
<thead>
<tr>
<th>Instruction</th>
<th>P-I</th>
<th>P-R</th>
<th>P-T</th>
<th>I-R</th>
<th>I-T</th>
<th>R-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.07</td>
<td>0.01</td>
<td>0.44</td>
<td>0.08</td>
<td>0.51</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(0.11)</td>
<td>(2.70)</td>
<td>(0.41)</td>
<td>(2.13)</td>
<td>(2.59)</td>
</tr>
<tr>
<td>Specific</td>
<td>0.03</td>
<td>0.02</td>
<td>0.43</td>
<td>0.01</td>
<td>0.46</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>(0.24)</td>
<td>(0.23)</td>
<td>(2.84)</td>
<td>(0.08)</td>
<td>(2.56)</td>
<td>(2.87)</td>
</tr>
<tr>
<td>Global</td>
<td>0.02</td>
<td>0.04</td>
<td>0.41</td>
<td>0.06</td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.36)</td>
<td>(2.80)</td>
<td>(0.11)</td>
<td>(2.87)</td>
<td>(2.59)</td>
</tr>
<tr>
<td>Total</td>
<td>0.02</td>
<td>0.01</td>
<td>0.42</td>
<td>0.03</td>
<td>0.44</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.09)</td>
<td>(2.80)</td>
<td>(0.19)</td>
<td>(2.35)</td>
<td>(2.70)</td>
</tr>
</tbody>
</table>

P=Pretest, I=Immediate Posttest, R=Retention Test, T=Transfer Test
Table 9: Between-Subjects Change Scores (Effect Size) for PPGRF (mbw).

<table>
<thead>
<tr>
<th>Condition</th>
<th>C-S</th>
<th>C-G</th>
<th>S-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>0.00(0.00)</td>
<td>0.00(0.10)</td>
<td>0.00(0.10)</td>
</tr>
<tr>
<td>Immediate Posttest</td>
<td>0.04(0.19)</td>
<td>0.05(0.57)</td>
<td>0.01(0.57)</td>
</tr>
<tr>
<td>Retention Test</td>
<td>0.03(0.31)</td>
<td>0.04(0.39)</td>
<td>0.07(0.69)</td>
</tr>
<tr>
<td>Transfer Test</td>
<td>0.01(0.05)</td>
<td>0.03(0.14)</td>
<td>0.02(0.10)</td>
</tr>
</tbody>
</table>

C=Control, S=Specific, G=Global
Figure 1: Chart of Mean LESS Scores across Testing Condition

All of the following are statistically significant at the p< 0.05 level:

Control Group:
  a Pretest to Retention Test
  b Retention Test to Transfer Test

Specific Group:
  c Pretest to Immediate Posttest
  d Pretest and the Retention Test
  e Immediate Posttest to Transfer Test
  f Retention Test to Transfer Test

Global Group:
  g Pretest to Immediate Posttest
  h Pretest to Retention Test
  i Immediate Posttest to Transfer Test
  j Retention Test to Transfer Test

Total Scores:
  k Pretest to Immediate Posttest
  l Pretest to Retention test
  m Immediate Posttest to Transfer test
  n Retention test to Transfer test
Figure 2: Graph of Mean LESS Scores across Group

LESS Scores across Group

All of the following are statistically significant at the p<0.05 level:

a. Control group and the Specific group for the Immediate Posttest
b. Control group and the Global group for the Immediate Posttest
c. Control group and the Global group for the Retention Test
Figure 3: Chart of Mean PVGRF (mbw) across Testing Condition

All of the following are statistically significant at the p<0.05 level:

Total Values:
- Retention Test to Transfer Test
- Immediate Posttest to Transfer Test
Figure 4: Graph of Mean PVGRF (mbw) across Group

PVGRF (mbw) across Group

Control
Specific
Global
Figure 5: Chart of Mean PPGRF (mbw) across Testing Condition

All of the following are statistically significant at the p<0.05 level:

Total Values:
- a Pretest to Transfer Test
- b Immediate Posttest to Transfer Test
- c Retention Test to Transfer Test
Figure 6: Graph of Mean PPGRF (mbw) across Group

PPGRF (mbw) across Group

- Control
- Specific
- Global

Testing Condition

Pretest | Immediate Posttest | Retention Test | Transfer Test
Figure 7: Chart of Change Scores for LESS Scores from Pretest to Immediate Posttest

Change Scores of LESS Scores from Pretest to Immediate Posttest

Subjects

LESS Scores

Control
Specific
Global
Figure 8: Chart of Change Scores for LESS Scores from Pretest to Retention Test
Figure 9: Chart of Change Scores for LESS Scores from Pretest to Transfer Test
Figure 10: Chart of Change Scores for PVGRF (mbw) from Pretest to Immediate Posttest

Change Scores for PVGRF (mbw) from Pretest to Immediate Posttest

Bars represent different conditions: Control, Specific, and Global.
Figure 11: Chart of Change Scores for PVGRF (mbw) from Pretest to Retention Test
Figure 12: Chart of Change Scores for PVGRF (mbw) from Pretest to Transfer Test
Figure 13: Chart of Change Scores for PPGRF (mbw) from Pretest to Immediate Posttest
Figure 14: Chart of Change Scores for PPGRF (mbw) from Pretest to Retention Test
Figure 15: Chart of Change Scores for PPGRF (mbw) from Pretest to Transfer Test
Discussion

Baseline

The inclusion criteria for the experiment stated that individuals must have a LESS score of 6 or higher for their pretest condition in order to continue on in the study. The counter-balanced assignment of these individuals into instructional groups resulted in equally distributed sets. All instructional groups had statistically equal pretest LESS scores, PPGRF values (mbw), and PVGRF values (mbw), creating a level baseline for comparison within groups and between testing sessions.

