THE EFFECT OF INSTRUCTIONS ON LOWER EXTREMITY BIOMECHANICS AND PERFORMANCE MEASURES

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ABSTRACT

Lauren Elizabeth Hawkinson: The Effect of Instructions on Lower Extremity Biomechanics and Performance Measures
(Under the direction of Darin Padua)

The type of instructions given during completion of an anterior cruciate ligament injury prevention program may influence its effect on injury prevention and performance benefits. Research has yet to identify the impact of different instructions on injury prevention variables – knee abduction angle, knee flexion angle, hip adduction angle, vertical ground reaction force – and performance variables – vertical jump height and stance time. A crossover research design was used. Participants received injury prevention and performance based instructions in counterbalanced order. Separate paired T-test’s were performed between change scores for each condition to determine the effect of different instructions on the dependent variables. A significant decrease in magnitude of hip adduction was found at initial contact when given injury prevention instructions and a significant decrease in magnitude of stance time resulted when given performance enhancement instructions during both landing tasks. A significant increase in magnitude of jump height resulted when given performance enhancement instructions.
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CHAPTER 1
INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common, and most debilitating, injuries sustained in sports. It is estimated that as many as 250,000 ACL injuries happen each year in the United States (Griffin et al., 2006). Females are more likely to sustain an ACL injury during sport in comparison to males (Arendt & Dick, 1995; Mountcastle, Posner, Kragh, & Taylor, 2007). Fortunately, a vast amount of injury prevention research has focused on this gender disparity and worked towards developing injury prevention programs (IPPs) that have been successful in reducing injury incidence (Gilchrist et al., 2008; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Mandelbaum et al., 2005). However, getting coaches and teams to comply with these IPPs is an ongoing issue and limits the scope of their effectiveness. Anecdotally, coaches may be more interested in these programs if they were presented as performance enhancing. However, evidence is lacking as to how these IPPs may affect sports performance and requires further study.

1.1 EPIDEMIOLOGY

ACL injury comes at a huge emotional, physical, and financial cost. The injury is not only painful, but costs athletes 6-9 months away from their sport. The emotional cost only increases when a college scholarship lies in the balance. Physically, the risk of re-injury is greater in young athletes trying to return to sport and the ability to maintain a physically active lifestyle is often diminished (Paterno, Rauh, Schmitt, Ford, & Hewett, 2012; Salmon, Russell, Musgrove, Pinczewski, & Refshauge, 2005; Shelbourne, Gray, & Haro, 2009). Additionally,
50% of those who suffer an ACL injury will show radiographic signs of osteoarthritis 12 years after injury (Lohmander, Ostenberg, Englund, & Roos, 2004). Financially, ACL reconstructive surgery is estimated to cost $20,000 per case (Brophy, Wright, & Matava, 2009), resulting in an annual financial burden of $1.6 - $5 billion.

Females tear their ACLs at much higher rate in sports that involve stopping quickly, cutting, and changing direction and are 4-8 times more likely to experience a non-contact knee injury compared to males (Barber-Westin, Noyes, & Galloway, 2006; Ireland, 2002). For the purposes of this study, a non-contact knee injury is defined as an injury occurring during sport, or sport-like activities, during which the knee is not struck directly and the injury occurs due to the athlete’s own movements (Marshall, 2010). Particularly in sports that involve large amounts of stopping quickly, cutting, and changing direction, such as soccer and basketball, females are 3 times and 2.4-4 time more likely, respectively, to tear their ACLs through a non-contact mechanism than their male counterparts (Arendt & Dick, 1995; Mountcastle et al., 2007). Females display more hip adduction and internal rotation causing valgus at the knee and tibial external rotation during a mini-squat (Ireland, 2002), a similar position to the one used when completing stopping and cutting maneuvers (Boden, Torg, Knowles, & Hewett, 2009; Krosshaug et al., 2007). Prospectively, females who went on to tear their ACLs had a knee abduction angle 8.4° larger than females who did not injure their knees (Hewett et al., 2005).

Many factors are thought to influence the likelihood of sustaining an ACL injury, including, but not limited to, anatomical, environmental, hormonal, and biopsychosocial factors (Elliot, Goldberg, & Kuehl, 2010; Griffin et al., 2006; Ireland, 2002; Shultz et al., 2012). While we acknowledge that the previous factors are all important in the study of ACL injury, the focus of this study will be on the biomechanical and neuromuscular factors linked with ACL injury.
These factors are known to contribute to the gender disparity in sport related injury and are the focus of ACL injury prevention programs because they are believed to be modifiable.

Research studies have investigated specific cadaveric loading states that place more strain on the ACL, identified biomechanical risk factors for ACL injury, and observed the motion patterns that occur when they do suffer an ACL injury via video analysis, and all are closely tied. When using cadaveric studies, it isn’t as simple as the sum of two forces; certain forces combined are more detrimental than others (Markolf et al., 1995). In particular, the highest ACL forces recorded by Markolf, et. al. were found when the knee was in flexion less than 20° and the anterior tibial force was combined with internal rotation torque. In addition, the authors purport anterior tibial shear force paired with valgus moment in knee flexion as well as anterior tibial shear force paired with varus moment in knee extension/hyperextension creates the most dangerous forces for the ACL.

Interestingly, it was found that greater knee valgus moments and angles and smaller knee flexion angles were significant predictors of future ACL injury (Hewett et al., 2005). Visual observation of this increase in knee valgus motion has been termed “medial knee displacement,” and has been identified in video footage of ACL injury events (Boden et al., 2009; Hewett, Torg, & Boden, 2009; Krosshaug et al., 2007). An important factor in the display of medial knee displacement (MKD) seems to be neuromuscular in nature, in particular, an increase in hip adductor activation (Padua, Bell, & Clark, 2012). In addition to the hip and knee position, greater vertical ground reaction force – that is, the force exerted during landing from the ground through the leg – and greater leg-to-leg differences in knee load were seen in injured compared to non-injured females (Hewett et al., 2005).
1.2 PREVENTION PROGRAMS

While all of these risk factors increase the likelihood that females will tear their ACLs, participation in ACL prevention programs has been found to reduce this likelihood (Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005). When female soccer players participated in an injury prevention program, they reduced the incidence of ACL injury by 74% compared to their age and skill matched controls who participated in a standard warm-up (Mandelbaum et al., 2005). Participating in an injury prevention program not only helps those females who have never been injured, but aids those who have been previously injured. Females who have previously suffered an ACL injury and then participated in an injury prevention program, suffered new ACL injuries at a rate five times less than previously injured females who do not participate in prevention programs (Gilchrist et al., 2008).

However, not all IPPs have been found to reduce the number of ACL injuries. In one study, the incidence rates of ACL injury were actually higher in the intervention group than in the control group (Soderman, Werner, Pietila, Engstrom, & Alfredson, 2000). Another study implemented an IPP, called the “11,” which uses core stability exercises, lower extremity strengthening exercises, and neuromuscular control and stability exercises (Steffen, Myklebust, Olsen, Holme, & Bahr, 2008). They found no difference in proportion of injuries or the location and severity of injury between the intervention and control groups. However, a very important factor reported by each of these authors was low compliance of the athletes, thereby potentially contributing to the ineffectiveness of the program.

The benefits of participating in an injury prevention program have been widely recognized by researchers. However, coaches and athletes are still lacking in motivation and compliance, which may be contributing factors to the overall effectiveness of the program.
(Myklebust et al., 2003; Soderman et al., 2000; Steffen, Myklebust, et al., 2008). In order for the prevention program to have a positive effect, compliance (attendance x completion) needs to reach at least 66% (Sugimoto et al., 2012).

Oftentimes, compliance starts at the coach’s level. Many IPPs are implemented as a team warm-up, however coaches frequently have a problem with the length of time required and are not willing to give up the practice time. Coaches are usually the ones required to teach and implement the program, which is a hurdle if they do not feel comfortable doing so. A survey of coaches agreed unanimously that these IPP’s were important, but they needed to be better educated on how to properly implement the program and better understand it’s positive effects (Joy, 2013). Finally, there are some coaches who simply do not feel the pressing importance of an injury prevention program because they have not experienced an injury of this magnitude on their team.

While compliance may start with the coach, it has to end with the athlete. Ultimately, the athlete will be the one an ACL injury most affects and he/she will be the one to reap the benefits of completing an IPP. Motivation is a key component not only in compliance, but in the effectiveness of the instructions/conditions (Wulf, Shea, & Lewthwaite, 2010). The question then becomes one of how to best motivate the athletes to comply, and the answer may be performance. An increase in performance is something both coaches and athletes agree is essential, and if clinicians are able to tap into it’s attraction, compliance with IPPs and the motivation to complete them may increase.
1.3 PERFORMANCE VARIABLES

While coaches and athletes may like to hear that they will see a decrease in the number of injuries, oftentimes performance on the field or court is just as important to increase motivation to participate in IPPs. However, research is currently lacking on the effect of injury prevention programs on overall improvements in athletic performance (Noyes & Barber-Westin, 2012) and the information we have is conflicting in its findings. One study had female soccer players participate in an IPP and subsequently measured linear sprint performance, countermovement jump height, and agility tests and found that the IPP reduced performance scores – slower sprint and agility tests and smaller jump height (Vescovi & VanHeest, 2010). In a review of IPPs by Noyes, et al. (Noyes & Barber-Westin, 2012), it was found that only two IPPs improved performance as well as reduced ACL injury. The Sportsmetrics program increased athletes’ performance in vertical jump height, single-leg crossover hops, tennis agility measures, and knee flexion peak torque values, while the Prevent Injury and Enhance Performance (PEP) program significantly improved peak torques for hip abduction, hip extension, and knee flexion (Noyes & Barber-Westin, 2012) – all of which are important in both injury prevention and performance enhancement.

Too often, sport performance and injury prevention are at odds with one another. Athletes need to have quick reaction times and force production to perform well, but this can come at the cost of safe movement patterns. In contrast, telling an athlete to land softly may impact his/her length of stance phase and ability to move quickly when landing from a jump. However, research is necessary to better understand these relationships to guide researchers and clinicians in packaging injury prevention programs to garner the most benefits.
Ideally, these same IPP’s that have decreased the incidence of ACL injury could also improve athletic performance. The ability to present these programs as injury preventing and performance enhancing may result in greater compliance by coaches and athletes overall. Programs that utilized verbal instructions in combination with injury prevention exercises have been shown to be most effective in altering variables believed to contribute to ACL injury (Herman et al., 2009; Padua & Distefano, 2009; Stroube et al., 2012). However, it is unknown if verbal instructions specific to ‘preventing injury’ or ‘enhancing performance’ could also impact these results.

Therefore, the primary purpose of this study is to evaluate the acute effects of an ACL injury prevention program with two different sets of verbal instructions on lower extremity kinematics and performance measures during sport specific movements in female participants with at risk movement patterns who have at some point participated in specific competitive sport. More specifically, verbal instructions packaged as “injury preventing” or “performance enhancing” will be utilized in a crossover format in all participants. Determining the best way to present an ACL injury prevention program could influence compliance among coaches and athletes and in turn, increase the effectiveness of ACL prevention programs.

1.4 RESEARCH VARIABLES

Independent Variables
The following independent variable will be used in this study:

1. Instructions
   a. Performance based instructions
   b. Injury Prevention based instructions

Dependent Variables
The following dependent variables will be used in this study:

1. Double Leg Jump Landing (JL)
a. The Change Score Between Pre and Post Test of the Following ACL Injury Prevention Variables

i. Knee abduction angle

ii. Hip adduction angle

iii. Knee flexion angle

iv. Vertical ground reaction force

b. The Change Score Between Pre and Post Test of the Following Sport Performance Variables

i. Length of stance phase

ii. Vertical jump height

2. Single leg cut (SLC)

a. The Change Score Between Pre and Post Test of the Following ACL Injury Prevention Variables

i. Knee abduction angle

ii. Hip adduction angle

iii. Knee flexion angle

iv. Vertical ground reaction force

b. The Change Score Between Pre and Post Test of the Following Sport Performance Variables

i. Length of stance phase
1.5 RESEARCH QUESTIONS/HYPOTHESES

The following research question has been identified for this thesis:

1. What are the effects of two sets of verbal instructions on lower extremity biomechanics and performance measures during a double leg jump-landing task and a single leg cut task?

The following research hypotheses have been developed for this thesis:

1. When given prevention based verbal instructions during an intervention, participants knee abduction angles, hip adduction angles, vertical jump heights and vertical ground reaction forces will have a greater magnitude decrease, while knee flexion angles and stance times will have a greater magnitude increase during a double leg jump landing task and single leg cut task than when given performance based verbal instructions.

2. When given performance based verbal instructions while completing an intervention, participants length of stance phases will have a greater magnitude decrease while vertical jump heights, knee flexion angles, and vertical ground reaction forces will have a greater magnitude increase during a double leg jump landing task, than participants given prevention based verbal instructions. No change is expected in knee abduction angles or hip adduction angles.

3. When given performance based verbal instructions while completing an intervention, participants knee abduction angles, hip adduction angles, and vertical ground reaction forces will have a greater magnitude increase while
length of stance phase will have a greater magnitude decrease during a single leg cut maneuver. No change is expected in knee flexion angles.

4. When completing the DL jump landing task, larger magnitude change scores will occur when receiving the prevention based instructions for knee abduction angles, hip adduction angles, and stance times and larger magnitude change scores will occur when receiving the performance based instructions for peak vertical ground reaction forces and vertical jump heights. No difference is expected for knee flexion angles.

5. When completing the single leg cut task, larger magnitude change scores will occur when receiving the prevention based instructions for stance time and larger magnitude change scores will occur when receiving performance based instructions for knee abduction angles, hip adduction angles, and peak vertical ground reaction forces. No difference is expected for knee flexion angles.

The following statistical hypotheses have been developed for this study:

1.1 $H_0$: $\mu$ prevention-based instructions DL landing and Single leg cut Kn Abd = $\mu$ performance-based instructions Kn Abd

$H_A$: $\mu$ prevention-based instructions DL landing and Single leg cut Kn Abd < $\mu$ performance-based instructions Kn Abd

1.2 $H_0$: $\mu$ prevention-based instructions DL landing and Single leg cut Hip Add = $\mu$ performance-based instructions Hip Add

$H_A$: $\mu$ prevention-based instructions Hip Add < $\mu$ performance-based instructions Hip Add
1.3 $H_0$: $\mu$ prevention-based instructions DL landing and Single leg cut $\text{VGRF} = \mu$ performance-based instructions $\text{VGRF}$

$H_A$: $\mu$ prevention-based instructions DL landing and Single leg cut $\text{VGRF} < \mu$ performance-based instructions $\text{VGRF}$

1.4 $H_0$: $\mu$ prevention-based instructions DL landing and Single leg cut

$\text{Kn Flex angle} = \mu$ performance-based instructions $\text{Kn Flex angle}$

$H_A$: $\mu$ prevention-based instructions DL landing and Single leg cut $\text{Kn Flex} > \mu$ performance-based instructions $\text{Kn Flex}$

1.5 $H_0$: $\mu$ prevention-based instructions DL landing and Single leg cut

$\text{stance time} = \mu$ performance-based instructions $\text{stance time}$

$H_A$: $\mu$ prevention-based instructions DL landing and Single leg cut $\text{stance time} > \mu$ performance-based instructions $\text{stance time}$

2.1 $H_0$: $\mu$ performance-based instructions DL landing $\text{stance time}= \mu$ prevention-based instructions $\text{stance time}$

$H_A$: $\mu$ performance-based instructions DL landing $\text{stance time} < \mu$ prevention-based instructions $\text{length of stance phase}$

2.2 $H_0$: $\mu$ performance-based instruction DL landing $\text{VJH}= \mu$ prevention-based instruction $\text{VJH}$

$H_A$: $\mu$ performance-based instruction DL landing $\text{VJH} > \mu$ prevention-based instruction $\text{VJH}$

2.3 $H_0$: $\mu$ performance-based instruction DL landing $\text{Kn Flex} = \mu$ prevention-based instruction $\text{Kn Flex}$
$H_A$: $\mu$ performance-based instruction DL landing Kn Flex $> \mu$ prevention-based instruction Kn Flex

2.4 $H_O$: $\mu$ performance-based instruction DL landing VGRF $= \mu$ prevention-based instruction VGRF

$H_A$: $\mu$ performance-based instruction DL landing VGRF $> \mu$ prevention-based instruction VGRF

2.5 $H_O$: $\mu$ performance-based instruction DL landing Kn Abd $\neq \mu$ prevention-based instruction Kn Abd

$H_A$: $\mu$ performance-based instruction DL landing Kn Abd $= \mu$ prevention-based instruction Kn Abd

2.6 $H_O$: $\mu$ performance-based instruction DL landing Hip Add $\neq \mu$ prevention-based instruction Hip Add

$H_A$: $\mu$ performance-based instruction DL landing Hip Add $= \mu$ prevention-based instruction Hip Add

3.1 $H_O$: $\mu$ performance-based instruction Single leg cut Kn Abd $= \mu$ prevention-based instruction Kn Abd

$H_A$: $\mu$ performance-based instruction Single leg cut Kn Abd $> \mu$ prevention-based instruction Kn Abd

3.2 $H_O$: $\mu$ performance-based instruction Single leg cut Hip Add $= \mu$ prevention-based instruction Hip Add

$H_A$: $\mu$ performance-based instruction Single leg cut Hip Add $> \mu$ prevention-based instruction Hip Add
3.3 $H_0$: $\mu$ performance-based instruction Single leg cut VGRF = $\mu$ prevention-based instruction VGRF

$H_A$: $\mu$ performance-based instruction Single leg cut VGRF > $\mu$ prevention-based instruction VGRF

3.4 $H_0$: $\mu$ performance-based instruction Single leg cut stance time = $\mu$ prevention-based instruction stance time