Peak Vertical Ground Reaction Force

The results for peak vertical ground reaction force in this study disagreed with the research hypotheses. Instruction had no effect on PVGRF as there were no differences noted between instructional groups for testing conditions or for total PVGRF values between instructional groups. These findings are contradicted in much of the previous literature in which instructions and feedback have been shown to reduce vertical ground reaction forces (Ayalon and Ben-Sira, 1988; Oñate et al, 2005; Oñate et al, 2001; McNair et al, 2000; Prapavessis and McNair, 1999).

The lack of effect of these instructions on PVGRF may be explained by the nature of the instructions. The instructions were focused on modeling body placement upon landing, with no reference to the amount of force the subject should be exerting upon landing. Other studies have used instructions such as “land as softly as possible” aimed at reducing forces and this line of research has seen decreases in ground reaction forces (Ayalon and Ben-Sira, 1988; Cowling et al 2003; Hewett et al, 1996; Lees, 1981; McNair et al, 2000, Oñate et al, 2005; Oñate et al 2001, Prapavessis and McNair, 1999). Since
high impact forces are considered a potential risk factor for ACL injury (Meyer et al. 2005), future studies should include combinations of the modeling instructions and force-reducing suggestions to determine if the latter's inclusion would change the ground reaction forces and landing motion patterns of individuals.

Our findings revealed there were no differences in PVGRF between the three testing sessions that utilized the box-drop task. Since instruction did not have any effect on PVGRF, these results are logical as the task (box-drop) did not vary between these three testing sessions. We did discover that there were statistical differences between the transfer test (run and jump-stop task) and the immediate posttest and retention test (box-drop task) for total PVGRF values regardless of instructional group with the transfer test resulting in higher PVGRF values. Researchers tend to use the standardized box-drop (Cowling et al., 2001; Cowling et al., 2003; Fagenbaum and Darling, 2003; McNair and Marshall, 1994; Leanhart et al., 2002; Boling et al., 2005, Devita and Skelly, 1992; Dufek and Bates, 1990; McNitt-Gray, 1991; Padua et al., 2004a) to control for experimental factors that may introduce error into the study. However, rarely in daily activities or athletics do individuals perform such a task. The differences in PVGRF between these two tasks help discern the differences between previous research findings using the box-drop and true athletic movements such as the running stop-jump. According to our results, PVGRF values of the box-drop task possibly cannot be clinically applied to running tasks.

**Peak Posterior Ground Reaction Force**

Contrary to our hypothesis, the findings revealed that instruction had no effect on peak posterior ground reaction force. Posterior ground reaction force has been correlated
to anterior shear force (Sell et al, 2004; Sell et al, 2006; Yu et al, 2006) and sagittal plane forces may affect ACL injury risk significantly (Kirkendall and Garrett, 2000). Our results did not demonstrate any benefit from the instructions on these potentially harmful sagittal plane forces.

According to our results, PPGRF were statistically higher in the transfer test than in all of the previous three box-drop landings. As stated previously, the transfer test is a running stop-jump task which is considered a more athletically challenging and realistic undertaking than the box-drop. Potentially, this increase in PPGRF may be due to the different landing patterns employed in the running task compared to the box-drop. The box-drop consists mainly of vertical velocity and velocity changes in the same plane, while the running task involved a high horizontal component along with the challenge of changing velocity form one plane to another. Observation of the trials, revealed that subjects landed with their ankles in a greater dorsiflexed position during the running task; while they landed in a primarily plantarflexed position from the box. This change in ankle position could be due to having to break themselves from the run in order to transfer their horizontal motion into a vertical direction for the jump. The braking force may be contributing to the higher PPGRF for the running task than the box-drop. The increase in PPGRF is another element to consider when deciding on tasks to be used in research to best model athletic jumping scenarios. Individuals may need to be trained in a running task in order to be able to benefit from instructions and reduce these potentially harmful PPGRFs.

According to our findings, instructions that only focus on body position and the process of changing body position to achieve an end modeling goal does not alter ground
reaction forces. Hewett et al (1996) found that in combination with plyometric training, instructions that focused on both body positioning and cuing the subject to land softly improved kinematics and decreased landing forces. Similarly most other instructional interventions utilized instructions that involved some reference to landing softly (Ayalon and Ben-Sira, 1988; Cowling et al 2003; Hewett et al, 1996; Lees, 1981; McNair et al, 2000, Oñate et al, 2005; Oñate et al 2001, Prapavessis and McNair, 1999). Other studies that do not involve instruction find that individuals who land with more force, land with different kinematic results, for example, decreased knee flexion angle, than those who land softly (Huston et al, 2001; Lephart et al, 2002). These kinematic results match up with certain criteria on the LESS and, if present would result in higher LESS scores. It would have seemed that if LESS scores improved, then decreased PVGRF should have been seen; however, this was not the case. Yu and associates (2006) propose that hip and knee motions, and not joint positioning at all, may be the key in reducing impact forces, both PVGRF and PPGRF. These findings suggest that it is in fact about the journey, not just the destination, in that ground reaction forces may be influenced more by the motions that get an individual into the final joint positions instead of just that fact that they achieve those positions. In future research, instructional intervention may need to include force-reducing cues or additional emphasis on the proper procedure and motions to get the body into the final positioning versus simply the end product in order to reduce ground reaction forces.

*Potential Learning Effect*

Within our results, we discovered that the control group improved their landing mechanics (decreased their LESS scores) between the pretest and the retention test.
These results, contrary to our hypothesis, reveal a potential for a learning effect with the LESS. Following three separate sessions of three trials of the same box-drop task (mean days between pretest and retention test = 19.2±7.1 days), individuals without any instructions decreased their LESS scores (improved their mechanics). The simplicity and the number of repetitions of the task may have contributed to the potential learning effect. While this finding may influence the results of the instructional groups within this study, it also has clinical application. There was no improvement between the pretest and the immediate posttest or between the immediate posttest and the retention test; thus the learning effect, if present, is only for longer spans of time and larger number of repetitions. This could be important in that even straight practice of jump-landings possible improve individuals’ landing mechanics.

*Effects of Instructions on Landing Motion Patterns*

Regardless of instructional group, individuals showed improvement from the pretest to the immediate posttest and to the retention test in landing mechanics (decrease in LESS scores). This main effect alone does not provide much information as far as instructional effects. However, both the specific and the global instructional groups showed significant decreases in LESS scores from their respective pretest to the immediate posttest sessions, in support of our original research hypothesis. This improvement, in combination with the lack of difference in the control group for the same testing sessions, demonstrates that these pictorial instructional interventions can improve jump-landing performance. Our findings agree with the results of Cowling et al (2003) in which they studied the immediate effects of telling individuals to “keep their knees bent while landing”. The use of various types of augmented feedback has been
shown to improve kinematics of jump-landings during performance testing sessions (Ofiate et al, 2005, Prapavessis and McNair, 1999). The type of instruction has also been shown to affect the performance changing capacity of the intervention. Wulf and colleagues (2004) found that both intrinsic and extrinsic foci helped to reduce postural sway in a balance task, while external focus improved performance on a suprapostural task. While both instructional tools aided with performance of the jump-landing task, the long-term learning effects of the intervention cannot be determined by the immediate posttest condition.

Retention tests are used in motor learning literature to study the learning effect of interventions. All three groups showed improvement from their respective pretests to the retention tests. These results are in partial agreement with our original hypothesis, as both modeling groups improved on the retention test, however the additional improvement in the control group is contrary to our research hypothesis concerning learning effect. The potential learning effect from the control group’s results may skew any conclusions to be drawn from the two modeling instructional groups’ results. However, this data does indicate that both global and specific modeling instructions produced a learning outcome in subjects. In addition to this, significant differences along with and high change scores were noted between instructional groups, indicating high clinical significance of the findings. In jump-landing research, augmented feedback instructions resulted in marked improvements in certain kinematic and kinetic factors during a one week retention test (Oñate et al, 2005). Wulf et al (2003) and Shea and Wulf (1999) determined that external focus groups had a more effective retention test
than the internal focus group in a balance learning task, partially in agreement with our findings, except that we found improvements in both groups.

**Difference between Instructional Groups**

While we have shown that both modeling instructional groups show performance and learning improvements, the quality of those changes is really shown by comparison back to the control group's results. In terms of immediate performance, both the specific and global instructional groups showed significantly lower LESS scores for the immediate posttest when compared to the control group's immediate posttest results, supporting the hypothesis that both instructional groups would show improvement in LESS scores for the immediate posttest, thus improved performance effects. The global and specific instructional groups both produced lower LESS scores possibly demonstrating that these individuals were landing with potentially better alignment for reducing ACL risk (less landing errors) – the ultimate goal of the intervention. Previous research has shown that both types of modeling, the specific based on intrinsic focus and the global based on external focus, produce immediate performance improvements (Wulf et al, 2004). However, retention of these landing skills needs to be the focus, since individuals will need to be able to produce these motion patterns during activity without instructions.