$H_A$: $\mu$ performance-based instruction Single leg cut stance time < $\mu$ prevention-based instruction stance time

3.5 $H_0$: $\mu$ performance-based instruction Single leg cut Kn Flex $\neq$ $\mu$ prevention-based instruction Kn Flex

$H_A$: $\mu$ performance-based instruction Single leg cut Kn Flex = $\mu$ prevention-based instruction Kn Flex

4.1 $H_0$: $\mu$ DL landing Kn Abd change score prevention-based instruction = $\mu$ DL landing Kn Abd change score performance-based instruction

$H_A$: $\mu$ DL landing Kn Abd change score prevention-based instruction > $\mu$ DL landing Kn Abd change score performance-based instruction

4.2 $H_0$: $\mu$ DL landing Hip Add change score prevention-based instruction = $\mu$ DL landing Hip Add change score performance-based instruction

$H_A$: $\mu$ DL landing Hip Add change score prevention-based instruction > $\mu$ DL landing Hip Add change score performance-based instruction

4.3 $H_0$: $\mu$ DL landing stance time change score prevention-based
instruction = µ DL landing stance time change score performance-based instruction

$H_A$: µ DL landing stance time change score prevention-based instruction > µ DL landing Kn Abd change score performance-based instruction

4.4 $H_0$: µ DL landing VGRF change score performance-based instruction
   = µ DL landing VGRF change score prevention-based instruction

$H_A$: µ DL landing VGRF change score performance-based instruction > µ DL landing VGRF change score prevention-based instruction

4.5 $H_0$: µ DL landing VJH change score performance-based instruction
   = µ DL landing VJH change score prevention-based instruction

$H_A$: µ DL landing VJH change score performance-based instruction > µ DL landing VJH change score prevention-based instruction

4.6 $H_0$: µ DL landing Kn Flex change score performance-based instruction
   ≠ µ DL landing Kn Flex change score prevention-based instruction

$H_A$: µ DL landing Kn Flex change score performance-based instruction
   = µ DL landing Kn Flex change score prevention-based instruction

5.1 $H_0$: µ Single leg cut stance time change score prevention-based instruction
   = µ Single leg cut stance time change score performance-based instruction

$H_A$: µ Single leg cut stance time change score prevention-based instruction
   > µ Single leg cut stance time change score performance-based instruction
5.2 H₀: $\mu$ Single leg cut Kn Abd change score performance-based instruction = $\mu$ Single leg cut Kn Abd change score prevention-based instruction

$H_A$: $\mu$ Single leg cut Kn Abd change score performance-based instruction > $\mu$ Single leg cut Kn Abd change score prevention-based instruction

5.3 H₀: $\mu$ Single leg cut Hip Add change score prevention-based instruction = $\mu$ Single leg cut Hip Add change score performance-based instruction

$H_A$: $\mu$ Single leg cut Hip Add change score prevention-based instruction > $\mu$ Single leg cut Hip Add change score performance-based instruction

5.4 H₀: $\mu$ Single leg cut VGRF change score prevention-based instruction = $\mu$ Single leg cut VGRF change score performance-based instruction

$H_A$: $\mu$ Single leg cut VGRF change score prevention-based instruction > $\mu$ Single leg cut VGRF change score performance-based instruction

5.5 H₀: $\mu$ Single leg cut Kn Flex change score performance-based instruction ≠ $\mu$ Single leg cut Kn Flex change score prevention-based instruction

$H_A$: $\mu$ Single leg cut Kn Flex change score performance-based instruction = $\mu$ Single leg cut Kn Flex change score prevention-based instruction
1.6 OPERATIONAL DEFINITIONS

The following operational definitions will be used in this study:

**Healthy College-aged Females:** Females between the ages 18-26 with no prior history of ACL injury or participation in an IPP

**Physically Active:** Engages in 30-60 min of physical activity at least three times a week

**Competitive Sport:** Sport that involves cutting, jumping, and/or quick changes of direction or would have included such movements during training, such as, but not limited to, volleyball, basketball, lacrosse, soccer, field hockey, and tennis. Competed at least one year at the varsity level in high school or competing currently in club sports.

**At Risk Movement Pattern:** Identified as accessory movements when completing a single leg squat, such as: shoulders not level, trunk rotated in (towards the stance leg), trunk rotated out (towards non-stance leg), hip hikes on non-stance leg, hip drops on stance leg ( +Trendelenburg), femoral adduction and medial knee displacement.

**Performance Based Instructions:** Instructional cues given with emphasis on performance gain aspects

**Injury Prevention Based Instructions:** Instructional cues given with emphasis on injury prevention aspects

**Double Leg Jump Landing (JL):** A double leg forward jump from a 30-cm box placed a distance of 50% of subjects’ standing height away from the landing surface (force plates), followed by an immediate maximal vertical jump
**Single-leg Land and Cut (SLC):** A double leg forward jump over a hurdle placed one foot in front of the force plate, land single leg on the force plate, and 45° cut to the contralateral side

**Dominant Leg:** The leg the subject would kick a soccer ball with

**Initial Contact:** The first time point during each trial of the jump landing and cutting tasks where the vertical ground reaction force recorded by the force plate registers over 10N

**Stance phase:** The time between initial contact and toe-off, while the foot is in contact with the force plate during both tasks

**Loading phase:** The time period from initial contact to peak knee flexion, representing the period of time where the subject is absorbing the landing forces during both tasks

**Push-off phase:** The period of time between the end of the loading phase at peak knee flexion and toe-off

**Initial Contact Knee Abduction Angle:** The knee abduction angle reached during initial contact of the foot with the force plate of the JL task and stance phase of the SLC task

**Initial Contact Hip Adduction:** The hip adduction angle reached during the initial contact of the foot with the force plate of the JL task and stance phase of the single leg cut task

**Initial Contact Knee Flexion:** The knee flexion angle reached during the initial contact of the foot with the force plate of the JL task and the stance phase of the single leg cut task
**Peak Knee Abduction Angle:** The maximum knee abduction angle reached during the loading phase of the JL task and stance phase of the SLC task

**Peak Hip Adduction:** The maximum hip adduction angle reached during the loading phase of the DL jump landing task and stance phase of the single leg cut task

**Peak Knee Flexion:** The maximum knee flexion angle reached during the loading phase of the DL jump landing task and the stance phase of the single leg cut task

**Peak Vertical Ground Reaction Force:** The peak vertical ground reaction force reached during the loading phase of the JL and SLC tasks, normalized to body weight (N)

**Stance Time:** The period of time between initial contact and toe off, representing the period of time the subject’s foot is in contact with the force plate during the JL task SCL task

**Max Vertical Jump:** The maximum height a subject can jump during the JL task, as measured by the force plate and “Time in Air” equation/displacement of the pelvis marker on the subject ($\frac{1}{2} g(t/2)^2$, where $g = 9.81 \text{ m} \cdot \text{sec}^{-2}$ and $t =$ time in air)

**Knee Abduction Displacement:** The amount of degrees the knee joint has rotated around the anteroposterior axis during the loading phase of the JL task and stance phase of the SLC task

**Hip Adduction Displacement:** The amount of degrees the hip joint has rotated around the anteroposterior axis during the loading phase of the JL task and stance phase of the SLC task

**Knee Flexion Displacement:** The amount of degrees the knee joint has rotated
around the mediolateral axis during the loading phase of the JL task and stance phase of the SLC task

**Wash-out Period:** The time between completion of condition one and condition two which, based on previous research studies, will be set at 7-10 days

**Change Score:** The difference between pre-test measurement and post-test measurement

### 1.7 ASSUMPTIONS

The following assumptions will be used in this study:

A. Force plate is an accurate measure of vertical ground reaction force
B. Force plate is an accurate measure of maximal vertical jump height
C. A electromagnetic tracking device is a reliable measure of body segment position and movement
D. Subjects are at about the same level of participation/talent, have similar backgrounds
E. Subjects are representative of all college-aged females with at risk movement patterns during a SL squat task

### 1.8 DELIMITATIONS

The following will be used as delimitations in this study:

A. College-aged (18-26) females who display at risk movement patterns
B. Subjects have participated in competitive sport
C. Subjects may NOT be varsity athletes at UNC-CH
D. Subjects will have no prior history of participating in an injury prevention program or injury prevention study
E. Subjects will have no prior history of ACL injury

F. Subjects will have no prior history of lower extremity injury in the past 6 months that kept them from activity for more than two days

G. Subjects may not be experiencing lower extremity pain

H. To reduce the possible carry-over effect of the cross-over design, the wash-out period will be 7-10 days

I. Intervention is an acute, pre/post test measure, not a motor learning type of design

J. Subjects will not be included if they have just begun a new workout regime, or another intervention study, and will not be allowed to make changes while participating in study

1.9 LIMITATIONS

The following have been identified as limitations of the study:

A. May have carryover effect between groups with crossover study

B. No long term effects will be gathered, only acute effects

C. The results of this study will only apply to college-aged females with at risk movement patterns who have no pathologies
CHAPTER 2
REVIEW OF THE LITERATURE

2.1 IMPACT OF ACL INJURY

Injury to the anterior cruciate ligament (ACL) is one of the most common, and devastating, injuries to sustain in athletics. It is estimated that between 80,000 and 250,000 ACL injuries happen per year, most occurring in athletes between the ages of 15-25 (Griffin et al., 2006). Females tear their ACL’s at a much higher rate in sports that involve stopping quickly, cutting, and changing directions such as soccer and basketball. Females are 4-8 times more likely to experience a non-contact ACL injury during these activities in comparison to males playing the same sports (Barber-Westin et al., 2006; Ireland, 2002). More specifically, females were three times more likely to suffer a non-contact ACL injury in soccer and four times more likely in basketball in comparison to males (Arendt & Dick, 1995).

Non-contact ACL injury mechanisms occur as a result of the player’s own movement during landing and cutting maneuvers and not a direct impact or contact to the knee. Due to past confusion, Marshall recommends classifying non-contact injuries into two categories, indirect contact and direct contact (Marshall, 2010). Indirect Contact (IC) is defined as a physical perturbation when the knee is not struck, but the injury happens due to the athlete’s own movements (Marshall, 2010). Classic Non-Contact (CNC) is defined as a “disruption to the planned motor task that requires a rapid update to the intended motor-control plan” during sport, or resembling sport, activities (Marshall, 2010).
An ACL injury comes at a serious cost to the athlete and their family, physically, financially, and emotionally. An ACL injury is extremely painful acutely, and often continues to create problems long term. The risk of osteoarthritis increases following ACL reconstruction, regardless of the surgical method used (Lohmander et al., 2004). Twelve years following ACL reconstruction, 50% of the women studied had radiographic osteoarthritis and 80% had radiographic features of osteoarthritis (Lohmander et al., 2004).

In addition, the risk of a second ACL injury is much higher than for those who are injury free. Young athletes who return to cutting and pivoting sports are 15 times more likely to reinjure compared to healthy controls, and females returning were 4 times more likely to reinjure than males (Paterno et al., 2012). Research has demonstrated an equal occurrence of re-injury among the contralateral and ipsilateral knees in returning athletes (Salmon et al., 2005), indicating the original contributing factors to ACL injury may not have been addressed in rehabilitation process.

The financial cost of the surgery can become a huge burden on the patient and their family. An ACL reconstructive surgery is estimated to be $20,000 (Brophy et al., 2009). If that number is factored into the number of injuries per year, the total cost of ACL surgery in the United States reaches roughly $1.6 - $5 billion each year.

Finally, the emotional cost of suffering an ACL injury should not be taken lightly. Not only will the patient pay for this injury monetarily, but it will also be paid for in time away from activities the patient enjoys. Rehabilitation can take as little as four to six months (Ardern, Webster, Taylor, & Feller, 2011; Prentice, 2009) while most athletes are cleared six to twelve months following injury (Ardern et al., 2011). That is six to twelve months away from athletics and recreational activities. Even at twelve months, only a third of those who underwent ACL
reconstruction had attempted play and their pre-injury level (Ardern et al., 2011). It also results in time away from work and school, and could even impact a current scholarship or future offers.

2.2 ANATOMY OF THE KNEE JOINT

The bony anatomy of the knee is comprised of three bones, the femur, the tibia, and the patella. The femur connects the pelvis and the tibia and broadens at it’s distal end to form the medial and lateral condyles which articulate with the tibia through the menisci (Starkey, Brown, & Ryan, 2010). The medial condyle is longer than the lateral condyle and although both condyles share an anterior surface, they are separated posteriorly by the intercondylar notch (Starkey et al., 2010). Anteriorly, there is a hollowed femoral groove, or trochlea, formed by the condyles where the patella articulates (Prentice, 2009). The medial and lateral tibial condyles fit with the femoral condyles, with the medial tibial condyle being 50% larger than the lateral condyle to accept the larger medial femoral condyle (Starkey et al., 2010). The tibia’s intercondylar eminence matches up with the femur’s intercondylar notch and separates the condyles (Starkey et al., 2010). It is also this area where the cruciate ligaments attach (Prentice, 2009). Finally, the patella sits within the patellar tendon and improves mechanical function of the quadriceps during extension, dissipates forces received from the extensor mechanism, and protects the anterior knee (Starkey et al., 2010).

The menisci, one medial and on lateral, sit between the femur and the tibia have several purposes including deepening the articulation between the femur and tibia. Their primary functions include improving lubrication for articulation, shock absorption, increasing stability, and limiting extreme flexion and extension (Starkey et al., 2010). Their wedge shape with the outer boarders thicker than the inner contribute to the fact that the knee is more stable when in
weight bearing than not (Starkey et al., 2010). The medial meniscus is especially crucial to this stabilization, particularly when the knee is in 90° of flexion (Prentice, 2009).

The ACL arises from the anteromedial intercondylar eminence of the tibia, travels posteriorly lateral to PCL, and inserts on medial wall of lateral femoral condyle (Starkey et al., 2010). The ACL’s main functions include prevention of anterior translation of the tibia, internal and external rotation of the tibia, and hyperextension of the tibiofemoral joint (Starkey et al., 2010). The ACL is comprised of two twisted bands, the anteromedial and posterolateral which change places when the knee moves; in flexion the posterolateral bundle is anterior and most taut while in extension the anteromedial bundle is anterior and most taut (Prentice, 2009; Starkey et al., 2010).

The posterior cruciate ligament (PCL) is much less frequently injured than the ACL being that it is stronger and 120%-150% wider than the ACL (Starkey et al., 2010). The PCL arises from posterior aspect of tibia, moves superior and anterior medial to ACL, and attaches on the lateral portion of the medial femoral condyle and prevents internal rotation of tibia, hyperextension of knee, anterior translation of femur in weight bearing, and posterior translation of tibia in non-weight bearing (Starkey et al., 2010). Finally the medial collateral ligament (MCL) and the lateral collateral ligament (LCL) protect the knee from frontal plane motion. The MCL is made up of a superficial and a deep layer and stretches from just above the medial joint line to just beneath the pes anserine (Starkey et al., 2010). It’s primary function is to protect the knee from valgus and secondarily protect against external rotation and anterior translation of the tibia when the ACL is torn (Starkey et al., 2010). The LCL is a round fibrous cord about the size of a pencil stretching from the lateral epicondyle of the femur to the head of the fibula and
prevents primarily against varus forces at the knee and secondarily internal tibial rotation (Starkey et al., 2010).

2.3 ETIOLOGY OF ACL INJURIES

There are many factors that influence the risk of sustaining an ACL injury. Any one or a number of factors can be the cause of an ACL injury and all must be taken into account when examining the etiology of the injury. Hormonal factors, particularly in females, have been shown in some studies to relate to ACL injury risk, but have not been associated with injury in others (Griffin et al., 2006; Ireland, 2002; Shultz et al., 2012). Bio-psychosocial factors are also gaining interest. More specifically, a recent study suggested that gender differences in areas other than the common muscle strength and anatomy may play a contributing role in ACL injury (Elliot et al., 2010). This study suggested attention to gender differences in the areas of overuse/burnout, diet, sleep/fatigue, substance use, and stress should be taken into account when looking at higher incidence rates of ACL injury among women.

Anatomically, those who have been injured have been found to possess a smaller ACL (area and volume) compared to uninjured (Chaudhari, Zelman, Flanigan, Kaeding, & Nagaraja, 2009). In addition to smaller ACL geometry, patients have displayed smaller femoral notch width and greater posterior tibial slope, (Ireland, 2002; Simon, Everhart, Nagaraja, & Chaudhari, 2010), which could influence the amount of impingement placed on the ACL and the amount of shear force respectively. A larger Q-angle in those who sustained ACL injuries (Griffin et al., 2006; Moul, 1998; Shambaugh, Klein, & Herbert, 1991) and the fact that female athletes are often hypermobile, which can especially be seen in the hyperextension of the knee, (Ireland, 2002), may also be anatomically significant factors which lead to injury.
Some research has been done investigating the effect of the environment on the rate of ACL injury. It has been found that athletes face a higher risk of sustaining ACL injury if playing on artificial floor rather than wood floor, but data has been inconsistent (Griffin et al., 2006; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2003). The type of footwear and use of knee braces are both still contested as possible risk factors in injury (Griffin et al., 2006). Shoes with shorter cleat length are associated with fewer ACL injuries, however, athletes also alter their movement patterns based on their footwear indicating it may be a combination of the two factors that lead to ACL injury (Griffin et al., 2006). With regard to bracing, one large study found prophylactic knee braces were associated with a decrease in knee injuries however, another study found no effect on the incidence of ACL graft tear one year following surgery (Griffin et al., 2006).

We acknowledge the fact that hormonal, bio-psychosocial, anatomical, and environmental factors contribute to ACL injury. However, for the purposes of this study, we will focus on biomechanical and neuromuscular factors.