Outside of extrinsic and intrinsic factor literature, there is a line of research that is focused on the effect of the volume of information provided during the performance and learning stages of a motor task (Schmidt, 1991; Anderson et al, 2005; Wulf and Weigelt, 1997). Anderson et al (2005) found that providing more information is beneficial in the early stages of learning, thus producing immediate performance results. Wulf and
Weigelt (1997) found that performance of a ski simulator task can be degraded by instructions. Again, our findings do not seem to support this trend as both groups improved, not just the specific group which had more information included in the instructional aide. Though Orrell et al (2006) found only weak connections between analogy and errorless learning strategies and the inability to acquire explicit rules, but that they found that all of the different learning strategies they implemented did result in learning of the task. Our results may differ from the previous literature due to the nature of the instructions and their deployment. The basis of Schmidt’s (1991) and Wulf and Weigelt’s (1997) research dealing with the amount of information given was based on one group receiving feedback frequently versus another group receiving feedback only occasionally, essentially promoting autonomy in the learning process over reliance on external feedback. During our study, both of the modeling groups received the instructions an equal number of times and only the amount of detail in the instructions changed.

As stated earlier, the difference between testing the performance effects of an intervention and the learning effects of an intervention is the practice of reproducing the task without the use of instructions or feedback. In our experiment, only the global group had significantly lower LESS scores than the control group for the retention test, showing that the global instructions had a higher propensity for long-term learning than the specific instructional group, supporting our hypothesis that the global group would produce more improvement in the retention test, providing the best overall learning effect.
The global modeling instructions were based upon the “athletic ready position” as terminal phase of the motor task, i.e. the landing position. There is research that provides support for the usage of key positional markers, especially the end position as a modeling tool, since the mind uses the proper end position as a “goal” to attain and a marker to refer back to in order to assess for mistakes (Adams, 1971; Sheffield, 1961). If our natural learning process involves the check/recheck of the properness of the movements to the end position, then it is logical to provide instruction as to how to attain that proper position as part of the learning process, such as our global modeling cue. The association of proper movements with a phrase or other such memory tool also can enhance the efficacy of the learning process (Sheffield, 1961). The connection between the proper landing positions to the “athletic ready position,” a concept utilized across many sports and physical education courses (Myer et al, 2004; Shim et al, 2005; Joseph, 1998; Colvin et al, 2000; Kravitz et al, 2003; Shoemaker, 2001), strengthens the mental relationship and could potentially ease recall when the instructions are removed. This is similar to Orrell et al (2006) that found that an analogy for a motor task helps the learning process. Our results agree with previous research in which extrinsic focus instruction improved learning of motor tasks (Shea and Wulf, 1999; Wulf and Weigelt, 1997; Wulf et al, 2004). These instructions involved placing focus on an outside source, similar to our global instructions. Our results are also in agreement with feedback research by Anderson and colleagues (2005) that states that less information provided during the early stages of learning invoke more long-term learning effects, though as stated earlier, our use of information volume differs from this study’s. Contrary to these studies and our findings, Scully and Carnegie (1998) discovered that verbally directing the attention
of observers to a specific joint (knees or ankles) improved performance of a dance maneuver.

Some items exist that may limit our ability to determine the true performance and learning effects of these instructional groups on the LESS and thus landing mechanics. In our study we used one week as a timeframe for assessing learning (our retention test). This is a timeframe that has been used previously for retention tests in motor learning research (Oñate et al, 2005, Oñate et al, 2001), however it is possible that permanent motor changes and learning cannot actually occur in that short of a time and that even if they do happen in that amount of time, they may not be able to truly test learning after only a week. Future studies should follow up with subjects past one week, especially since we are seeking long term improvement of landing mechanics to hopefully reduce ACL injury over a career. Future studies should possibly evaluate longer intervention time to apply the instructions to the subjects to see 1) if time has any affect of the uptake of the instructions and 2) if longer times could cause more retention. This could be especially important in instances of trying to incorporate these skill acquisition sessions into military training, athletic practice schedules, or physical education classes. Another limitation is the age group of this study. We used physically active individuals ages 18 to 25. Beyond this scope, we cannot make inferences as to the results of the instructions. Future studies should look at different ages and backgrounds in order to encompass all individuals that may benefit from intervention, especially youth age groups to see the potential use of the intervention on physical education classes and youth sports that would be teaching these athletes for the first time and varied ages and backgrounds for military training purposes.
Differences in Box-drop and Running Tasks

Already in our research we have touched on the differences between the transfer test and other three box-drop testing sessions in ground reaction forces. The landing mechanics (LESS scores) also showed marked differences between the box-drop and the running task. An overall increase in LESS scores was seen in the transfer test from the both the immediate posttest and the retention test. This main effect helps to emphasize the differences in the two tasks as far as their biomechanical demands are concerned. However, our findings disagree with our hypothesis that instruction would be able to transfer to the novel task. The specific and global groups showed significant increases between the immediate posttest and the transfer test sessions within their respective groups. However, all three groups degraded (increased LESS scores) between the retention test and the transfer test and there were no significant differences between the groups during the transfer test. As stated by Salmoni et al (1984), essentially whichever group performs best on the transfer test, demonstrates the strongest acquisition. As both the repeated measures ANOVA as well as a follow-up one-way ANOVA strictly for the transfer test values reveal no significant differences between instructional groups during the transfer test, we believe that our instructions demonstrated limited to no transferability to the novel task.

According to our findings, the running task varies significantly from the post-instructional and practiced box-drop task for landing motion patterns (LESS scores) and in general, for PPGRF and PVGRF. These results help define the biomechanical profile differences between these two tasks. Similarly, the findings of Sell et al (2004) discovered differences in kinematics, i.e. decreased knee flexion angle and moment, and
kinetic, i.e. increased PPGRF, in reactive jumps, meant to replicate athletic situations compared to planned jumps, commonly used in laboratory settings. Sell and colleagues (2004) followed up this study in 2006 with similar results. While our study compared box-drop versus stop-jump tasks and Sell et al’s (2004) work focused on two stop-jump tasks, the results both indicate that more athletically-based maneuvers increase PPGRF and may result in more harmful positioning than the commonly-used controlled box-drop tasks.

Our study agrees with previous research that has found that a stop-jump task results in motion patterns and forces that are specific to the running task and may differ from the box-drop (Yu et al, 2006; Yu et al, 2005; Oñate et al, 2005; Sell et al, 2006; Malinzak et al, 2001). These differences make any inference very difficult between the laboratory setting that uses the box-drop and the athletic or active settings, where the stop-jump task is more commonly seen. However, we did see a weak but significant correlation for LESS scores, PVGRF, and PPGRF between the retention test and the transfer test, which occurred on the same day. This correlation could provide some support that the tasks were similar in landing yet different in approach. Future studies should focus on utilizing running tasks in order to study landing kinetics and kinematics that need to be applied clinically. If standardization is a concern, timing devices, runway length, and cuing mechanisms could be employed in the laboratory setting. Discovering other athletic or active tasks where individuals are at risk for ACL injury and configuring it to the laboratory setting should be a priority in future research.

The use of a transfer test assists in determining the learning value of the instructional intervention (Magill, 2001; Salmoni et al, 1984). A novel activity that is at
the same time a similar task can test whether the instructional effects apply only to the task practiced on, or if the individual can reproduce the results in varied situations in the same vein of activity (Magill, 2001; Salminen et al., 1984; Lai et al., 2002; Wulf and Schmidt, 1997; Park and Shea, 2005; Choi et al., 2001). Our results indicate that these instructional cues could not be applied to this stop-jump task, and perhaps other athletic tasks, when compared to the practiced condition of the box-drop landing. This could be explained by either the nature of the instructions or the differences between the box-drop and stop-jump tasks. These instructions or any instructional intervention may need to be altered to be applicable to the run-jump task, either by practicing the instructions with the stop-jump task or by changing the instructions to better encompass both tasks. Future studies should also examine the effect of instructions on the individual graded items of the LESS in order to determine which aspects are best targeted by the instructions, as well as discovering how to construct the instructions to improve the most criteria of the landings.

One consideration when designing future studies is the potential need to accept the inherent nature of the biomechanics of the running tasks versus the box-drop task, i.e. the dorsiflexed position of the ankle at initial contact, and working to create instructional interventions that target the specific potentially harmful positions of the stop-jump task. The LESS has yet to be shown to be a reliable and valid tool for use with the stop-jump task. We utilized the LESS as an evaluating tool for both the box-drop task as well as the stop-jump task for two reasons. First, the LESS measures against the most proper positioning to keep the body aligned in a way to reduce injury risk, so no matter the task and how the body wants to land from that task, the LESS measures against the safest way
for the landing to occur. Also, the LESS measures components of the landing from a jump, regardless of what the individual does before to get in the position to be landing. However, further testing should be performed to determine the validity and reliability of the LESS across different jumping tasks as it is not known if the LESS is the best tool to use in these different tasks.

**Gender Issues**

The purpose of this study was to discover the effect of instruction on jump-landing motion patterns and impact forces on those individuals in need of intervention – those with higher LESS scores (poor landing mechanics). Previous research has shown that females have a higher risk of ACL injuries (Owings and Kozak, 1998) and tend to put themselves in riskier biomechanical positions than males during activities (Ford et al, 2004; Lephart et al, 2002; Padua et al, 2004a). With this foundation for female-focused ACL injury research, it would have seemed appropriate to focus this study on females, especially due to the skewed subject population (44 females and 7 males). However, all individuals, male or female, who put themselves in a potentially harmful position, are possibly in need of assistance in changing their mechanics (Chaudhari and Andriacchi, 2006; McLean et al, 2005). The LESS is an objective measuring tool that measure landing errors (Padua et al, 2004a; Padua et al, 2004b; Boling et al, 2005). By standardizing the inclusion criteria to those with high LESS scores (Padua et al, 2004b), this study aimed to improve positional faults in all individuals who may be in need of correction. However, as stated by Padua et al (2004a), females tend to have higher LESS scores. Our demographics agree with Padua and his colleagues' results, as 86% of our participants with LESS scores of 6 or higher were female. The skewed gender
distribution may appear to affect the results of this study; however, separate analyses composed solely of female participants was performed as well. These analyses revealed no statistical differences from the total experimental population. So, while gender may play a role in ACL risk, it does not seem to have any effect on the results of this study and the use of the LESS on individuals with potentially faulty movement patterns during landing.
CHAPTER V
CONCLUSION

There are several studies that have examined the effect of instruction on jump-landing motion patterns and impact forces in an attempt to prevent ACL injuries, however, there are few that rely strictly on visual modeling cues without any other preventative techniques, such as plyometric or strength training; and even fewer, that can be given to large groups without significant time needed from an instructor. Most research determines that providing instruction and practice can improve the mechanics of an individual during landing. In addition, many studies measure the results of their interventions with kinematic and kinetic data, yet even less utilize relatively easy to implement and cost-effective means to measure the landing mechanics. In our study, we aimed to create an intervention program that would be efficient and effective in the clinical setting in order to reach the most individuals that are in need of biomechanical intervention due to potentially harmful positioning before injury occurs.