2.4 ACL LOADING

Research using cadaver knees found combined loading forces are more detrimental to the ACL (Markolf et al., 1995). The highest ACL forces recorded, were found when anterior tibial shear force was paired with a valgus moment in flexion and a varus moment in extension/hyperextension (Markolf et al., 1995). Anterior tibial shear force is the most direct loading mechanism for the ACL as this is the motion that the ligament works to prevent. However, combined loading in other planes of motion can be potentially more problematic.

This potential loading mechanism on the ACL is often seen in non-contact or indirect contact injuries captured on video. These injuries occur due to noncontact or indirect contact
mechanisms in which the knee is not struck directly, rather a physical perturbation caused from their own movement or a disruption in the planned movement require a sudden change that lead to injury (Marshall, 2010). Several studies have completed video analyses of ACL injuries and some common themes have emerged. It seems the time period shortly after landing from a jump or cutting is the most dangerous for female athletes; in particular, females show much greater knee abduction angles (knee valgus collapse) during the landing phase at the time of injury than do males (Boden et al., 2009; Hewett et al., 2009; Krosshaug et al., 2007).

This increase in knee abduction makes the risk of knee valgus collapse 5.3 times more likely in females than in males (Krosshaug et al., 2007). Females also tend to have an increased lateral trunk angle during movements when an ACL injury is sustained (Hewett et al., 2009). Poor core control contributes to faulty lower extremity biomechanics due to the fact that it provides a stable base of support to reduce the forces transmitted through the lower extremity (Ireland, 2002; Shultz et al., 2012). Generally, landing or making ground contact in a relatively upright position with little hip and knee flexion, a relatively straight back, with excessive knee valgus collapse is often demonstrated during a noncontact ACL injury event, termed the “position of no return” (Ireland, 2002). When landing in a more upright position, the resulting vertical ground reaction force increases the amount of anterior tibial translation which, in turn, effects the amount of strain placed on the quadriceps and hamstrings to control the movement and unanticipated cutting places a similar strain on the muscles acting on the knee (Dai, Herman, Liu, Garrett, & Yu, 2012a; Griffin et al., 2006; Ireland, 2002; Shultz et al., 2012).

Prospective risk factors for ACL injury have also been identified in hopes of identifying those at risk and correcting the deficiencies/imbalances to prevent the injury from occurring. Females that went on to injure their ACL (n=8) had knee abduction (valgus) angles during a
double leg drop landing that were 8.4° larger in comparison to those that did not sustain an ACL injury (Hewett et al., 2005). In addition, a high correlation was found between greater vertical ground reaction forces (VGRF) and larger knee abduction angles in the injured group compared to those who did not sustain an injury (Hewett et al., 2005). In a larger prospective study, Pauda et al. (Padua, Boling, & Goerger, 2012) found military cadets that went on to suffer an ACL injury (n=98) demonstrated greater hip adduction and external rotation as well as knee valgus upon landing from a double leg jump.

In combination, previous research has demonstrated that performing landing movements with a small degree of knee flexion and a large degree of knee valgus and hip adduction, may contribute to an individual sustaining an ACL injury. Fortunately, movement re-training may be effective in modifying these movement patterns to potentially decrease the risk of ACL injury.

2.5 ACL INJURY PREVENTION

The current knowledge of prospective risk factors as well as biomechanical profiles during injury events has highlighted double leg jump landings and cutting tasks as effective movements to identify risky movement profiles. This has allowed researchers to work toward developing clinical screening tools to identify individuals that may be at greater risk for suffering an ACL injury. Padua et al. (Padua et al., 2009) developed the Landing Error Scoring System (LESS) screening process, in which researchers evaluated the movement patterns during a double leg jump landing. They found significant differences in sagittal, frontal, and transverse plane biomechanics and in vertical ground reaction force between subjects who had poor and excellent LESS scores (Padua et al., 2009), thereby validated the LESS screening as a reliable means of identifying poor jump landing biomechanics. It was also observed that women were more likely to score poorly on the LESS than their male counterparts. Clinical screening tools are
beneficial in identifying individuals at greater risk of suffering an ACL injury as well as re-assessing modifications in movement as injury prevention interventions are implemented.

All of the studies above (Boden et al., 2009; Dai et al., 2012a; Griffin et al., 2006; Hewett et al., 2009; Ireland, 2002; Krosshaug et al., 2007; Markolf et al., 1995; Shultz et al., 2012) are in agreement that a certain dynamic load place on the knee during activity is a major contributor to ACL injury. This dynamic load, which happens when completing activities such as cutting and landing from a jump, can be modified with training and therefore reduce ACL injury risk (Griffin et al., 2006).

Injury prevention programs focus on training individuals to modify their movement patterns in hopes of reducing ACL injury rate. Different injury prevention programs place emphasis on different aspects of training (strength, flexibility, balance, plyometrics, and core). However, those programs that incorporate aspects of each component are the most successful in preventing ACL injury (Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005). Many of these programs are implemented as a warm up (Bien, 2011), and take as little as 15-20 minutes to complete. There is a reason programs that incorporate all of the variables listed above are more successful in preventing ACL injury as each impacts the body in a different way.

Strength training is important with regard to increasing muscle strength as well as decreasing landing forces (Hewett et al., 1999). Specifically, females tend to have a poor hamstring to quadriceps ratio, hamstrings are weaker than the quadriceps, which is detrimental as quadriceps dominance increases ACL injury risk and the hamstrings are important in preventing anterior tibial translation (Bien, 2011). Flexibility of the hamstrings and quadriceps is important to assure full hip flexion and knee flexion and adequate range at the ankle (resulting in less frontal plane knee movement) is a result of increased flexibility of the gastrocnemius and soleus.
There has been research using EMG information indicating a quicker hamstrings activation and a greater peak hamstring activation following balance training (Hurd, Chmielewski, & Snyder-Mackler, 2006). Plyometric training has been found to decrease landing forces as well as adduction and abduction knee moments (Hewett, Stroupe, Nance, & Noyes, 1996), which have been identified as dangerous moments for the knee with regard to ACL injury (Hewett, Stroupe, Nance, & Noyes, 1996; Markolf et al., 1995).

Previous research has also found more distinct gains in those subjects who display poor biomechanics before the intervention (DiStefano, Padua, DiStefano, & Marshall, 2009). Those subjects identified as having “poor” landing mechanics using the LESS grading scale, improved 3 times more than the overall mean improvement and those in the “moderate” and “good” groups improved significantly more than those in the “excellent” group (DiStefano et al., 2011). The authors concluded those athletes who have poor movement techniques are those with whom improvement is most critical to reducing injury risk. Therefore, female participants in the current study will be identified as displaying medial knee displacement during a functional task.

It is important to remember not all injury prevention programs are created equal. While those programs that are integrative have shown marked improvement in the rate of ACL injury, those programs that are less comprehensive show little to no effect on the athlete’s participating in them. Incorporation of many different types of exercises is important in a successful program, however, there are several factors that contribute to the overall effectiveness of ACL injury prevention programs.

2.6 EFFECTIVENESS OF ACL INJURY PREVENTION PROGRAMS

Athletes who participate in injury prevention programs (IPPs) have shown a marked decrease in the number of ACL injuries compared to those who do not (DiStefano et al., 2011;
Female athletes may even benefit more from participating in injury prevention programs. High school aged female athletes who participated in volleyball, basketball and soccer, and completed an IPP, incidence of injury was 2.4 times lower than their counterparts who did not complete an IPP (Hewett et al., 1999). The same study found trained females reduced their rate of injury to the level of untrained males while untrained females were injured at a rate 4.8 times higher than the males (Hewett et al., 1999). Those serious knee injuries recorded in the female soccer athletes all occurred to those in the untrained group however, the incidence of serious knee injury among female basketball players was insignificant (Hewett et al., 1999).

Participation of female soccer players, age 14-18, over a two-year period and participating in the Prevent Injury and Enhance Performance (PEP) IPP, reduced ACL tears by 74% compared to age and skill matched controls that participated in a standard warm-up (Mandelbaum et al., 2005). It is suggested by the authors of the PEP program that it be completed three times per week, but it was not specified in the study how often each team completed the program. Yet another study used National Collegiate Athletic Association (NCAA) Division I women’s soccer teams and assigned them randomly to either the intervention (completing the PEP program 3 times per week) or control group over one fall season (Gilchrist et al., 2008). Risk of ACL injury in the IPP group was 1.7 times less than that of the control group and non-contact injury risk was 3.3 times less than the control group (Gilchrist et al., 2008). No ACL injuries occurred during practice of those participating in the IPP, while six occurred in the control’s practices and game ACL injury rate was cut in half compared to the control group (Gilchrist et al., 2008). Additionally, those women with previous ACL injuries
who participated in the IPP, suffered new ACL injuries at a rate five times less than those in the control group with a previous ACL injury (Gilchrist et al., 2008).

However, some research investigating the benefits of an ACL injury prevention program has not observed a decrease in injury rates. One study, whose population included female soccer teams in the Under-17 division in southeast Norway, reported no difference in the rate of ACL injury between the control and intervention groups even though they employed the “11,” a varied program including flexibility, core, strength, and plyometrics (Steffen, Myklebust, et al., 2008). They used a varied program, but had no progression within the exercises, which the authors state may have influenced the participants’ motivation to complete the study, the average player only completed 15 intervention sessions, and in turn led to a low team compliance rate (52%) (Steffen, Myklebust, et al., 2008).

A second study used only balance board training and had even worse results. Female soccer players from the second and third Swedish divisions between the ages of 20-25 completed five balance board exercises at home, each completed daily for the first 30 days and 3 days a week after that (Soderman et al., 2000). Four of the five ACL injuries that occurred while completing the program happened in the intervention group (Soderman et al., 2000). As with the previous study, variation in exercises were lacking, the only progression being an increase in height of the balance board, potentially leading to low motivation to complete them and a higher than expected drop out rate (37%) (Soderman et al., 2000).

Finally, a third study experienced good results using a balance IPP using three different exercises, but only at the elite athlete level (Myklebust et al., 2003). The authors followed female teams in the elite, second, and the four third division conferences of the Norwegian Team Handball Federation league for a control season followed by two intervention seasons. The teams
were instructed to perform the program 3 times a week during a 5-7 week training period and once a week in-season (Myklebust et al., 2003). The overall compliance for the three divisions was only 29% and that of just the elite division, where improvements were seen, 50% (Myklebust et al., 2003). This low compliance rate was the authors’ explanation for poor results at the lower levels.

Another aspect that has to be considered when determining the effectiveness of ACL IPPs is the age of those participating. Those in different age groups have different biomechanical and neuromuscular patterns and studies have been done to investigate whether training programs would be effective with those of different ages.

One study found that female athletes under the age of 18 were able to reduce their risk of ACL injury by 72% compared to only 16% reduction in those over 18 (Myer, Sugimoto, Thomas, & Hewett, 2012). The idea being that clinicians may have the ability to fix the biomechanical deficiencies before they become motor patterns. Contradictory to these findings are two other studies, which suggested that programs implemented before the ages of 12 to 14 made no difference in altering lower extremity biomechanics (DiStefano et al., 2011; Sheerin, Hume, & Whatman, 2012). In a study by Barber-Westin et. al (Barber-Westin et al., 2006) a strength and gender comparison was made when completing a jump landing. It wasn’t until the age of 14 that males and females displayed differences in muscle strength peak torques and limb symmetry. Due to the results of these studies, the current study will examine the population over the age of 18. Although the pediatric population is important to investigate, it will not be the focus of this study. If significance is found in increased performance based on an altered motivation focus, the next step may be to evaluate its effectiveness among the youth.
Reviewing previous literature has made it possible to identify factors that may contribute to the success or failure of injury prevention programs in decreasing injury rates. Prevention programs that use an integrative approach have more success in preventing ACL injury (Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005). Another common theme throughout effective programs is a progression of exercises. The exercises increase in difficulty as the athletes progress. This progression of exercises may also help with compliance and motivation. Lack of compliance and motivation were common reasons given in those programs without positive outcomes (Myklebust et al., 2003; Soderman et al., 2000; Steffen, Myklebust, et al., 2008). Finally, the use of verbal instructions or feedback was present in studies with positive results following an ACL IPP (Herman et al., 2009; Myer et al., 2013; Padua & Distefano, 2009). The question then becomes, how can the use of each of these factors be implemented or increased in the IPP’s currently in use?

2.7 INCREASING EFFECTIVENESS OF PREVENTION PROGRAMS

A common theme in these effective programs is the integrative approach to exercises included in the IPP. Two of the three studies cited above (Gilchrist et al., 2008; Mandelbaum et al., 2005) used the Prevent Injury and Enhance Performance (PEP) IPP, which includes flexibility, strengthening, agility, and plyometric components. In addition, the PEP is short, taking only 15-20 minutes to complete and only needs to be completed three times a week. While the Hewett study did not use the PEP IPP, the authors still included aspects of flexibility, strength, agility, power, and plyometric training. The program was performed three times a week, but was much longer than the PEP, lasting 60-90 minutes.

While the PEP IPP was integrative, it did not have a progression to more difficult exercises. The Performance Enhancement and Kinetic Control (PEAKc) IPP, developed here at
the University of North Carolina Chapel Hill however, includes both an integrative approach to a prevention program and a progression to more difficult exercises. Therefore, as the PEAKc addresses both, it will be the IPP used in the current study.

It is widely recognized that participation in an ACL injury prevention program cuts down on the number of ACL injuries. However, compliance and motivation to participate in the program are still lacking and this lack of compliance and motivation has a negative impact on the program’s effectiveness. One study had great results with regard to cutting down ACL injuries, yet the same study found that coaches “knowledge, attitudes, beliefs, and behaviors regarding injury prevention” was not different between the coaches of intervention and control groups (Gilchrist et al., 2008). While the authors did not elaborate on this finding, the fact that the attitudes and beliefs of the coaches were similar across the board indicates they were not completely comfortable with the implications of having their team perform an IPP. If there is a lack of knowledge of what these IPPs do, it may lead to less enthusiasm on the coaches’ part to complete the program, which could influence the athletes’ attitudes and behaviors.

Another study looked more closely at factors that contributed to coaches of female soccer teams implementing the prevention programs (Joy et al., 2013). The authors found that the higher the level of education, personal playing experience, more than seven years of coaching experience, and higher rate of ACL injuries on the team increased likelihood of implementation (Joy et al., 2013). “Best practice” coaches agreed unanimously that ACL injury prevention programs have performance enhancing benefits and that further education of coaches is needed on ACL injury and injury prevention programs. Over half of these coaches felt they needed better training on how to give correct feedback to their athletes while performing the program (Joy et al., 2013).
It is important to get coaches on board, as their support would help with compliance rates. As mentioned earlier, low compliance rates may explain some of the ineffectiveness of prevention programs that have been looked at in recent studies (Dai, Herman, Liu, Garrett, & Yu, 2012b). This fact is further exemplified in a meta-analysis which found that the overall compliance rate (attendance x completion) needed to be more than 66% to effectively reduce the risk of ACL injury (Sugimoto et al., 2012). The average overall compliance rate of all studies involved in the meta-analysis was only 45.3% and it was this number the authors used to separate out high compliance (>45.3%) and low (<45/3%) compliance rates (Sugimoto et al., 2012). After the authors compared the number of ACL injuries within each of these groups, compliance rates were further separated out into the final categories of high (<66%), moderate (33.3%-66.6%), and low (>33.3%) (Sugimoto et al., 2012). The question is then, how can IPPs become more attractive to coaches?

Coaches like the idea of injury prevention programs increasing the level of performance in their players. Overall, the literature is lacking in the number of studies that look at the effects on performance of ACL prevention programs (Noyes & Barber-Westin, 2012). The same study found that two programs, Sportsmetrics and PEP, not only reduced the number of ACL injuries, but helped athletes to increase several common performance measures while participating, including isokinetic knee flexion peak torque value, hamstrings:quadiceps ratio, countermovement vertical jump, abdominal strength, estimated VO₂ max, speed on shuttle runs, distance hopped on a single leg, and agility. These two programs differ in the length of time needed to complete them (120min vs. 15-20min respectively, and when during the training cycle they are completed (prior to the beginning of practices and used in-season as a warm-up respectively) however, both had high compliance rates compared to the others included in the
study; suggesting that not only is high compliance important to injury prevention, but increasing sport performance as well.

A second study found minimal to no effect on performance after the completion of a prevention program, but also attributed this to the fact that the performance tests used lacked specificity with the prevention program training (Vescovi & VanHeest, 2010). Athletes were put through a linear sprint, countermovement jump, Illinois agility, and Pro-agility performance tests. The authors used the PEP IPP, which while it included a vertical jump component; the agility components included no shuttle run like portions, which would most mimic the Illinois agility and Pro-agility tests gauged by the authors. The authors also suggested that improvement in countermovement jump height may have more to do with how the drill is performed (Vescovi & VanHeest, 2010); where is the athlete’s focus? This variable will be taken into account in the current study.

It is important to understand why performance variables such as stability, agility and power are important to coaches and athletes alike. Specifically, having good core stability can directly influence the stability of the distal joints (Kibler, Press, & Sciascia, 2006). A strong core is essential to the ability to generate proper force in the extremities as well as placing the joints in the correct position for efficient movement (Kibler et al., 2006).

Agility has been defined as the ability to change direction quickly and accurately without the loss of speed (Clark & Lucett, 2010) and examples of its importance in sport are limitless – a lacrosse attacker dodging a defender, a basketball defender keeping their opponent from scoring, a tennis player effectively returning a serve, the list goes on. The rate of torque production of a muscle is an important component of agility. Rate of torque production has been defined as “the rate of rise in contractile force at the onset of contraction,” (Aagaard, Simonsen, Andersen,
Magnusson, & Dyhre-Poulsen, 2002). Authors of one study found an increase in rate of torque production following resistance training, which led them to believe this increase in rate of torque production allowed for an increase in maximal force and velocity during rapid movements (Aagaard et al., 2002), important aspects to agility, power, and athletic performance overall. If an athlete is able to increase their rate of torque production, this in turn should decrease the length of their stance phase, allowing them to move more quickly when performing cutting maneuvers, making them more difficult to defend.