We utilized the LESS (a relatively inexpensive, easy to use, reliable and valid objective tool) as a means of measuring landing motion patterns and found that instructional cues based on internal focus (specific modeling instructions in which individual joints and positions were pointed out to the individual) and external focus (global modeling instructions in which individuals were to land in the “athletic ready position”) were able to improve landing performance (lower LESS scores) immediately after intervention when compared to their pretest scores and a control group. Both groups also showed an improvement from their baseline scores during a retention test, indicating successful learning. However, the global instructional group was able to retain
the information more effectively than the specific group as only it was significantly lower than the control group during retention testing. Ground reaction force data (PVGRF and PPGRF) showed no effect for instruction, which may be due to the nature of the instructions, which were based solely on body positioning and not force of landing or the joint motions during the landing.

Our study demonstrated kinematic and kinetic differences between the box-drop task and the stop-jump task. LESS scores, PVGRF, and PPGRF all presented with higher values than the retention test values and equaled (PVGRF and LESS scores) or exceeded (PPGRF) the pre-intervention scores for the groups. Due to the different demands of the stop-jump task and the more athletic nature of the maneuver, it should be the task of choice for instructional intervention studies, with the instructions being aimed at and practiced for this or similarly athletic tasks.

While both instructional groups showed marked improvement in LESS scores throughout the box-drop trials, our results determined that implementing a pictorial representation of the “athletic ready position” will result in improved performance immediately on a box-drop task along with enabling individuals to retain the knowledge of proper landing positioning and perform the task over time without further instructions. However, those individuals were unable to transfer the learned skills to a novel task, such as the stop-jump landing. The instructions also did not reduce impact forces.

While the use of this easy to implement modeling cue of the “athletic ready position” should be considered a viable option to improve jump-landing motion patterns, especially in large group settings, such as physical education classes, athletic teams, and military training, in hopes of reducing ACL injury risk, further research needs to be
conducted to truly measure the efficacy of the instruction. More studies should be performed to determine if additional cues pertaining to joint motion throughout the landing phase or force-reducing statements would improve the impact forces of the landings while maintaining the positive effects of the instructions. Furthermore, we should investigate how to implement these instructions into more athletic jump-landings so that the positive findings of this study can be transferred out of the laboratory and into the clinical setting. Next, we need to examine how the global instructional cue fares in prospective longitudinal intervention, with increased practice and instructional time and increased follow-up timeframes, across a variety of age groups, in order to truly understand the potential of these instructions to not only change motion patterns and impact forces, but to potentially reduce ACL injury risk. As well as the ecological validity of the instructions, meaning how the instructions fare during jump-landing tasks in an athletic environment, with all the distractions and noise that goes along with realistic scenarios. Finally, there is a need to determine the effect of these or any instructional interventions on the reduction of ACL injury rates. After all, we can hypothesize that by correcting faulty landing patterns and impact forces, we can reduce the risk of ACL injury, but the theory is tested with actually injury rates, we do not know the true effects of the intervention.
REFERENCES


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Sell TC, Ferris CM, Abt JP, Tsai Y-S, Myers JB, Fu FH, Lephart SM. The effect of duration and reaction on the neuromuscular and biomechanical characteristics of


INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: The effect of instruction on jump-landing motion patterns as measured by the Landing Error Scoring System.

INTRODUCTION
The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. All testing will take place in The Sports Medicine Research Lab, 112-113 Spong Hall on the campus of Old Dominion University.

RESEARCHERS
Responsible Project Investigator:
James A. Ofiate, Ph.D ATC – Assistant Professor, Graduate Athletic Training Program; Director, Sports Medicine Research Lab
Department: Exercise Science, Sport, Physical Education, Recreation; College: Education

Co-Investigator:
Mary E. Joos, BA ATC – Masters Student, Graduate Athletic Training Program
Department: Exercise Science, Sport, Physical Education, Recreation; College: Education

DESCRIPTION OF RESEARCH STUDY
Several studies have been conducted looking into reducing knee injuries, specifically Anterior Cruciate Ligament (ACL), through the use of plyometrics, balance, and strength training programs. An additional method that is currently gaining notice is the use of instructions to correct improper landing mechanics. No research to date has evaluated the use of viewing pictures (models) of proper landing position as instructional tools. The ability to improve landing mechanics will be measured using a clinical assessment tool, known as the Landing Error Scoring System (LESS) along with measuring how hard you land (peak vertical ground reaction force).