Power is defined as the ability to produce a large amount of force quickly (Prentice, 2009). Just as rate of torque production can be used as a measure of agility, so can it be used as a measure of power. The double-leg jump task/countermovement jump task has been used in several studies as a measure of performance (Kilding, Tunstall, & Kuzmic, 2008; Reis, Rebelo, Krstrup, & Brito, 2013; Steffen, Bakka, Myklebust, & Bahr, 2008) and power is needed to perform well during this task. Performing well on a double leg jump task is also relevant to sport performance as is evident when completing a block on the volleyball court, shooting over a defender on the basketball court, and heading the ball on the soccer field.

While it is important to have the coach’s support, ultimately, the athlete needs to be motivated to complete the program, and complete it well. In the past, the majority of IPPs have been introduced as just that, an injury prevention program. No emphasis has been placed on the possibility that the program may enhance performance as well. If coaches and players alike were told the program would increase performance, it may be a step in the right direction to increase motivation to complete the program, and in turn, increase compliance and positive injury prevention results.
Motivation to complete the injury prevention program may play a role in increased compliance, as well as influence learning and are tied to the way the subjects are instructed. In turn, the effectiveness of the instructions can rely on the motivation of the learner (Wulf et al., 2010). If clinicians were able to improve the motivation of the learner, would they be able to improve overall performance as well? Essentially, would a different instructional focus (injury prevention vs. improved performance) change the way the individual practiced and learned the exercises?

Instructions and feedback on correct lower extremity movement patterns have also been found to have an impact on the effectiveness of ACL IPPs. Video assisted feedback was found to decrease peak vertical ground reaction forces, knee valgus moment and hip abduction moment as well as increase knee flexion angle, hip flexion angle and hip abduction angle when combined with a strength-training program (Herman et al., 2009). When verbal instructions and feedback are given during specific tasks, it was found that valgus knee position and vertical ground reaction forces were reduced and found to be modifiable factors (Padua & Distefano, 2009; Stroube et al., 2012). In addition, it has been observed that feedback given during one task (tuck jump) successfully transfers to other tasks (drop vertical jump), indicating that feedback given during an IPP, could transfer to related movements an athlete completes while participating in sports (Myer et al., 2013). However, one study found the type of instructions given to be unfavorable to overall performance, stating that as the instructions given during the completion of the IPP emphasized slow speeds, proper control, and small landing forces rather than the explosive qualities important when completing performance measures at higher speeds. (Lindblom, Walden, & Hagglund, 2012).
These previous findings have influenced the hypotheses in the current study. We hypothesize that when given injury prevention instructions, hip adduction, knee abduction, and vertical ground reaction force will decrease while knee flexion will increase. These changes in variables play an important role in ACL injury prevention, however it may come at the detriment of performance, thus we hypothesized that vertical jump height will decrease and stance time will increase with prevention instructions. Conversely, when given performance instructions performance variables such as length of stance time and vertical jump height will change accordingly during the jump landing task (decrease and increase respectively), but at the expense of those injury prevention variables – increased vertical ground reaction force and no change in knee abduction and hip adduction. Though increased knee flexion would fall under injury prevention, during the jump landing task it is hypothesized that knee flexion would increase when given performance based instructions due to the fact our subjects will try to increase their vertical jump by increasing the flexion at their knees. Similar hypotheses were made for the single leg cut task when given performance instructions with the exception of no change expected in knee flexion and increased knee abduction and hip adduction angle due to the expected increase in speed of task completion following performance instructions.
2.8 PROTOCOL AND TESTING

In the current study, subjects will participate in the PEAKc IPP. This program consists of dynamic stretching, balance/stability, strength, and plyometric/agility exercises, which are progressed in difficulty throughout a season. The current study is interested in a single intervention session combined with different verbal instructions, therefore Phase I will be used. The program is currently used as a warm-up prior to the beginning of practice and takes only 10-15 minutes to complete. The goal of this particular IPP is to improve an individual’s stability, agility, and power – important components in both injury prevention and athletic performance. Each subject will complete the program twice, receiving different set of standardized verbal instructions each time.

Subjects used will be females displaying at risk movement patterns during a functional task. Those with improper/poor mechanics to begin with see larger improvements compared with those who have good or excellent movement mechanics (DiStefano et al., 2009). It is these individuals with poor movement mechanics who are most likely to injure themselves in the first place and therefore could benefit the most from an injury prevention program.

Subjects will be screened for at risk movement patterns when performing a single-leg squat. Each subject will be asked to perform five consecutive trials of the single-leg squat and if in at least three trials the patella moves medial to the great toe, she will be automatically qualified to participate (Mauntel et al., 2012). If she displays any two or more of the following, she will also be qualified: femoral adduction, hip drops on the stance leg (+Trendelenburg), hip hikes on the non-stance leg, trunk rotated out (toward non-stance leg), trunk rotated in (toward stance leg), and shoulders not level.
Hip adduction, knee flexion, and knee valgus, in addition to vertical ground reaction force, will be used as injury prevention measures and will be measured for each subject prior to and following the intervention using a double-leg and single leg functional task. The use of the double leg jump landing (JL) has been used in several studies to identify these injury prevention measures with good results (DiStefano et al., 2009; Hewett et al., 2005; Shultz et al., 2012).

The Single leg cut (SLC) maneuver has been shown to be successful in highlighting risky movement patterns (Kipp, McLeanb, & Palmieri-Smithb, 2011). Gradual and controlled hip flexion during early landing and overall hip flexion motion throughout the landing movement may minimize knee adduction and internal rotation torques (Kipp et al., 2011). If the landing motion is controlled, this may lead to a smaller vertical ground reaction force which has been tied to a smaller risk of injury (Hewett et al., 2005). Vertical ground reaction force will be measured using a floor embedded force plate and hip adduction, knee flexion, and knee valgus will be measured using an electromagnetic tracking device which has been shown to be a reliable device for tracking body motion (An, M.C. Jacobsen, L.J. Berglund, & Chao, 1988).

Length of stance phase and vertical jump height will be used as measures of sport performance in the current study. Previous studies have used these, or variables very similar to these, to track changes in sport performance (Kilding et al., 2008; Lindblom et al., 2012; Noyes & Barber-Westin, 2012; Reis et al., 2013; Vescovi & VanHeest, 2010). It has also been suggested that an increase in the rate of torque production increases the amount of maximal force and velocity generated during quick movements (Aagaard et al., 2002), important components in increasing performance. The quicker an athlete is able to generate force, the shorter the stance phase will be and the faster the athlete will be able to adapt on the court or field. Stance phase will be measured as stance time and vertical jump height using the force plate to determine the
amount of time in air in order to use the “Time in Air” equation to determine jump height (jump height = \( \frac{1}{2} g \left( \frac{t}{2} \right)^2 \), where \( g = 9.81 \text{ m} \cdot \text{sec}^{-2} \) and \( t = \text{time in air} \)) as well as the pelvis marker used through Motion Monitor (VanderZanden, Wurm, & Hopkins, 2010).

CONCLUSION

Studies have shown females are at a much higher risk of suffering a non-contact ACL injury than males. Specific risk factors have been identified, as well as prevention programs, biomechanical patterns most at risk, and screening tools that have the ability to cut down on these injuries. What is still unknown, however, is how to best implement these programs to gain optimal results in all areas, including compliance, improvement of lower extremity biomechanics, and performance gains. Specifically, more research needs to be done in the areas of effects on performance of ACL prevention programs, the effect of instruction on outcome, the rate of compliance, and how they can best be delivered (Griffin et al., 2006; Powers & Fisher, 2010; Shultz et al., 2012). In this current study, we will assess all participants on measures of hip adduction, knee flexion, knee abduction, VGRF, stance time, and vertical jump height (JL task only) during the performance of the JL and SLC functional tasks before and after an intervention is implemented. Therefore, the purpose of this study is to determine the acute effects of two types of instructions of lower extremity biomechanics and performance measures in those who have the greatest possibility for an ACL injury (females with at risk movement patterns). It is our hope the results of this study will aid in developing more effective injury prevention programs in the future.
CHAPTER 3
METHODS

3.1 SUBJECTS

23 physically active females with at risk movement patterns during a single leg (SL) squat were recruited for this research study. A power analysis was conducted a priori and it was determined 11-30 subjects would be needed to reach approximately 80% power for hip adduction (11) (DiStefano et al., 2011), knee flexion (14) (Herman et al., 2009), knee valgus (30) (Mizner, Kawaguchi, & Chmielewski, 2008), and peak vertical ground reaction force (25) (Milner, Fairbrother, Srivatsan, & Zhang, 2012). Physically active was defined as engaging in 30-60min of physical activity 3 or more days per week. Subjects must have had previous experience participating in competitive sport (at least one year at the varsity level in high school or current participation in club sports). Screening sessions were performed to identify subjects with at risk movement patterns. Medial knee displacement was visually identified by the primary investigator if the midpoint of the patella moved medial to the great toe in three or more completions of a SL squat in a set of five (Mauntel et al., 2012). Research has identified medial knee collapse prominently in female athletes at the time of ACL injury (Boden et al., 2009; Hewett et al., 2009; Krosshaug et al., 2007) therefore this population was representative of a high risk population and subjects displaying MKD will automatically qualify. The subject also qualified if she displayed any two or more of the following during the SL squat: femoral adduction, hip drops on the stance leg (+Trendelenburg), hip hikes on the non-stance leg, trunk rotated out (toward non-stance leg), trunk rotated in (toward stance leg), and/or shoulders not
level. All subjects were between the ages of 18-26 years and were recruited from the students at the University of North Carolina at Chapel Hill.

To be included in this study, all subjects satisfied the following criteria:

- Female
- MKD or any two or more of the following: femoral adduction, hip drops on the stance leg (+Trendelenburg), hip hikes on the non-stance leg, trunk rotated out (toward non-stance leg), trunk rotated in (toward stance leg), and/or shoulders not level, on at least three trials of the single leg squat performed on the dominant kicking leg
- Past participation in competitive sport
- May NOT currently be varsity athlete at UNC-CH
- No history of ACL injury
- No history of participating in an ACL injury prevention program or injury prevention research study
- No history of musculoskeletal injury in the past 6 months that kept them from activity for more than two days or currently experiencing lower extremity pain
- May not have just began a new workout regime, or another intervention research study, and will not be allowed to make changes while participating in study

3.2 INSTRUMENTATION

Kinematic data was recorded using an electromagnetic motion capture system (Motion Star, Ascension Technologies Inc., Burlington, VT) sampled at 140 Hz during the jump landing and single leg hop to cut tasks. The equipment was calibrated according to manufacturer guidelines. Electromagnetic sensors were secured over the foot, shank, and thigh of the dominant limb as well as the sacrum and C7 vertebrae. Participants stood in a neutral position while
additional landmarks were digitized using a 0.165 m stylus, including 1) lateral malleolus, 2) medial malleolus, 3) lateral femoral condyle, 4) medial femoral condyle, 5) T12/L1 vertebrae, 6) right ASIS, 7) left ASIS, 8) distal phalanx of the second phalange of the foot. Local coordinate systems for each body segment were aligned such that the X-axis was positive anterior to the subject, the Y-axis was positive to the left of the subject, and the Z-axis was positive superior to the subject.

Two floor embedded force plates (Bertec 4060, Columbus, OH) were used as a time marker of initial ground contact and push-off to determine the length of the stance phase, peak vertical ground reaction force during the loading phase, and a component in calculating vertical jump height. All data was captured via The Motion Monitor data acquisition software (Innovative Sports Training, Inc., Chicago, IL). Kinetic data was sampled at 1400 Hz and the kinematic data will be time synchronized with the ground reaction force data and re-sampled at 1400 Hz via linear interpolation. This instrumentation has been used previously in our lab during these tasks with reliable measures.

3.3 PROCEDURES

Prior to participation in this research study, all subjects read and signed an informed consent form approved by the University’s Institutional Review Board.

Subject Screening

Potential subjects reported to the Sports Medicine Research Laboratory for a screening session to determine inclusion criteria. After reading and signing the consent form, each subject performed a set of five single leg squats on her dominant leg, defined as the leg chosen to kick a soccer ball for maximum distance, while wearing comfortable athletic shoes. Prior to performing
the screening, the subject was asked to move into 60° of knee flexion, as measured by a goniometer. A tripod was adjusted to the correct height and placed behind the subject to serve as a guide in order to reach the correct squat depth. When the subject’s gluteal fold made contact with the tripod, the subject knew to return to the upright position. The potential subject was instructed to stand with the feet shoulder width apart, both hands on hips, and then raise one foot about 5-10cm off the ground. The subject was asked to descend into a squat, 60° knee flexion, and then return to the upright posture taking about two seconds to reach the tripod and two seconds to return to standing. If the middle of the patella moved medial to the great toe in three or more squat trials, the subject does display medial knee displacement and was automatically included in the study (Mauntel et al., 2012). If the subject displayed any two or more of the following variables, she will also qualify: femoral adduction, hip drops on the stance leg (+Trendelenburg), hip hikes on the non-stance leg, trunk rotated out (toward non-stance leg), trunk rotated in (toward stance leg), and/or shoulders not level. Video was taken of the frontal and sagittal plane movements of each screening subject to ensure qualifying body mechanics are present. Those who did not display MKD or any two of the other qualifying variables were thanked and excused. All qualifying subjects were scheduled for their first data collection session prior to leaving the lab after the screening session.

Data Collection

All subjects reported to the Sports Medicine Research Laboratory for a one-hour data collection session on two separate days, with 7-10 days in between. Each session consisted of anthropometric data recording, motion analysis, verbal instructions intervention (counterbalanced between Day 1 and Day 2), followed by the same motion analysis. The injury
prevention and sports performance verbal instructions were implemented in a counterbalanced order during the Performance Enhancement and Kinetic Control (PEAKc) program (Padua, 2011). Subjects were asked to wear athletic shorts and a t-shirt with their own comfortable athletic shoes for testing. Shoes worn on Day 2 were the same as those worn on Day 1. All biomechanical data was recorded unilaterally on the dominant kicking limb.

Anthropometric data was recorded prior to testing, including subject’s height (cm) and mass (kg). A cardiovascular warm-up was not be performed prior to testing, as the main goal is to see how the ACL injury prevention program, designed to be a dynamic warm-up, alters movement patterns acutely.

**Motion Analysis**

The single leg squat (SLS), double leg jump landing (JL), and single leg cut (SLC) tasks were performed in a randomized order prior to and after the completion of the PEAKc program with verbal instructions. Electromagnetic sensors were placed on the subject with double sided tape and secured using pre-wrap and athletic tape at the sacrum, C7 spinous process, the lateral aspect of the thigh, the anteromedial tibia, and between the second and third metatarsal heads of the foot. Digitization bony landmarks included T12/L1 spinous process, right ASIS, left ASIS, and the following landmarks on each individual subject’s dominant limb: medial femoral condyle, lateral femoral condyle, medial malleolus, lateral malleolus, and distal phalanx of the second phalange of the foot.

In order to perform the intervention for this study, the sensors needed to be removed following pre-test and then re-applied for post-test. To ensure sensor placement as close as possible during post-test as to sensor placement during pre-test, sensors were marked superiorly
with permanent marker. To ensure digitization of the same bony landmark following the intervention, each of the aforementioned landmarks were marked using a permanent marker.

To safeguard correct sensor placement during the second intervention as close to sensor placement during the first intervention, sensors were placed at the midpoint between two bony landmarks during pre-test of both sessions. The sacrum was identified upon palpation, as was C7. The lateral aspect of the thigh was identified as the midpoint between the greater tubercle of the femur and the lateral joint line, the anteromedial tibia was identified as the midpoint between the medial malleolus and pes anserine, and the dorsal foot sensor was placed at the midpoint between the bases of second and third metatarsals.

To perform the single leg squat (SLS), subjects completed the same procedures as during the screening session. Subjects stood with one foot on each force plate with feet shoulder width apart, both hands on hips, and raised their non-dominant foot about 5-10 cm off the ground. They descended into a squat, 60° knee flexion, and then returned to a full upright posture. Subjects were instructed to perform five consecutive squats while keeping their hands on their hips and non-dominant foot off of the ground. Incorrect completion was defined if any of the following occurred during the squat: hands came off hips, heel of foot left ground, the subject did not reach 60° knee flexion, and/or the subject did not return to the full, upright position. This task was performed at both pre-test and post-test for each verbal instructions intervention because it was the same exercise used to screen subjects for participation. However, data from this task was not utilized in the analysis of this project.

To perform the double leg jump landing (JL), subjects jumped from a 30-cm box to a force plate a distance of 50% of their height away from the box and immediately went into a maximal jump upon landing (LESS set-up protocol) (Padua et al., 2009). Subjects were
instructed to “jump forward into the target area with both feet and immediately jump straight up as high as you can.” No demonstration was given, however subjects performed up to three practice trials to familiarize themselves with the task. Subjects completed five successful trials, with 10-20 seconds of rest between. Incorrect completion was defined as leaving the box pushing off of one foot, jumping for maximal height off the box rather than jumping forward, and if their feet did not land on the force plate. Hip adduction, knee abduction, knee flexion, vertical jump height, vertical ground reaction force, and length of stance phase were measured.

To perform the single leg cut (SLC), subjects completed a DL forward jump from the ground, over a hurdle, placed one foot away from the force plates. Subjects landed on their dominant leg on the force plate, and cut away from the landing leg at a 45° angle. Subjects were instructed to “jump forward into the target area with both feet, land on your dominant limb and immediately cut away from your landing leg.” No demonstration was given, however subjects performed up to three practice trials to familiarize themselves with the task. Subjects performed five successful trials with 10-20 seconds of rest between. Incorrect completion was defined as jumping off of one foot, landing on two feet, missing the force plate on landing, and if they did not make a 45° cut. Hip adduction, knee abduction, knee flexion, vertical ground reaction force, and length of stance phase were recorded.

Verbal Instructions Intervention

Following the completion of the pre-test motion analysis, subjects completed a modified version of Phase I of the PEAKc ACL injury prevention program (Padua, 2011). A piece of athletic tape was placed 10 yards from the starting line and each exercise was completed to this line, with the exception of high knee skipping and 45° cuts which were completed to a doorway
about 30 yards from the starting line and back. The intervention was performed in Fetzer Hall, in the hallway behind the Sport Medicine Research Laboratory. All subjects received both verbal instruction intervention conditions (injury prevention, sports performance) in a counterbalanced order on two separate days. There were an equal number of subjects performing each order of testing to prevent the influence of an order effect.

A modified version of Phase I of the PEAKc ACL injury prevention program was performed, which includes flexibility (warm-up), stability, strength, and plyometric components (Padua, 2011). Injury Prevention Instructions consisted of phrases often used in rehabilitation and injury prevention settings. These cues are more specific to the proper lower extremity alignment. Key phrases included, “Keep your toes pointing straight ahead,” “Keep your knees over your toes,” “Don’t let your knee(s) fall in,” “Land softly,” “Light as a feather,” “On your toes,” and “Bend at the knee and hip,” many of which have been used in previous studies (Milner et al., 2012; Padua & Distefano, 2009). Performance Based Instructions consisted of the phrases, “Quick/ Faster,” “Power up,” “Reach higher,” “Drive your knee up,” and “Hard cuts/Push off hard.” The importance of cuing and feedback with regard to performance and learning has been emphasized in previous studies (Baechle & Earle, 2000; Wulf et al., 2010).

The individual exercises are outlined below followed by the verbal instructions based on each condition; injury prevention (IP) or sports performance (SP). The same instructions were used for both conditions when completing the flexibility portion of the PEAKc.

**Flexibility**

- Dynamic hip adductor stretches (Right and Left): Begin with right shoulder facing tape. Lead with right foot, lean toward right leg and hold for three seconds, and continue to the tape. Repeat action with left shoulder facing the tape, lead with left foot, lean toward left
leg, hold for three seconds, and continue to the tape. Keep toes and hips pointing forward and head and chest up throughout movement

- Dynamic hip flexor stretches (Right and Left): Begin with both feet on starting line facing the tape. Stride forward with one foot while kneeling with the other leg, keep front foot facing forward and knee in line with foot, place hands on pelvis. Glide pelvis forward without arching low back, front knee should bend to 90 degrees. Return to upright position by bringing kneeling leg in line with front foot and repeat on opposite side while moving toward the tape. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching tape.

- Dynamic calf/hamstring stretches (Right and Left): Begin with both feet on starting line facing the tape. Step forward with one leg, place heel on ground, keep toes pulled up, bend trunk forward while keeping back straight, return to upright, and repeat on opposite side. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching tape.

**Stability and Strength**

- “L” hop to balance: Begin in SL stance position on right leg. Hop forward and land on right leg. Hop backward landing on right leg at the starting point. Hop sideways to the right landing on right leg. Hop to the left off the right leg, landing on the right leg at the starting point. Repeat 10 times in a row. Repeat on left leg.

  - Injury Prevention Instructions:
    - “Land light as a feather”
    - “Keep your knee over your toes/Don’t let your knee fall in”
    - “Bend at the knee and hip”
• Performance Enhancement Instructions:
  - “Get balanced as quickly as possible”
  - “Push off hard”
  - “Quick! Faster!”

• Single leg ball toss: Begin in SL stance on right leg six feet away from research assistant.
  Toss ball to assistant for 20 tosses. Repeat on left leg.

• Injury Prevention Instructions:
  - “Keep your knee over your toes”
  - “Keep your toes pointing straight ahead”
  - “Keep your trunk centered over your hips”

• Performance Enhancement Instructions:
  - “Pass the ball faster”
  - “Strong passes”

• Single leg squat: Stand on right leg with right hand on pelvis. Squat down bending at the knee and hip and touch your right foot with your left hand, then return to upright position.
  Repeat motion standing on left leg with left hand on pelvis, bending at the knee and hip and touch our left foot with your right hand. Repeat 10 times on each leg.

• Injury Prevention Instructions:
  - “Keep your toes pointing straight ahead”
  - “Keep your knee over your toes”
  - “Don’t let your knee fall in”

• Performance Enhancement Instructions:
  - “Make sure your thigh is parallel to the floor”
Plyometric/Agility

- Squat jump: Begin in a standing position with feet shoulder width apart and hands at sides. Flex at the knees, hips, and trunk and jump upward for maximal vertical height. Land on both feet and hold for two seconds. Perform 10 repetitions.
  - Injury Prevention Instructions:
    - “Land softly”
    - “Land on your toes and bend at the knee and hips”
    - “Keep your knees over your toes”
    - “Keep your toes pointing straight ahead”
  - Performance Enhancement Instructions:
    - “Jump as quickly as possible”
    - “Power up”
    - “Reach higher”
    - “Quick/Faster”

- Lateral jumps: Begin in SL stance position on right leg. Perform a single leg hop to the left, land on left leg, and immediately hop back to the right leg. Perform 10 repetitions and repeat beginning on left leg, hop to the right, land on right leg, and immediately hop back to the left leg.
  - Injury Prevention Instructions:
    - “Land softly”
    - “Land on your toes and bend at the knee and hips”
    - “Keep your knees over your toes”
“Keep your toes pointing straight ahead”

Performance Enhancement Instructions:
- “Push off hard”
- “Quick/Faster”
- “Power across”

Sideways shuffles: Begin with feet on starting line facing 90° from the tape. Knees and hips should be bent and hands held in front of body. Sideways shuffle to the right until tape is reached, the sideways shuffle to the left back to the starting point. Repeat down and back twice.

Injury Prevention Instructions:
- “Stay low, keep your knees and hips bent”
- “Keep your knees over your toes”
- “Keep your toes pointing straight ahead”

Performance Enhancement Instructions:
- “Shuffle as fast as you can between the cones”
- “Stay low”
- “Quick/Faster”

High knee skipping: Begin with both feet on starting line facing tape. Move forward skipping allowing arms to swing to facilitate momentum. Continue for 30 yards and back to starting line.

Injury Prevention Instructions:
- “Land softly”
- “Land on your toes, bend at the knee and hip”
“Keep your toes pointing straight ahead”

- Performance Enhancement Instructions:
  - “Skip as high as possible”
  - “Power up”
  - “Reach higher”

- Run cuts at 45-degrees: Begin with both feet on starting line facing the tape. Bend at the knees and hips so upper body leans forward. Sprint forward to the right at 45° angle for about 4 steps, plant outside leg and cut 45° in opposite direction, sprint another 4 steps, plant left leg and cut 45° in opposite direction. Continue for 30 yards and back to starting line.

- Injury Prevention Instructions:
  - “Lean your trunk in the direction you’re cutting”
  - “Keep your knees over your toes”
  - “Bend at the knee and hip”

- Performance Enhancement Instructions:
  - “Make quick cuts”
  - “Push off hard”
  - “Quick/Faster”

Immediately after finishing the intervention, subjects completed post motion analysis testing in the exact same fashion as pre testing. All subjects performed the single leg squat, double leg jump landing, and single leg cut tasks in a randomized order.

When the first testing session was complete, subjects will complete a 7-10 day washout period. Other studies have used a range of 48-72hr and 72hrs-1wk wash-out periods when
looking at the effects of exercise (Ghoname et al., 1999; Pober, Braun, & Freedson, 2004; Simao, Farinatti Pde, Polito, Maior, & Fleck, 2005; Spreuwenberg et al., 2006). None of these studies gave verbal instruction therefore, due to the verbal instruction given in this study it was decided to extend the washout period slightly to ensure a full washout. Subjects returned for second testing session using the same protocol outlined above but they were assigned to the opposite group – “Performance Based Instructions” or “Injury Prevention Based Instructions.”

3.4 DATA PROCESSING AND ANALYSIS

Embedded right-hand Cartesian coordinate systems were defined for the trunk, pelvis, and thigh segments to describe the segmental three-dimensional positions and orientations. The positive X-axis was directed anteriorly, the positive Y-axis was directed toward the left, and the positive Z-axis was directed superiorly relative to the participant. Euler angles were be used in Y’, X’’, Z’’’ global axis sequence, the distal segment compared relative to proximal segment.

Kinematic and kinetic data were exported into a customized MATLAB software program (Mathworks, Natick, MA, version 13.0) for data reduction. Kinematic and kinetic data were filtered using a 4th order low pass Butterworth Filter with a cutoff frequency of 14 Hz. Ground reaction force data was normalized to each participants body weight (N). The vertical ground reaction data defined the landing and push-off phases during both the jump landing and single leg cut tasks. Initial contact was defined as the first time point during each trial that the vertical ground reaction force exceeded 10N, and toe-off was defined as the first time point during each trial that the vertical ground reaction force dropped below 10N. The overall stance phase was defined as the time period from initial contact to toe-off. The stance phase was broken into two distinct phases for both the double leg jump landing and single leg cut for further data reduction.
The loading phase was defined as the first half (50%) of the stance phase and was used to identify peak joint angles and peak VGRF. The push-off phase was defined as the second half of the stance phase and was used to identify vertical jump height.

Kinematic joint angles for *initial contact hip adduction*, *initial contact knee abduction*, and *initial contact knee flexion* were identified at initial contact of the foot with the force plate (the first time the force plate reads over 10N). Kinematic joint angles for *peak hip adduction*, *peak knee abduction*, and *peak knee flexion* were identified during the loading phase (first 50%) of the jump landing and single leg cut tasks. Similarly, *peak VGRF* was identified for both tasks during the loading phase for each trial. Subtracting the initial contact angles from the peak joint angles identified kinematic joint angles for *hip adduction displacement*, *knee abduction displacement*, and *knee flexion displacement*.

The variable for *stance time* was derived for both tasks as the total length of time (ms) of the stance phase, or how long the participant was in contact with the forceplate for each trial. This variable was indicative of how quickly the participant could redirect into the subsequent maximum vertical jump or cutting movement.

*Vertical jump height*, or total vertical displacement of the center of mass (COM), was calculated for the double leg jump landing task only. The positive vertical displacement of the COM during stance and that at toe-off was added to the jump height calculated from the following equation: $\text{Jump Height} = \frac{\text{TOV}^2}{2 \cdot g}$, where $\text{TOV}$ = vertical velocity of the COM at toe-off and $g = 9.81 \text{ m} \cdot \text{sec}^{-2}$. This allowed the calculation of total positive vertical displacement of the COM from the participant’s start of the push-off phase to the maximum vertical projection during flight (Moir, Garcia, & Dwyer, 2009).
Change scores were calculated for each dependent variable for both verbal instruction conditions. Change scores were calculated as the difference between pre-test and post-test mean values for each dependent variable on each test day. Separate paired samples T-test’s were performed to determine the effect of performance-based instructions vs. injury prevention-based verbal instructions within this sample on the dependent variable change scores.

- **Jump Landing: (6)**
  - $\Delta$ Knee Flexion (initial contact, peak, and displacement)
  - $\Delta$ Knee Abduction (initial contact, peak, and displacement)
  - $\Delta$ Hip Adduction (initial contact, peak, and displacement)
  - $\Delta$ Peak Vertical Ground Reaction Force
  - $\Delta$ Vertical Jump Height
  - $\Delta$ Stance Time

- **Single leg cut: (5)**
  - $\Delta$ Knee Flexion (initial contact, peak, and displacement)
  - $\Delta$ Knee Abduction (initial contact, peak, and displacement)
  - $\Delta$ Hip Adduction (initial contact, peak, and displacement)
  - $\Delta$ Peak Vertical Ground Reaction Force,
  - $\Delta$ Stance Time

Descriptive statistics (mean ± SD and 95% confidence interval) were also calculated for each task during each set of instructions. An a priori alpha level was set at 0.05 when completing the T-tests and all statistical analysis will be performed using SPSS statistical software version 20.0.
CHAPTER 4

MANUSCRIPT

The Effect of Instructions on Lower Extremity Biomechanics and Performance Measures

OVERVIEW

The type of instructions given during completion of an anterior cruciate ligament injury prevention program may influence its effect on injury prevention and performance benefits. Research has yet to identify the impact of different instructions on injury prevention variables – knee abduction angle, knee flexion angle, hip adduction angle, vertical ground reaction force – and performance variables – vertical jump height and stance time. A crossover research design was used. Participants received injury prevention and performance based instructions in counterbalanced order. Separate paired T-test’s were performed between change scores for each condition to determine the effect of different instructions on the dependent variables. A significant decrease in magnitude of hip adduction was found at initial contact when given injury prevention instructions during the jump landing task ($t_{21} = -2.381, p = 0.027$) and single leg cut task ($t_{21} = -4.301, p < 0.001$) and a significant decrease in magnitude of stance time resulted when given performance enhancement instructions during the jump landing task ($t_{21} = 2.803, p = 0.011$) and during the single leg cut task ($t_{21} = 2.92, p = 0.008$). A significant increase in magnitude of jump height resulted when given performance enhancement instructions ($t_{21} = -2.21, p = 0.038$). These results indicate type of instruction may influence biomechanics and performance measures.
INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common, and most debilitating, injuries to sustain in sports today, with as many as 250,000 ACL injuries happening in the United States each year (Griffin et al., 2006). Injury prevention programs (IPPs) have been moderately successful in reducing ACL injury incidence (Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005). However, getting coaches and teams to comply with these IPPs is an ongoing issue and limits their effectiveness. Anecdotally, coaches may be more compliant if IPPs aided with performance enhancement in addition to injury prevention. However, evidence is lacking as to how these IPPs affect sports performance.

Females tear their ACLs at a much higher rate in sports that involve stopping quickly, cutting, and changing direction and are 4-8 times more likely to experience a non-contact knee injury compared to males (Barber-Westin et al., 2006; Ireland, 2002). Females display more hip adduction and internal rotation causing valgus at the knee and tibial external rotation during a mini-squat (Ireland, 2002), a similar position as during dynamic stopping and cutting maneuvers (Boden et al., 2009; Krosshaug et al., 2007). Greater knee valgus moments and positioning coupled with smaller knee flexion angles (Hewett et al., 2005) and greater hip adduction (Padua, Boling, et al., 2012) upon landing from a double leg jump are prospective risk factors for ACL injury. Visual observation of greater hip adduction motion in the closed kinematic chain has been termed “medial knee displacement,” and has been observed in video footage of ACL injury events (Boden et al., 2009; Hewett et al., 2009; Krosshaug et al., 2007). An important factor in the display of medial knee displacement (MKD) seems to be neuromuscular in nature, in particular, an increase in hip adductor activation (Padua, Bell, et al., 2012).
Ideally, IPPs that have decreased the incidence of ACL injury by modifying some of the factors mentioned above, would also improve athletic performance. Demonstrating that these programs both reduce injury risk and enhance performance may improve compliance by coaches and athletes. Programs that utilized verbal instructions in combination with injury prevention exercises have been most effective in altering variables believed to contribute to ACL injury (Herman et al., 2009; Padua & Distefano, 2009; Stroube et al., 2012). However, it is unknown if verbal instructions specific to ‘preventing injury’ or ‘performance enhancement’ could also impact these results.

Athletes need to have quick reaction times and force production to perform well, but this may come at the cost of safe movement patterns. In contrast, telling an athlete to land softly may impact the length of the stance phase and the ability to move quickly following ground contact. However, research is necessary to better understand these relationships to guide researchers and clinicians in packaging injury prevention programs to garner the greatest benefits.

Therefore, the primary purpose of this study was to evaluate the acute effects of an ACL injury prevention program with two different sets of verbal instructions on lower extremity kinematics and performance measures in females who display at risk movement patterns during a single leg squat. We hypothesized that giving subjects “injury prevention” (IP) instructions would acutely improve lower extremity biomechanics associated with ACL injury, but at the detriment of performance variables such as jump height and length of stance phase. Conversely, we hypothesized that giving subjects “performance enhancement” (PE) instructions would acutely improve performance variables, but at the detriment of lower extremity biomechanics.
METHODS

Experimental Approach to the Problem

This study utilized a crossover design, in which all participants completed the intervention with both sets of verbal instructions, on two separate testing occasions, in a counterbalanced order. Change scores were calculated for each subject from pre-test and post-test during two tasks (double leg jump landing (JL) and single leg cut (SLC)) after having received either “injury prevention” or “performance enhancement” instructions during the IPP intervention.

Subjects

Twenty-three physically active females between the ages of 18-26 years participated in this study. Physically active was defined as a minimum of 30-60 minutes of moderate activity 3-5 times/week. However, they were not included if they had just begun a new workout regime, or another intervention study, and were not allowed to make changes to their routine while participating in study. All participants had no history of ACL injury or prior participation in an ACL injury prevention program. They were also excluded if they had prior history of lower extremity injury in the past 6 months that kept them from activity for more than two days or if they were currently having lower extremity pain. Participants also had at least one year of experience participating in competitive sport (at least one year at the varsity level in high school or current participation in club sports). Subjects were also required to display faulty lower extremity biomechanics during a single leg squat as part of a screening process described below. This was performed to ensure that there was room for improvement in biomechanics and focus on a population that would typically be targeted for injury prevention training. All subjects gave informed consent for participation in the study, which was approved by the university’s
Institutional Review Board. One subject was lost due to attrition after the first data collection session: therefore a total of twenty-two subjects completed the study.