If you decide to participate, then you will join a study involving research of jump landing mechanics. You will be asked to jump off a box (30cm high), landing on both legs onto two force plates (80cm x 60cm), and then jump up straight in the air as high as you can, landing again on both force plates. You will get to practice this jump two times and then you will be asked to perform the jump three times for testing. This initial testing will be considered your baseline test. The investigator, within one week, will then inform you if you have met the criteria to proceed in the study. At that time, you will schedule a time to come in and jump three more times. During this round of testing, you may or may not receive visual and verbal instruction on how to change your jump landing technique. You will
then need to report again to the Sports Medicine Research Lab one week later to jump three more times without any further instruction. At the session one week later, you will also be performing a run, stop, and jump task. You will run at full speed, take off on one leg, land with one foot on each of the force plates, jump up straight in the air for a maximum jump height, and then land back on the force plates with one foot on each plate. You will repeat this for a total of three trials. You will be videotaped during all jump landing trials for the use of the investigator to score the jump landings using the LESS. If you say YES, then your participation will last for 20 minutes for the pre-testing, and a subsequent 20 minutes for the post-testing and 20 minutes for the one-week retention testing (a total of 60 minutes over the course of 3 sessions) at the Sports Medicine Research Lab, 112-113 Spong Hall on Old Dominion University's campus. Approximately 100 physically active individuals, between the ages of 18-25 years old, will be participating in this study.

EXCLUSIONARY CRITERIA
You must be of the ages 18-25 and participate in some form of exercise for a minimum of 20 minutes 3 times a week. To the best of your knowledge, you should not have a history of any lower extremity injury within the last 2 months that limited activity for more than one day, no current history of lower extremity instability, or underwent any previous lower extremity surgery within the past 2 years that would keep you from participating in this study. You must not participate in any jump-landing instructional program during the duration of your participation in this study.

RISKS AND BENEFITS
RISKS: If you decide to participate in this study, then you may face a risk of falling while performing the jump-landing task or landing awkwardly from the jumps. The researcher has tried to reduce these risks by providing you practice opportunities performing the jump-landing task and by removing any obstacles around the jump-landing area. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits to you for participating in this research. Others may benefit through the use of the results of this study to help form prevention strategies to reduce the risk of knee injuries (e.g., ACL) in physically-active individuals.

COSTS AND PAYMENTS
You will receive five dollars for your participation in the baseline testing session of this project following the testing session. If your participation is needed further in this study, you will be contacted and given the option to continue. If you choose to continue in the study, you will receive an additional five dollars following the completion of the subsequent testing.

NEW INFORMATION
If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY
All information obtained about you in this study is strictly confidential unless disclosure is required by law. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE
It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY
If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. James Oñate, the principal investigator of this study, at 757-683-4351 or Dr. David Swain the current IRB chair at 757-683-6028 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT
By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Dr. James Oñate 757-683-4351
Mary Joos 757-889-1275

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. David Swain, the current IRB chair, at 757-683-6028, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.
## INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject’s questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

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Revised 8/06
APPENDIX 2

SPECIFIC MODELING INSTRUCTIONS
Specific Modeling Group Instructions (written on paper and given to the subjects):

“Look at the picture below. The image is how you should be positioned upon landing from a jump. On your subsequent jump, please focus on landing in a position in which your hips and knees are pointing straight ahead; trunk, hips, knees are flexed to at least 30 degrees; feet are shoulder width apart; knees do not collapse in; toes are pointed straight ahead; and you are landing evenly on both legs, similar to the picture below. Each of these elements is important and you should try to imitate them in your next landing. Both landings of the task are important so please try to incorporate these instructions into both landings. You have two minutes to review this position and how you can incorporate it into your next jump. Please take the full time and focus on the task at hand. When you are ready please step back onto the box.”
APPENDIX 3
GLOBAL MODELING INSTURCTIONS
Global Modeling Group Instructions (written on paper and given to the subject):

“Look at the picture below. This image is the proper position your body should be in when you land from a jump. You may know this position as the ‘athletic ready position,’ also known as an ‘athletic stance’ or defensive position,’ from sports you have participated in. On your subsequent jump, please attempt to land in an athletic ‘ready position,’ similar to the picture below. Both landings of the task are important and you should try to land in the ‘athletic ready position’ on both landings. You have two minutes to review this position and how you can incorporate it into your next jump. Please take this full time and focus on the task at hand. When you are ready please step back onto the box.”
APPENDIX 4

PICTURES OF JUMP-LANDING TASK
APPENDIX 5

DIAGRAM OF STOP-JUMP PHASE
Stop Jump Phase

Initial Contact

Peak VGRF

300 ms

Take-off Phase
APPENDIX 6

PHOTO AND VIDEO CONSENT FORM
INFORMED CONSENT DOCUMENT
FOR USE OF PHOTO/VIDEO MATERIALS

STUDY TITLE: The effect of instruction on jump-landing motion patterns as measured by the Landing Error Scoring System.

DESCRIPTION:
The researchers would like to take photographs or videotapes of you performing various movement tasks in order to analyze the data and illustrate the research in teaching, presentations, and/or publications.

CONFIDENTIALITY:
You would not be identified by name in any use of the photographs or videotapes. All videotapes and photographs will be stored using a subject number; no names will be recorded. At the completion of this study all videotapes will be erased and photographs destroyed.