Procedures

Kinematic data was recorded using an electromagnetic motion capture system (Motion Star, Ascension Technologies Inc., Burlington, VT) sampled at 140 Hz during the JL and SLC tasks. The equipment was calibrated according to manufacturer guidelines. Electromagnetic sensors were placed on the subject with double sided tape and secured using pre-wrap and athletic tape at the sacrum, C7 spinous process, the lateral aspect of the thigh, the anteromedial tibia, and between the second and third metatarsal heads of the foot. Participants stood in a neutral position while additional landmarks were digitized including the medial and lateral malleoli, the medial and lateral femoral condyles, T12/L1 vertebrae, right and left ASIS, distal end of the second phalanx of foot. All unilateral digitizations and sensor markers were placed on the dominant limb.

To perform the intervention for this study, the sensors needed to be removed following pre-test and then re-applied for post-test. To maximize similarity of sensor locations between pre- and post-intervention measurements, sensor locations and digitization landmarks were marked with permanent marker. To facilitate correct sensor placement during the second testing session (i.e. approximately 1 week later), sensors were placed at the midpoint between two bony landmarks. The sacrum was identified upon palpation, as was C7. The lateral aspect of the thigh was identified as the midpoint between the greater tubercle of the femur and the lateral joint line, the anteromedial tibia was identified as the midpoint between the medial malleolus and pes anserine, and the dorsal foot sensor was placed at the midpoint between the bases of second and third metatarsals.
Embedded right-hand Cartesian coordinate systems were defined for the trunk, pelvis, and thigh segments to describe the segmental three-dimensional positions and orientations. The positive X-axis was directed anteriorly, the positive Y-axis was directed toward the left, and the positive Z-axis was directed superiorly relative to the participant. Euler angles were used in $Y'$, $X''$, $Z'''$ global axis sequence, the distal segment compared relative to proximal segment.

Local coordinate systems for each body segment were aligned such that the X-axis is positive anterior to the subject, the Y-axis is positive to the left of the subject, and the Z-axis is positive superior to the subject. Two floor embedded force plates (Bertec 4060, Columbus, OH) were used to identify initial ground contact and push-off to determine the duration of the stance phase, peak vertical ground reaction force during the loading phase, and estimate vertical jump height. All data was captured via The Motion Monitor data acquisition software (Innovative Sports Training, Inc., Chicago, IL). Kinetic data was sampled at 1,400 Hz and the kinematic data was time synchronized with the ground reaction force data and re-sampled at 1,400 Hz via linear interpolation.

**Subject Screening**

Potential subjects reported to the laboratory to determine if they met the study inclusion criteria. Each subject performed a set of five single leg squats on her dominant leg, defined as the leg chosen to kick a soccer ball for maximum distance, while wearing comfortable athletic shoes. Prior to performing the screening, a tripod was positioned behind the subject such that the gluteal fold contacted the tripod when the subject reached 60° of knee flexion during the squat as measured by a goniometer. The subject was instructed to stand with the feet shoulder distance apart, both hands on hips, and then raise one foot about 5-10cm off the ground and to descend into a squat and return to the upright posture. If the middle of the patella moved medial to the
great toe in three or more squat trials, the subject was deemed as displaying medial knee
displacement and was automatically included in the study (Mauntel et al., 2012). If the subject
displayed any two or more of the following variables, she also qualified: femoral adduction, hip
drops on the stance leg (+Trendelenburg), hip hikes on the non-stance leg, trunk rotation (toward
stance or non-stance leg), and/or shoulders not level. Video data were recorded in the frontal and
sagittal planes to ensure qualifying body mechanics were present. Those who did not display
MKD or any two of the other qualifying variables were not included in the study. All qualifying
subjects were scheduled for their first data collection session prior to leaving the lab after the
screening.

Data Collection

Subjects who met the inclusion criteria returned to the laboratory on two additional
occasions for data collection. Motion analysis was performed while subjects the DL and SCL
tasks prior to and following the completion of an IPP. Data were collected on the subjects’
dominant limb only. To perform the JL, subjects jumped from a 30-cm box to a force plate over
a distance of 50% of their height and immediately went into a maximal vertical jump upon
landing (Padua et al., 2009). Subjects were instructed to “jump forward into the target area with
both feet and immediately jump straight up as high as you can.” Subjects completed five
successful trials, with 10-20 seconds of rest between. Incorrect completion was defined as
leaving the box pushing off of one foot, jumping for maximal height off the box rather than
jumping forward, and if their feet did not land on the force plate. To perform the SLC, subjects
completed a double leg forward jump from the ground, over a hurdle, placed one foot away from
the force plates. Subjects landed on their dominant limb on the force plate, and cut away from
the landing leg at a 45° angle in the opposite direction of their landing leg. Subjects were
instructed to “jump forward into the target area with both feet, land on your dominant limb and immediately cut away from your landing leg.” Subjects performed five successful trials with 10-20 seconds of rest between. Incorrect completion was defined as jumping off of one foot, landing on two feet, missing the force plate on landing, and if they did not make a 45° cut. No demonstration was given for either task, however subjects performed up to three practice trials to familiarize themselves with the tasks.

Verbal Instructions Intervention

Between the pre-test and post-test motion analysis, subjects completed a modified version of Phase I of the PEAKc (Performance Enhancement and Kinetic Control) ACL injury prevention program, which includes flexibility (warm-up), stability, strength, and plyometric components (Padua, 2011). A piece of athletic tape was placed 10 yards from the starting line and each exercise was completed to this line, with the exception of high knee skipping and 45° cuts which were completed over a distance of 30 yards from the starting line and back. All subjects received both verbal instruction intervention conditions (injury prevention, sports performance) in a counterbalanced order on two separate days while completing the modified version of Phase I of the PEAKc ACL IPP. Injury Prevention (IP) Instructions consisted of phrases often used in rehabilitation and injury prevention settings. These cues are more specific to the proper lower extremity alignment. Key phrases included, “Keep your toes pointing straight ahead,” “Keep your knees over your toes,” “Don’t let your knee(s) fall in,” “Land softly,” “Light as a feather,” “On your toes,” and “Bend at the knee and hip.” Performance Enhancement (PE) Instructions consisted of the phrases, “Quick/ Faster,” “Power up,” “Reach higher,” “Drive your knee up,” and “Hard cuts/Push off hard.” Subjects returned to the laboratory for a second testing
session after a 7-10 day washout period and followed the same protocol outlined above, but received the opposite verbal instructions from their initial testing session.

**Data Reduction**

Three-dimensional coordinates of lower extremity bony landmarks were estimated using Motion Monitor Software (Innovative Sports Training, Chicago, IL). Embedded right-handed Cartesian coordinate systems were defined for the shank, thigh, and pelvis segments to describe the three-dimensional position and orientation of these segments. Euler angles were used to calculate knee and hip joint angles as motion of the distal segment relative to the proximal segment in a rotation order of (1) flexion-extension about the y-axis (2) valgus-varus knee or adduction-abduction hip about the x-axis (3) internal-external rotation about the z-axis; Force plate data were not filtered. Kinematic data were lowpass filtered at 14 Hz (4\text{th} order Butterworth).

Kinematic and kinetic data were reduced using custom Matlab software (Mathworks, Natick, MA, version 13.0). Hip adduction, knee flexion, and knee valgus angles were determined at the time point of initial ground contact (IC) and the peak during the stance phase of the jump-landing task. The stance phase was defined as the time period between initial ground contact (vertical ground reaction > 10 N) and takeoff (vertical ground reaction force < 10 N). Additionally, displacement was calculated for hip adduction, knee flexion, and knee valgus as the difference between the peak joint angle during the stance phase and the angle at IC. The average values across 3-trials were calculated for each kinematic variable. Peak vertical ground reaction forces were normalized to body weight (%BW).
Statistical Analysis

Change scores were calculated for each dependent variable (post-test – pre-test) for both verbal instruction conditions. These variables included knee flexion angle, knee abduction angle, and hip adduction angle at initial contact, peak stance phase angles, and stance phase angular displacements, peak vertical ground reaction force, and stance time for both the JL and SLC, as well as vertical jump height for JL.

Separate paired samples t-test’s were performed to determine the effect of performance-based instructions vs. injury prevention-based verbal instructions within this sample on the dependent variable change scores. Descriptive statistics (mean ± SD and 95% confidence interval) were also calculated for each task during each set of instructions. All statistical analyses were performed using SPSS statistical software version 20.0 with an a priori alpha level set at 0.05.

RESULTS
Jump Landing

There was a significant difference in the change scores for hip adduction at initial contact between the IP and PE instructions ($t_{21} = -2.38, p = 0.03$). Specifically, there was a decrease in hip adduction at initial contact (Mean Difference = 3.26° decrease in hip adduction) following the IP instructions (95% CI = -6.22, -0.31); however, no such change was observed following the PE instructions (95% CI = -2.77, 2.52). No other significant differences in change scores were observed for the other joint kinematics variables at initial contact or the stance phase peaks ($p < 0.05$). While the change in knee valgus angle at initial contact was not significantly different between IP and PE instructions ($p = 0.347$), there was a significant increase in knee valgus at
initial contact (2.67° increase on average) when given PE instructions (95% CI = -5.15, -0.19) as the 95% CI values did not cross zero. However, there was no apparent change following IP instructions as the 95% CI’s did cross zero (95% CI = -4.17, 2.05).

We did not observe any significant differences in change scores for the joint displacement variables (p < 0.05). However, the change in knee flexion displacement trended towards being significantly different between the IP and PE instructions (p = 0.061). Inspection of the 95% CI’s for the change in knee flexion displacement reveals a significant increase in knee flexion displacement (Mean Difference = 3.95° increase in knee flexion displacement) following the IP instructions as the 95% CI values did not cross zero (95% CI = 1.441, 6.46). This was not the case following PE instructions (Mean Difference = 0.95° increase in knee flexion displacement) as the 95% CI values crossed zero (95% CI = -1.4, 3.267). Thus, it seems as if knee flexion displacement during a jump-landing increases following IP instructions.

Following the PE instructions, we observed a significant difference in the magnitude of change in vertical jump height (t_{21} = -2.21, p = 0.038) and stance time (t_{21} = 2.803, p = 0.011) between the PE and IP instructions. Specifically, the change in vertical jump height following PE instructions was greater than IP instructions. However, inspection of the 95% CI’s for the change in vertical jump height indicates this change may not be significant (95% CI = -0.005, 0.016) as the upper and lower limits of the 95% CI’s cross zero. The 95% CI values for the stance time change scores support the significant decrease in stance time with PE instructions (95% CI = -.04, -.001) and not the IP instructions (95% CI = -.008, .028). Descriptive statistics of jump landing change scores (means, SD, 95% CI) and the raw means utilized to calculate change scores are presented in Tables 1-2, respectively.
Single Leg Cut

Similar to the jump-landing task, the change in hip adduction at initial contact between the IP and PE instructions was significantly different ($t_{21} = -4.301, p < 0.001$). Specifically, there was a decrease in hip adduction with the IP instructions (95% CI = -5.735, -0.020) at initial contact (Mean difference = 2.88° decrease in hip adduction). In addition, there was an increase in hip adduction with the PE instructions (95% CI = 1.161, 6.042) at initial contact (Mean difference = 3.60° increase in hip adduction). Thus, IP instructions result in decreased hip adduction, whereas PE instructions facilitate an increase in hip adduction during a single leg cut task.

We did not observe any other statistically significant differences in change scores for the kinematic variables ($p < 0.05$). However, there was a trend for a decrease in knee valgus at initial contact ($p = 0.052$), when subjects were given IP instructions compared to PE instructions. Inspection of the 95% CI’s for knee valgus at initial contact reveals a significant increase in knee valgus (Mean Difference = 2.662° increase in knee valgus) following the PE instructions as the 95% CI values did not cross zero (95% CI = -5.189, -.135). In contrast, the change in knee valgus with IP instructions was small (Mean Difference = 1.287° decrease in knee valgus, but not significant as the 95% CI values crossed zero (95% CI = -2.805, 4.659). Thus, it seems as if knee valgus at initial contact during a single leg cut increases following PE instructions, but is not changed with IP instructions.

While the magnitude of change in knee flexion angle at initial contact was not significantly different following IP and PE instructions ($p = 0.115$), there was a significant increase in knee flexion at initial contact (a 3.452° increase on average) when given IP instructions (95% CI = -5.902, -1) as the 95% CI values do not cross zero. However, there was
no apparent change following PE instructions as the 95% CI’s crossed zero (95% CI = -3.306, 1.247). Thus, it appears that IP instructions may result in greater knee flexion at initial contact. Yet again, the change in knee flexion displacement was not significantly different between IP and PE instructions ($p = 0.594$). However, knee flexion displacement was improved significantly ($4.282^\circ$ increase in knee flexion on average) when given IP instructions (95% CI = 2.312, 6.251) as the 95% CI values do not cross zero. There was no apparent change following PE instructions (95% CI = -0.3, 7.272) as the 95% CI’s crossed zero.

Following the PE instructions (95% CI = -0.04, -0.001), we observed a significantly greater magnitude decrease ($t_{21} = 2.92, p = 0.008$) in stance time, compared to the IP (95% CI = -0.007, 0.034), instructions. Descriptive statistics of the single leg cut change scores (means, SD, 95% CI) and the raw means utilized to calculate change scores are presented in Tables 3-4, respectively.

**DISCUSSION**

We compared the effects of two different instruction interventions (Injury Prevention based instructions and Performance Enhancement based instructions) during two sessions of a modified ACL injury prevention program on lower extremity kinematics and performance based measures during both jump-landing and single leg cutting tasks. This study is unique in that we included females who displayed faulty movement patterns. One of the most important findings of the current study was that use of IP based instructions during an ACL injury prevention program resulted in a greater magnitude decrease in hip adduction during the jump-landing and single leg cutting tasks, which was not the case with PE based instructions. In contrast, PE based instructions resulted in greater magnitude increase in hip adduction and knee valgus. Improvements in hip adduction following IP based instructions were not associated with
decreased performance during the jump-landing and cutting tasks. Thus, IP based instructions resulted in improved biomechanics without compromising performance. The PE instructions, on the other hand, influenced a greater magnitude improvement in traditional variables used to measure sport performance. Particularly, a larger magnitude decrease in stance time (quicker) during both tasks and a larger magnitude increase in vertical jump height during the jump landing task were observed when PE instructions were given during the intervention rather than IP. However, there were no improvements in hip and knee biomechanics in these subjects with at risk movement patterns. In fact, subjects displayed worse biomechanics – greater magnitude increase in hip adduction and knee valgus at initial contact – during a cutting task following performing tasks from an ACL prevention program while receiving PE instructions.

It is also important to note other changes in lower extremity biomechanics that were observed. During both jump-landing and single-leg cutting tasks, we observed a larger magnitude increase in knee flexion displacement following IP instructions. When PE instructions were given, there was a larger magnitude increase in knee valgus displacement during the jump-landing task and knee valgus at initial contact during the single-leg cutting task. Both of these variables, knee valgus and knee flexion, are important variables to target during injury prevention programs. There was also a greater magnitude increase in peak hip adduction during the double leg jump landing when subjects were given PE instructions. All of these findings emphasize the importance of instructions and/or feedback when implementing ACL injury prevention programs.

The changes observed in lower extremity biomechanics when subjects were given PE instructions are essential to keep in mind when thinking about injury risk. The population used in this study was made up of females who displayed poor lower extremity biomechanics and, as the
above results indicate, some of these only got worse with the PE instruction intervention. Even those variables that did not change may be problematic to these subjects given the fact they were required to display faulty movement patterns to be enrolled. Several studies have completed video analyses of ACL injuries and some common themes have emerged. It seems the time period shortly after landing from a jump or cutting is the most dangerous for female athletes; in particular, females show much greater knee abduction angles (knee valgus collapse) during the landing phase at the time of injury than do males (Boden et al., 2009; Hewett et al., 2009; Krosshaug et al., 2007). Rather than reducing injury risk, there could be a possibility of increasing injury risk when performing an ACL injury prevention program combined with PE instructions.

The fact that we were able to decrease the magnitude of hip adduction during jump-landing and single-leg cutting tasks with IP instructions is important in reducing injury risk, as hip adduction is a key variable in ACL injury and injury prevention. Previous studies have found an increase in hip adduction predisposes individuals to an increase in knee valgus, and knee valgus is correlated with ACL injury (Bien, 2011). In addition, decreased neuromuscular control at the trunk, leads to an increase joint load at the knee (knee abduction, or valgus) due to lateral motion of the ground reaction force and hip adduction (Hewett & Myer, 2011). In a large prospective study, Padua et al. (Padua, Boling, et al., 2012) found military cadets that went on to suffer an ACL injury (n=98) demonstrated greater hip adduction during a jump-landing task. With regard to injury prevention, it’s been found in previous studies that neuromuscular training may help increase coronal plane trunk and hip control in female subjects (Hewett & Myer, 2011). It is encouraging to see such improvements in hip adduction acutely in the current study. These results may bode well for ACL injury prevention programs incorporating IP based
instructions that are implemented over a more extended period of time for reducing the risk of injury to those who participate.

A unique aspect of this study was that we utilized individuals with faulty movement patterns. Previous research has also found more distinct gains in those subjects who display poor biomechanics before the intervention (DiStefano et al., 2009). Those subjects identified as having “poor” landing mechanics using the LESS grading scale, improved 3 times more than the overall mean improvement and those in the “moderate” and “good” groups improved significantly more than those in the “excellent” group (DiStefano et al., 2011). The authors concluded those athletes who have poor movement techniques are those with whom improvement is most critical to reducing injury risk. Using this unique population of women who have participated/are participating in competitive sport and display poor biomechanics, is a strength of the current study.

Another strength and unique aspect of this study is that the instructions were given outside of the testing task (jump-landing and single-leg cutting). In addition to being provided outside of the testing task, they were given while participants completed exercises included in an injury prevention program. The fact that the instructions given during the modified IPP intervention transferred over to the double leg jump landing and single leg cut tasks is key. Some studies have found success with this in the past, feedback given during a tuck jump successfully transferred to the drop vertical jump (Myer et al., 2013), and although instructions weren’t applied previously during an injury prevention program, the findings encouraged us to try the technique in this study. Other studies up to this point have given instruction during the task tested and measured the results (Herman et al., 2009). Thus, we believe this is the first study to investigate whether an individual would be able to transfer changes in movement to another task.
Ericksen et al. performed a meta analysis of seven research studies, all of which provided feedback during the task, and looked specifically at its effect on GRF (Ericksen, Gribble, Pfile, & Pietrosimone, 2013). The authors found three had a small effect size and two had strong effect size with regard to immediate effects. Most showed moderate to high effect size with delayed effects of feedback. The results of the current study, and of those mentioned above, should lend encouragement to those who are implementing injury prevention programs in that what they are instructing will transfer over to sport movement when the athlete gets on the field or court.

A previous study found the type of instructions given to be unfavorable to overall performance, stating the instructions given during the completion of IPPs emphasized slow speeds, proper control, and small landing forces when it makes more sense to emphasize explosive qualities, as those are needed for sport performance (Lindblom et al., 2012). Findings in the current study seem to agree with that statement as stance time tended to increase by a tenth during the jump-landing task following IP based instructions, though this was not a significant increase. However, there were large, favorable, acute effects found on decreased magnitude of hip adduction with IP instructions. Perhaps some performance variables may have to be sacrificed in the early stages while an appropriate base of correct functional movement is laid. That is not to say that those variables will be sacrificed forever however.

When working with athletes during an injury prevention program, training program, or rehabilitation program, we suggest starting with injury prevention instructions. As the athletes become more comfortable and show biomechanical improvement, instructions may be progressed to include performance enhancement instructions. Goekleler, et. al. performed a review of previous studies that used feedback during ACL reconstruction rehabilitation and came to the conclusion based on those previous studies that properly learned motor skills will become
permanent with only small reviews needed (Gokeler et al., 2013). This would suggest, that if clinicians did move on to PE based instructions, if they provided a good base of IP instructions, athletes would retain those motor patterns needed for proper biomechanics. If an injury prevention program is put together using this basis, it may be more attractive to coaches to implement. Already, “best practice” coaches agreed unanimously that ACL injury prevention programs have performance enhancing benefits (Joy et al., 2013).

In addition to its attractiveness to coaches, a progression of exercises could be more attractive to the athletes performing an injury prevention program. In fact, a common theme throughout effective programs is a progression of exercises. The exercises need to increase in difficulty as the athlete progresses. The use of verbal instructions or feedback was also present in studies with positive results following an ACL injury prevention programs (Herman et al., 2009; Myer et al., 2013; Padua & Distefano, 2009). This progression of exercises may also help with compliance and motivation. Lack of compliance and motivation were common reasons given in those programs without positive outcomes (Myklebust et al., 2003; Soderman et al., 2000; Steffen, Myklebust, et al., 2008). For an injury prevention program to work, the clinician needs to keep the athlete’s attention and interest. This fact is further exemplified in a meta-analysis which found that the overall compliance rate (attendance x completion) needed to be more than 66% to effectively reduce the risk of ACL injury (Sugimoto et al., 2012).

Injury prevention programs focus on training individuals to modify their movement patterns in hopes of reducing ACL injury rate. Different injury prevention programs place emphasis on different aspects of training (strength, flexibility, balance, plyometrics, and core). However, those programs that incorporate aspects of each component are the most successful in preventing ACL injury (Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005).
Many of these programs are implemented as a warm up (Bien, 2011), and take as little as 15-20 minutes to complete.

Some limitations of the current study include the fact that the results are only applicable to the population used in the subject pool (women who display poor biomechanics, age 18-26, and have participated in competitive sport). In addition, some of the subjects remembered the instructions given during their first session when they returned for the second. However, the 7-10 day washout period was chosen based on previous research as follows. Other studies have used a range of 48-72hr and 72hrs-1wk washout periods when looking at the effects of exercise (Ghoname et al., 1999; Pober et al., 2004; Simao et al., 2005; Spreuwenberg et al., 2006). None of these studies gave verbal instruction therefore, due to the verbal instruction given in this study it was decided to extend the washout period slightly to ensure a full washout. Finally, in the current study, the results pertain to acute effects only. Further research needs to be done to look into long-term effects and retention of the instructions over time.

PRACTICAL APPLICATIONS

There is a reason programs that incorporate all of the variables listed above are more successful in preventing ACL injury as each impacts the body in a different way. An appropriate progression of exercises and instruction needs to be utilized during the IPP. For an athlete to improve in both injury prevention and performance enhancement, there has to be cooperation between the athletic trainer and strength coach. Each has specific skill set that needs to be utilized in the best interests of the athlete. The athlete will need continued instruction and feedback from both to perform at his/her highest level.
### Table 1. Double Leg Jump Landing Change Scores (Δ)

<table>
<thead>
<tr>
<th></th>
<th>Injury Prevention Instructions Paired Statistics</th>
<th>Performance Enhancement Instructions Paired Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Hip Adduction IC (°) Δ*</td>
<td>-3.263</td>
<td>6.659</td>
</tr>
<tr>
<td>Knee Valgus IC (°) Δ</td>
<td>1.472</td>
<td>6.221</td>
</tr>
<tr>
<td>Hip Adduction PK (°) Δ</td>
<td>-3.066</td>
<td>6.901</td>
</tr>
<tr>
<td>Knee Flexion PK (°) Δ</td>
<td>-0.155</td>
<td>7.03</td>
</tr>
<tr>
<td>Knee Valgus PK (°) Δ</td>
<td>0.411</td>
<td>10.597</td>
</tr>
<tr>
<td>Hip Adduction DSP (°) Δ</td>
<td>0.312</td>
<td>3.603</td>
</tr>
<tr>
<td>Knee Flexion DSP (°) Δ~</td>
<td>3.951</td>
<td>5.66</td>
</tr>
<tr>
<td>Knee Valgus DSP (°) Δ</td>
<td>-1.061</td>
<td>7.019</td>
</tr>
</tbody>
</table>

| VGRF PK (N) Δ                | .091       | .473          | (-.119, .301)           | .112       | .53           | (-.348, .123)           |
| Jump Ht (m) Δ *              | -0.007     | 0.019         | (-.016, .001)           | 0.005      | 0.024         | (-.005, .016)           |
| Stance Time (s) Δ *          | 0.01       | 0.041         | (-.008, .028)           | -0.02      | 0.043         | (-.04, -.001)           |

(* indicates a significant difference in the magnitude of change, *p* < 0.05)
(~ indicates a trend toward significant difference in the magnitude of change)
Table 2. Double Leg Jump Landing Mean Scores

<table>
<thead>
<tr>
<th></th>
<th>Injury Prevention Instructions</th>
<th>Performance Enhancement Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td><strong>Hip Adduction IC (°)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Hip Adduction IC (°)</td>
<td>-4.742</td>
<td>6.706</td>
</tr>
<tr>
<td>Knee Flexion IC (°)</td>
<td>22.094</td>
<td>5.71</td>
</tr>
<tr>
<td>Knee Valgus IC (°)</td>
<td>-1.275</td>
<td>4.344</td>
</tr>
<tr>
<td><strong>Hip Adduction PK (°)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Hip Adduction PK (°)</td>
<td>2.179</td>
<td>7.456</td>
</tr>
<tr>
<td>Knee Flexion PK (°)</td>
<td>86.826</td>
<td>10.826</td>
</tr>
<tr>
<td>Knee Valgus PK (°)</td>
<td>-17.918</td>
<td>9.951</td>
</tr>
<tr>
<td><strong>Hip Adduction DSP (°)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Knee Flexion DSP (°)</td>
<td>64.732</td>
<td>8.454</td>
</tr>
<tr>
<td><strong>VGRF PK (N)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>VGRF PK (N)</td>
<td>2.792</td>
<td>0.662</td>
</tr>
<tr>
<td><strong>Stance Time (s)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Stance Time (s)</td>
<td>0.371</td>
<td>0.112</td>
</tr>
<tr>
<td><strong>Jump Height (m)</strong></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.229</td>
<td>0.065</td>
</tr>
</tbody>
</table>

(+) Hip Adduction, Knee Flexion / (-) Knee Valgus
Table 3. Single leg cut Change Scores (Δ)

<table>
<thead>
<tr>
<th></th>
<th>Injury Prevention Instructions Paired Statistics</th>
<th>Performance Enhancement Instructions Paired Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Hip Adduction IC (°) Δ</strong></td>
<td>-2.878</td>
<td>6.445</td>
</tr>
<tr>
<td><strong>Knee Flexion IC (°) Δ</strong></td>
<td>-3.452</td>
<td>5.526</td>
</tr>
<tr>
<td><strong>Knee Valgus IC (°) Δ~</strong></td>
<td>1.287</td>
<td>7.604</td>
</tr>
<tr>
<td><strong>Hip Adduction PK (°) Δ</strong></td>
<td>-1.417</td>
<td>6.485</td>
</tr>
<tr>
<td><strong>Knee Flexion PK (°) Δ</strong></td>
<td>0.83</td>
<td>6.45</td>
</tr>
<tr>
<td><strong>Knee Valgus PK (°) Δ</strong></td>
<td>1.023</td>
<td>10.713</td>
</tr>
<tr>
<td><strong>Hip Adduction DSP (°) Δ</strong></td>
<td>1.658</td>
<td>4.04</td>
</tr>
<tr>
<td><strong>Knee Flexion DSP (°) Δ</strong></td>
<td>4.282</td>
<td>4.441</td>
</tr>
<tr>
<td><strong>Knee Valgus DSP (°) Δ</strong></td>
<td>-0.264</td>
<td>4.602</td>
</tr>
<tr>
<td><strong>VGRF PK (N) Δ</strong></td>
<td>.117</td>
<td>.433</td>
</tr>
<tr>
<td><strong>Stance Time (s) Δ</strong></td>
<td>0.013</td>
<td>0.046</td>
</tr>
</tbody>
</table>

(~ indicates a trend toward significant difference in the magnitude of change)
(* indicates a significant difference in the magnitude of change, \( p < 0.05 \))
Table 4. Single leg cut Mean Scores

<table>
<thead>
<tr>
<th></th>
<th>Injury Prevention Instructions</th>
<th></th>
<th>Performance Enhancement Instructions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Mean</td>
<td>SD</td>
<td>Post Mean</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Knee Flexion IC (°)</strong></td>
<td>19.596</td>
<td>6.454</td>
<td>16.144</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Knee Valgus IC (°)</strong></td>
<td>-1.155</td>
<td>6.153</td>
<td>0.132</td>
<td>6.444</td>
</tr>
<tr>
<td><strong>Hip Adduction PK (°)</strong></td>
<td>0.315</td>
<td>7.607</td>
<td>-1.102</td>
<td>8.375</td>
</tr>
<tr>
<td><strong>Knee Flexion PK (°)</strong></td>
<td>56.653</td>
<td>7.818</td>
<td>57.483</td>
<td>7.061</td>
</tr>
<tr>
<td><strong>VGRF PK (N)</strong></td>
<td>3.153</td>
<td>0.852</td>
<td>3.037</td>
<td>0.678</td>
</tr>
<tr>
<td><strong>Stance Time (s)</strong></td>
<td>0.357</td>
<td>0.065</td>
<td>0.37</td>
<td>0.061</td>
</tr>
</tbody>
</table>

((+ Hip Adduction, Knee Flexion / (-) Knee Valgus))
APPENDIX 1: CONSENT FORM

University of North Carolina at Chapel Hill
Consent to Participate in a Research Study
Adult Participants

Consent Form Version Date: July 15, 2013
IRB Study # 13-2305
Title of Study: The Effect of Instructions on Lower Extremity Biomechanics and Performance Measures
Principal Investigator: Lauren Hawkinson
Principal Investigator Department: Exercise and Sport Science
Principal Investigator Phone number: 608-553-0447
Principal Investigator Email Address: hawkinso@live.unc.edu
Co-Investigators: Troy Blackburn, Rebecca Begalle, Shiho Goto

Faculty Advisor: Darin Padua
Faculty Advisor Contact Information: Phone number: (919) 843-5117, Email address: dpadua@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the research study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this research study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.

You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this research study at any time.

What is the purpose of this research study?
The purpose of this research study is to determine the effect of instructions on lower extremity movement during two common tasks performed during sports. More specifically, joint angles, leg movement, landing forces, and speed of force production will be measured before and after receiving instructions.
You are being asked to be in the research study because:

- You are a female
- You are physically active (30-60 min of physical activity 3 or more days/week)
- You have participated in competitive sport in the past

Are there any reasons you should not be in this research study?
You should not be in this research study if you do not meet all of the inclusion criteria above and/or:

- You have prior history of ACL injury
- You have prior history of participating in an ACL injury prevention program or injury prevention research study
- You have prior history of musculoskeletal injury in the past 6 months that kept them from activity for more than two days or currently experiencing lower extremity pain
- You have just began a new workout regime, or another intervention research study
- You plan on making changes to your current workout regime while completing the study; a length of approximately 7-10 days

How many people will take part in this research study?
There will be approximately 20 people in this research study.

How long will your part in this research study last?
Your participation in this research study will be approximately 2 hours and 30 minutes in total. This will include one screening session that will take approximately 30 minutes to confirm inclusion criteria. Then two data collection sessions lasting approximately 1 hour each will be scheduled/performed. The data collection sessions will take place 7-10 days apart. There will be no follow-up as part of this research study.

What will happen if you take part in the research study?
Before you participate in this research study, we ask that you fill out a health history and physical activity questionnaire. Please read the consent form thoroughly and fully understand the purpose and procedures for this research study and then sign the back page if you are interested in participation.

For the purposes of motion analysis, we have asked you to wear spandex shorts and a fitted tank top/sports bra. This is so that the sensors that track your movement will not be affected by baggy clothing that moves. If you do not have your own, this clothing can be provided for you. You will be required to return the spandex at the completion of testing.
SCREENING SESSION:

The purpose of this session is to determine if you fit the inclusion criteria for this study. If you do, a second data collection session will be scheduled immediately. The investigators will ask you to perform one task to decide.

1. **Single-leg Squat**
   a. You will be asked to stand with feet shoulder distance apart, both hands on hips, and then raise your non-dominant foot about 5-10cm off the ground. While standing on your dominant (kicking) foot, you will squat to 60° of knee flexion, as measured by the investigator. A tripod will be adjusted to the correct height and placed behind you to serve as a guide in order to reach the correct squat depth. When your gluteus maximus (buttock muscle) makes contact with the tripod, you will know to return to standing. Once you are comfortable with the task we will ask you to perform 5 squats in a row while we observe.

The investigators will immediately let you know if you qualify for this research study and will schedule you to return to the Sports Medicine Research Laboratory for the data collection session (outlined below).

DATA COLLECTION SESSION

Prior to testing, measurements such as height and weight will be recorded. These measurements will be followed by motion analysis and the intervention protocol. All movements will be videotaped.

3D Motion Analysis Testing

Prior to completion of analysis, you will be fitted with 3D motion analysis sensors. The sensors will be outlined in permanent marker to ensure the same placement following the intervention.

1. **Single-leg Squat**
   a. You will be asked to stand with feet shoulder distance apart, both hands on hips, and then raise your non-dominant foot about 5-10cm off the ground. While standing on your dominant (kicking) foot, you will squat to 60° of knee flexion, as measured by the investigator. A tripod will be adjusted to the correct height and placed behind you to serve as a guide in order to reach the correct squat depth. When your gluteus maximus (buttock muscle) makes contact with the tripod, you will know to return to standing. Once you are comfortable with the task we will ask you to perform 5 squats in a row while we observe and your movements are recorded.

2. **Double-leg Jump Landing**
   a. The double-leg jump landing task involves a double-leg takeoff and double leg landing, jumping forward from a 30 cm box to the ground and then immediately jumping in the air for maximal height. You will jump down and forwards towards a target that is placed a set distance in front of the box (50% of your height). You
will be instructed to jump onto the force measuring device and immediately recoil and perform a second vertical jump for maximal height. You will perform 5 trials of this task.

3. **Single-leg Land and Cut**
   
a. You will be asked to perform a single leg cut using your dominant leg, starting from behind a 6-inch hurdle placed one foot away from the force measuring device. You will perform a double leg hop over the hurdle to then land on a single leg (dominant) on the force plate before immediately changing direction to cut in the opposite direction at a 45° angle. For example, you would hop over the hurdle pushing off of both feet, land on the right foot and pivot to cut toward the left. You will perform 5 trials of this task.

**Training Intervention**

Following the motion analysis, you will complete Phase I of an ACL injury prevention program called the Performance Enhancement and Kinetic Control (PEAKc) program while receiving instructions from the investigator. The program consists of completing the following exercises:

**Flexibility**

- Dynamic hip adductor stretches
- Dynamic hip flexor stretches
- Dynamic calf/hamstring stretches

**Stability and Strength**

- “L” hop to balance: Begin in SL stance position on right leg. Hop forward and land on right leg. Hop backward landing on right leg at the starting point. Hop sideways to the right landing on right leg. Hop to the left off the right leg, landing on the right leg at the starting point. Repeat 10 times in a row. Repeat on left leg.
- Single leg ball toss: Begin in SL stance on right leg six feet away from research assistant. Toss ball to assistant for 20 tosses. Repeat on left leg.
- Single leg squat: Stand on right leg with right hand on pelvis. Squat down bending at the knee and hip and touch your right foot with your left hand, then return to upright position. Repeat motion standing on left leg with left hand on pelvis, bending at the knee and hip and touch our left foot with your right hand. Repeat 10 times on each leg.