VOLUNTARY CONSENT
By signing below, you are granting to the researchers the right to use your likeness, image, appearance and performance - whether recorded on or transferred to videotape, film, slides, photographs - for presenting or publishing this research. No use of photos or video images will be made other than for professional presentations or publications. The researchers are unable to provide any monetary compensation for use of these materials. You can withdraw your voluntary consent at any time.

If you have any questions later on, then the researchers should be able to answer them: contact Dr. James Ofiate (757) 683-4351. If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. David Swain, the current IRB chair, at 757-683-6028, or the Old Dominion University Office of Research, at 757-683-3460.

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<th>Investigator’s Printed Name &amp; Signature</th>
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APPENDIX 7

LANDING ERROR SCORING SYSTEM SHEET
Landing Error Scoring System (LESS)  Date: __________

Subject ID: __________  Rater: __________________________
Project: __________

* Note: Initial contact is **first frame** that shows **any** foot contact with the floor
* Note: if asymmetrical landing, score the instrumented leg or the first landing leg

1. Ankle Plantar-Flexion Angle at Initial Contact: Toe to Heel  Trial #1 #2 #3
   (+0) Yes
   (+1) No

2. Knee Flexion Angle at Initial Contact: Greater than 30°  Trial #1 #2 #3
   (0) Yes
   (+1) No

3. Trunk Flexion Angle at Initial Contact: Trunk in front of hips  Trial #1 #2 #3
   (+0) Yes
   (+1) No

4. Knee Flexion ROM GREATER than 30°  Trial #1 #2 #3
   (0) Yes
   (+1) No

5. Trunk Flexion at Max Knee Flexion Angle: Trunk in front of hips  Trial #1 #2 #3
   (0) Yes
   (+1) No

6. Initial Foot Contact  Trial #1 #2 #3
   (0) Symmetric foot contact
   (+1) Asymmetric foot contact

7. Foot Position at Initial Contact: Toes > 30 of ER  Trial #1 #2 #3
   (+1) Yes
   (+0) No

8. Foot Position at Initial Contact: Toes > 30 of IR  Trial #1 #2 #3
   (+1) Yes
   (+0) No

9. Stance Width at Initial Contact: LESS than shoulder width  Trial #1 #2 #3
   (+1) Yes
   (+0) No
10. **Stance Width at Initial Contact: GREATER than shoulder width**

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<thead>
<tr>
<th>Trial #1</th>
<th>#2</th>
<th>#3</th>
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<tr>
<td>(+1) Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+0) No</td>
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11. **Knee Valgus Angle at Initial Contact: Knees over mid-foot**

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<tr>
<td>(+0) Yes</td>
<td></td>
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<tr>
<td>(+1) No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. **Lateral Trunk Flexion at Initial Contact**

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0) Sternum centered over hips</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+1) Lateral deviation of sternum over hips</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. **Knee Valgus ROM: Greater than great toe**

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+1) Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0) No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. **Joint Displacement: (Sagittal Plane)**

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+0) Large joint motion (quiet / soft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+1) Average joint motion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+2) Small joint motion (loud / stiff)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15. **Overall Impression**

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+0) Excellent (maintains frontal alignment, lands w/ &gt; 30° of knee flexion, undergoes &gt; 30° of displacement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+1) Average (small frontal motion, straight/stiff landing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+2) Poor (large frontal motion)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Score** #1 ___ #2 ___ #3 ___
VITA

Mary Elizabeth Joos

Department of Study

Old Dominion University
Department of ESPER
Spong Hall
Norfolk, VA 23529

Education

May 2007    Master of Science in Education
            Athletic Training
            Old Dominion University
            Norfolk, Virginia

May 2005    Bachelor of Arts
            Exercise and Sports Science – Athletic Training
            Minor: Chemistry
            University of North Carolina at Chapel Hill
            Chapel Hill, North Carolina

Professional Experience

01/07 - 05/07    Old Dominion University; Norfolk, VA
     Co-Instructor: Advanced First Aid and CPR (HE224, 3 credits)
     • Created lesson plans, skill laboratories and practice sessions, assignments, examinations, and practical examinations following the curriculum of the American Red Cross; responsible for daily teaching responsibilities and administration duties

08/06 – 12/06    Old Dominion University; Norfolk, VA
     Teaching Assistant: Gross Anatomy for the Sports Medicine Clinician (ESPR691, 4 credits)
     • Assisted professor, conducted dissection sessions, and performed exam review sessions for a graduate course in the Post-professional Graduate Athletic Training Program

8/05 – 5/07    Old Dominion University; Norfolk VA
     Graduate Assistant Athletic Trainer
     • Certified athletic trainer with varsity athletes during Athletic Training Room coverage; rotations with Men’s Varsity Soccer, Women’s Varsity Lacrosse, Men’s Varsity Baseball, Women’s Field Hockey, Women’s Basketball;
practice and game coverage of Men’s and Women’s Varsity Tennis, Men’s and Women’s Varsity Swimming and Diving, and a variety of club sports

- Performed daily evaluations of athletic injuries, created and supervised treatment and rehabilitative protocols for athletes, and assisted staff ATC with administrative duties