**Plyometric/Agility**

- Squat jump: Begin in a standing position with feet shoulder width apart and hands at sides. Flex at the knees, hips, and trunk and jump upward for maximal vertical height. Land on both feet and hold for two seconds. Perform 10 repetitions.
- Lateral jumps: Begin in SL stance position on right leg. Perform a single leg hop to the left, land on left leg, and immediately hop back to the right leg. Perform 10 repetitions and repeat beginning on left leg, hop to the right, land on right leg, and immediately hop back to the left leg.
• Sideways shuffles: Begin with feet on starting line. Knees and hips should be bent and hands held in front of body. Sideways shuffle to the right, then sideways shuffle to the left back to the starting point. Repeat 10 times.
• High knee skipping: Begin with both feet on starting line. Move forward skipping allowing arms to swing to facilitate momentum.
• Run cuts at 45-degrees: Begin with both feet on starting line. Bend at the knees and hips so upper body leans forward. Sprint forward to the right at 45° angle for about 4 steps, plant outside leg and cut 45° in opposite direction, sprint another 4 steps, plant left leg and cut 45° in opposite direction.

Following the training intervention, a second 3D motion analysis will be completed consisting of the same tasks and procedures as are described above in the 3D motion analysis section.

What are the possible benefits from being in this research study?
Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this research study?
This research study involves squatting, jumping, lunging and cutting tasks that may involve the following risks and/or discomforts to you:

• Possibility of a ligament injury to the joints of your lower extremities.
• Possibility of a muscle strain/pull/soreness in your lower extremities.
• There may be uncommon of previously unknown risks.

You should report any problems to the researcher.

What if we learn about new findings or information during the research study?
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will information about you be protected?
The subjects of this research study will not be identified in any report or publication about this study. Subjects will be assigned an identification number for data collection and all data will be stored on computers in the Sports Medicine Research Lab, which require a password for access. Only members performing research have access to these computers. Data analysis will also be performed on these computers.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for
example, the FDA) for purposes such as quality control or safety.

**What will happen if you are injured by this research?**

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this research study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

**What if you want to stop before your part in the research study is complete?**

You can withdraw from this research study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire research study has been stopped.

**Will you receive anything for being in this research study?**

You will not receive anything for being in this research study.

**Will it cost you anything to be in this research study?**

It will not cost you anything to be in this research study.

**What if you are a UNC student?**

You may choose not to be in the research study or to stop being in the research study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

**What if you have questions about this research study?**

You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the research study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

**What if you have questions about your rights as a research participant?**

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.
**Participant’s Agreement:**

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_________________________________________________  ______________________
Signature of Research Participant                      Date

_________________________________________________
Printed Name of Research Participant

_________________________________________________
Signature of Research Team Member Obtaining Consent  Date

_________________________________________________
Printed Name of Research Team Member Obtaining Consent
APPENDIX 2: SCREENING FORM

Subject ID: _________________________________
Date: ____________________

Single Leg Squat Screening

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulders</td>
<td>Shoulders are not Level</td>
<td>Yes (1)</td>
</tr>
<tr>
<td>Trunk</td>
<td>Trunk is Rotated In (Toward stance leg)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Trunk is Rotated Out (Toward non-stance leg)</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>Hip Hikes on Non-Stance Leg</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Hip Drops on Non-Stance Leg (+Trendelenburg)</td>
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</tr>
<tr>
<td>Femur</td>
<td>Adduction</td>
<td>Yes</td>
</tr>
<tr>
<td>Knee</td>
<td>MKD (Center of Patella Medial to Great Toe)</td>
<td></td>
</tr>
</tbody>
</table>

Total Score: _____ / 5

*MKD automatically qualifies a participant
**2+ other variables qualifies
APPENDIX 3: TASK INSTRUCTIONS

Single-leg Squat Instructions:

Stand with one foot on each force plate with feet shoulder width apart. Place both hands on your hips and keep the foot you would use to kick a soccer ball on the ground while raising the other about 5-10 cm off the ground. Descend into a squat until you feel the tri-pod hit your butt, then return to standing. You will complete three practice trials then complete five testing squats while keeping your hands on your hips and your non-dominant foot raised. Do you have any questions?

(IF they do any of the following during the practice squats correct them: hands come off hips, heel of foot leaves ground, the subject doesn’t touch the tri-pod, and/or they don’t return to upright position.)

Double-leg Jump Landing Instructions:

Come to the front of the box so your toes are on the edge. Jump forward to land with one foot on each of the force plates then immediately jump straight up as high as you can. It’s very important that your feet land fully on the force plates.

(Demonstrate with hand)
You will have three practice trials then complete five testing trials of the jump landing with 30 seconds of rest in between. Do you have any questions?

(IF they do any of the following during the three practice trials correct them: jump off the box from one foot, jump for maximal height off the box rather than jumping forward, and/or their feet don’t land fully on the force plates.)

Single-leg Land and Cut Instructions:

Jump over the hurdle off of both feet. Land on the leg you would kick a soccer ball with and immediately cut hard in the opposite direction at a 45° angle. Take a couple steps after cutting hard away from your landing leg. Be sure your landing foot lands fully on the force plate. Be careful not to step on the force plate when returning to your starting position for the next trial.
You will complete three practice trials then five testing trials of the land and cut with 30 seconds of rest in between. Do you have any questions?

(IF they do any of the following during the three practice trials correct them: jump off of one foot, miss the force plate when they land, and if they do not make a 45° cut or it’s in the wrong direction.)
APPENDIX 4: MODIFIED PEAKC INSTRUCTIONS

PEAK Control
Training Program: Phase 1

Field Set Up

Warm-Up & Flexibility: Phase 1
Athletes line up in 2 single file lines (Line 1 and Line 2). Athletes repeat the exercises in a continuous and controlled manner from the first set of blue cones to red cones. When reaching the red cones, the athlete performs a progressive sprint to second blue cones. Athletes circle the second blue cone and jog back to the starting point.

1. **Left Dynamic Hip Adductor Stretch**: Start with right shoulder facing red cones, lead with right foot, lean toward right leg and hold for 3 seconds, continue to red cone.

2. **Right Dynamic Hip Adductor Stretch**: Start with left shoulder facing red cones, lead with left foot, lean toward left leg and hold for 3 seconds, continue to red cone.

3. **Dynamic Hip Flexor Stretch**: Stride forward with one leg while kneeling with the other leg, hold for 3 seconds, repeat on each leg until reaching red cones.

4. **Dynamic Calf Hamstring Stretch**: Step forward with one leg, place heel on ground, and keep toes pulled up, bend trunk forward while keeping spine straight, repeat on each leg until reaching red cones.

Authored by the UNC - Sports Medicine Laboratory All rights reserved, 2011.
PEAK Control
Training Program: Phase 1

Stability & Strength: Phase 1
Athletes line up across the field with half of the players along the first set of blue cones and the other half along the red cones (facing each other).

5. "L" Hop to Balance: Hop forward and land on right leg. Hop backward and land on right leg. On the right leg hop to the left, then hop to the right. Repeat ten times. Repeat on the left leg in the opposite direction.

6. One-Leg Ball Toss: Split team in half and line up in pairs (~6 feet apart). Single leg balance and toss ball between players for 20 tosses. Repeat on opposite leg.

7. One-Leg Squat: Bend right knees/hips, touch right foot with left hand, return to upright. Repeat 10-15 times on both legs.

8. Hip Bridge: Lift hips unin-lined with trunk and thighs. Hold for 2 seconds, then return hips to ground. Repeat 10-15 times.


10. Side Plank: Maintain position for 30 seconds. Repeat on opposite side.

Plyometric / Agility: Phase 1
Players re-form single file lines and perform exercises in a continuous, but controlled manner as during Warm Up/Flexibility exercises.

11. Squat Jumps: Jump up for max height, land on both feet with a large amount of flexion, hold landing for 2 seconds. Repeat 10-15 times.

12. Lateral Jumps: Single leg, hop to side, land on opposite leg. Immediately hop back to the starting point. Repeat 10-15 times in both directions.

13. Sideways Shuffle: Side shuffle to the right as fast as possible to red cones, jog back to start. Repeat moving to the left.

14. High Knee Skipping: Skip to 50% of maximal height, raise knees high in air, allow upward arms swing. Repeat on each leg until reaching red cones.

15. Run Cuts @ 45-deg: Sprint ~4 steps to right at 45-deg angle, plant outside leg and cut 45-deg in opposite direction. Repeat in both directions until reaching blue cones.

Keep Knees Over Toes
Avoid Straight Leg
Injury Prevention Verbal Instructions Script

You are going to complete Phase I of the Performance Enhancement and Kinetic Control, or PEAK c program. I will instruct you on starting position and completion of each exercise, as well as provide instruction while you are completing each exercise.

Do you have any questions before we begin?

We are going to begin with flexibility.

**Dynamic Hip Adductor Stretches (Right and Left):** Begin with your right shoulder facing the red cone. Lead with right foot, lean toward right leg and hold for three seconds, and continue to the red cone. Jog back to starting cone. Repeat action with left shoulder facing red cone, lead with left foot, lean toward left leg, hold for three seconds, and continue to red cone. Keep toes and hips pointing forward and head and chest up throughout movement. (Subject will be reminded of this as they complete the stretch)

**Dynamic hip flexor stretches (Right and Left):** Begin with both feet on starting line facing red cone. Stride forward with one foot while kneeling with the other leg, you’re your front foot facing forward and knee in line with foot, place hands on pelvis. Glide pelvis forward without arching low back, front knee should bend to 90 degrees. Return to upright position by bringing kneeling leg in line with front foot and repeat on opposite side while moving toward red cones. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching red cone.

**Dynamic calf/hamstring stretches (Right and Left):** Begin with both feet on starting line facing red cone. Step forward with one leg, place heel on ground, keep toes pulled up, bend trunk
forward while keeping back straight, return to upright, and repeat on opposite side. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching red cone.

We will now begin the stability and strength portion of the program.

**“L” hop to balance:** Begin in SL stance position on right leg. Hop forward and land on right leg. Hop backward landing on right leg at the starting point. Hop sideways to the right landing on right leg. Hop to the left off the right leg, landing on the right leg at the starting point. Repeat 10 times in a row. Repeat on left leg.

Subject will receive the following instructions while performing exercise:

- “Land light as a feather”
- “Keep your knee over your toes/Don’t let your knee fall in”
- “Bend at the knee and hip”

**Single leg ball toss:** Begin in SL stance on right leg six feet away from research assistant. Toss ball to assistant for 20 tosses. Repeat on left leg.

Subject will receive the following instructions while performing exercise:

- “Keep your knee over your toes”
- “Keep your toes pointing straight ahead”
- “Keep your trunk centered over your hips”

**Single leg squat:** Stand on right leg with right hand on pelvis. Squat down bending at the knee and hip and touch your right foot with your left hand, then return to upright position. Repeat motion standing on left leg with left hand on pelvis, bending at the knee and hip and touch our left foot with your right hand. Repeat 10 times on each leg.
Subject will receive the following instructions while performing exercise:

- “Keep your toes pointing straight ahead”
- “Keep your knee over your toes”
- “Don’t let your knee fall in”

We will now complete the plyometric and agility portion of the program

**Squat jump:** Begin in a standing position with feet shoulder width apart and hands at sides.

Flex at the knees, hips, and trunk and jump upward for maximal vertical height. Land on both feet and hold for two seconds. Perform 10 repetitions.

Subject will receive the following instructions while performing exercise:

- “Land softly”
- “Land on your toes and bend at the knee and hips”
- “Keep your knees over your toes”
- “Keep your toes pointing straight ahead”

**Lateral jumps:** Begin in SL stance position on your right leg. Perform a single leg hop to the left, land on your left leg, and immediately hop back to the right leg. Perform 10 repetitions and repeat beginning on left leg, hop to the right, land on right leg, and immediately hop back to the left leg.

Subject will receive the following instructions while performing exercise:

- “Land softly”
- “Land on your toes and bend at the knee and hips”
- “Keep your knees over your toes”
- “Keep your toes pointing straight ahead”
**Sideways shuffles:** Begin with both of your feet on starting line facing 90° from the red cone. Knees and hips should be bent and hands held in front of body. Sideways shuffle to the right until blue cone is reached, then sideways shuffle to the left back to the starting point. Repeat 10 times.

Subject will receive the following instructions while performing exercise:

- “Stay low, keep your knees and hips bent”
- “Keep your knees over your toes”
- “Keep your toes pointing straight ahead”

**High knee skipping:** Begin with both feet on starting line facing far, red cone. Move forward skipping allowing arms to swing to facilitate momentum. Continue to far, red cone.

Subject will receive the following instructions while performing exercise:

- “Land softly”
- “Land on your toes, bend at the knee and hip”
- “Keep your toes pointing straight ahead”

**Run cuts at 45-degrees:** Begin with both feet on starting line facing blue cone. Bend at the knees and hips so upper body leans forward. Sprint forward to the right at 45° angle for about 4 steps, plant outside leg and cut 45° in opposite direction, sprint another 4 steps, plant left leg and cut 45° in opposite direction. Continue to far, red cone.

Subject will receive the following instructions while performing exercise:

- “Lean your trunk in the direction you’re cutting”
- “Keep your knees over your toes”
- “Bend at the knee and hip”
You are going to complete Phase I of the Performance Enhancement and Kinetic Control, or PEAK c program. I will instruct you on starting position and completion of each exercise, as well as provide instruction while you are completing each exercise.

Do you have any questions before we begin?

We are going to begin with flexibility.

**Dynamic Hip Adductor Stretches (Right and Left):** Begin with your right shoulder facing the red cone. Lead with right foot, lean toward right leg and hold for three seconds, and continue to the red cone. Jog back to starting cone. Repeat action with left shoulder facing red cone, lead with left foot, lean toward left leg, hold for three seconds, and continue to red cone. Keep toes and hips pointing forward and head and chest up throughout movement. (Subject will be reminded of this as they complete the stretch)

**Dynamic hip flexor stretches (Right and Left):** Begin with both feet on starting line facing red cone. Stride forward with one foot while kneeling with the other leg, you’re your front foot facing forward and knee in line with foot, place hands on pelvis. Glide pelvis forward without arching low back, front knee should bend to 90 degrees. Return to upright position by bringing kneeling leg in line with front foot and repeat on opposite side while moving toward red cones. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching red cone.

**Dynamic calf/hamstring stretches (Right and Left):** Begin with both feet on starting line facing red cone. Step forward with one leg, place heel on ground, keep toes pulled up, bend trunk
forward while keeping back straight, return to upright, and repeat on opposite side. Hold each stretch for three seconds prior to returning to upright position. Repeat until reaching red cone.

We will now begin the stability and strength portion of the program.

“L” hop to balance: Begin in SL stance position on right leg. Hop forward and land on right leg. Hop backward landing on right leg at the starting point. Hop sideways to the right landing on right leg. Hop to the left off the right leg, landing on the right leg at the starting point. Repeat 10 times in a row. Repeat on left leg.

Subject will receive the following instructions while performing exercise:

- “Get balanced as quickly as possible”
- “Push off hard”
- “Quick! Faster!”

Single leg ball toss: Begin in SL stance on right leg six feet away from research assistant. Toss ball to assistant for 20 tosses. Repeat on left leg.

Subject will receive the following instructions while performing exercise:

- “Pass the ball faster”
- “Strong passes”

Single leg squat: Stand on right leg with right hand on pelvis. Squat down bending at the knee and hip and touch your right foot with your left hand, then return to upright position. Repeat motion standing on left leg with left hand on pelvis, bending at the knee and hip and touch our left foot with your right hand. Repeat 10 times on each leg.

Subject will receive the following instructions while performing exercise:

- “Make sure your thigh is parallel to the floor”
We will now complete the plyometric and agility portion of the program

**Squat jump:** Begin in a standing position with feet shoulder width apart and hands at sides. Flex at the knees, hips, and trunk and jump upward for maximal vertical height. Land on both feet and hold for two seconds. Perform 10 repetitions.

Subject will receive the following instructions while performing exercise:
- “Jump as quickly as possible”
- “Power up”
- “Reach higher”
- “Quick/Faster”

**Lateral jumps:** Begin in SL stance position on your right leg. Perform a single leg hop to the left, land on your left leg, and immediately hop back to the right leg. Perform 10 repetitions and repeat beginning on left leg, hop to the right, land on right leg, and immediately hop back to the left leg.

Subject will receive the following instructions while performing exercise:
- “Push off hard”
- “Quick/Faster”
- “Power across”

**Sideways shuffles:** Begin with both of your feet on starting line facing 90° from the red cone. Knees and hips should be bent and hands held in front of body. Sideways shuffle to the right until blue cone is reached, then sideways shuffle to the left back to the starting point. Repeat 10 times.
Subject will receive the following instructions while performing exercise:

- “Shuffle as fast as you can between the cones”
- “Stay low”
- “Quick/Faster”

**High knee skipping:** Begin with both feet on starting line facing far, red cone. Move forward skipping allowing arms to swing to facilitate momentum. Continue to far, red cone.

Subject will receive the following instructions while performing exercise:

- “Skip as high as possible”
- “Power up”
- “Reach higher”

**Run cuts at 45-degrees:** Begin with both feet on starting line facing blue cone. Bend at the knees and hips so upper body leans forward. Sprint forward to the right at 45° angle for about 4 steps, plant outside leg and cut 45° in opposite direction, sprint another 4 steps, plant left leg and cut 45° in opposite direction. Continue to far, red cone.

Subject will receive the following instructions while performing exercise:

- “Make quick cuts”
- “Push off hard”
- “Quick/Faster”
REFERENCES


