Spring 2009

The Effect of Instruction on Jump-Landing Kinematics in Collegiate Age Female Athletes Over Time

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THE EFFECT OF INSTRUCTION ON JUMP-LANDING KINEMATICS IN COLLEGIATE AGE FEMALE ATHLETES OVER TIME

By

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B.S. May 2007, The Pennsylvania State University

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

MASTER OF SCIENCE IN EDUCATION

ATHLETIC TRAINING

OLD DOMINION UNIVERSITY
May 2009

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ABSTRACT

THE EFFECT OF INSTRUCTION ON JUMP-LANDING KINEMATICS IN COLLEGE AGE FEMALE ATHLETES OVER TIME

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The use of verbal and video instruction is a simple feedback tool that can be implemented into almost all clinical rehabilitative and prevention programs. The purpose of this study was to determine whether self or a combination of self and expert feedback will have a long term effect on box-drop jump(BDJ), running-stop jump(RS), and side-step maneuver(SS) lower extremity kinematics (knee flexion, knee valgus, hip flexion, hip abduction) over time in healthy college age female athletes. A repeated measures design was used. Forty-three physically active females (age=21.47±1.55years; height=1.65±0.08m; weight=63.78±12kg) were randomly assigned to three groups; 15 self feedback(S), 15 combo (self and expert) feedback(CB), and 13 control(CT). Subjects performed 5 trials of a box-drop jump for pretest and then received self, combo (self and expert) or no video and verbal feedback about their landing mechanics. Following the intervention, subjects participated in an immediate posttest of 5 trials of the box-drop jump and a transfer test of 5 trials of a running-stop jump. Subjects returned one month later for a retention test consisting of 5 trials of the following: box-drop jump, running-stop jump, and a sidestep maneuver (delayed transfer test). A series of oneway ANOVAs and repeated measures ANOVAs were conducted, with a significance of $p \leq 0.05$ *a priori*. There was a significant feedback group main effect for peak knee flexion during the BDJ and RS, revealing that CB was significantly greater than S

indicating a positive transfer. There was also a significant test time main effect, revealing that hip flexion at PKF and peak knee flexion angles at posttest were significantly greater than pretest. Hip flexion at PKF was significantly greater at retention test compared to posttest, revealing that the task was able to be retained. It appears that BDJ verbal and video feedback involving the combination of self and expert video is effective at improving peak knee flexion angles during a BDJ and RS. Also, global combo feedback can improve large joint movements immediately and over time. Future research needs to focus on improving initial contact kinematics and retention of this learning.

I would like to dedicate the work I have done
to those people in my life who have kept me sane
and helped me through this difficult yet rewarding process.
Mom, Dad, Jamie, all my family, Bryan; to all my friends new and old
and also to those who have played a major role in the development
of this thesis – Jimmy, Bonnie, & Nelson

You all have stood by me, held my hand, and were only a phone call away
as I went through this life experience. Thank you does not begin to
describe how grateful I am for all of your help. I am truly
blessed to have such wonderful people in my life.

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CHAPTER I

INTRODUCTION

The anterior cruciate ligament (ACL) is the primary restraint of anterior tibial translation generated by the quadriceps contraction (Dienst, Burks, & Greis, 2002; Karmani & Ember, 2003; Zantop, Petersen, & Fu, 2005). A growing number of ACL injuries has been shown in a variety of sports, including basketball, soccer, and volleyball (Agel, Arendt, & Bershadsky, 2005; Agel, Evans, Dick, Putukian, & Marshall, 2007; Arendt & Dick, 1995; Dick, Putukian, Agel, Evans, & Marshall, 2007). The ACL is most commonly injured due to a noncontact mechanism (Boden, Dean, Feagin, & Garrett, 2000; Ireland, 1999). It has been shown that up to 72% of ACL injuries are due to a noncontact mechanism (Boden et al., 2000; Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007; Griffin et al., 2000). A noncontact ACL injury typically occurs during activities that include deceleration, jump-landing, and side-stepping (Boden et al., 2000; Cochrane et al., 2007; Griffin et al., 2000).

In addition to the short term consequences of an ACL injury, including surgical repair and an extensive rehabilitation, a serious long term consequence that may result is osteoarthritis (Lohmander, Englund, Dahl, & Roos, 2007; Lohmander, Ostenberg, Englund, & Roos, 2004; Roos, Adalberth, Dahlberg, & Lohmander, 1995). Patients with a knee injury may develop osteoarthritis at a younger age than those who have not had an injury (Roos et al., 1995). A patient with a history of knee injury during their adolescence will have a three times greater risk of osteoarthritis by the age of 65 (Lohmander et al., 2004). Osteoarthritis is characterized by pain and functional impairment, and when present in a younger population can lead to a life-long disability (Lohmander et al., 2007; Lohmander et al., 2004).

Four categories of risk factors have been identified for noncontact ACL injuries. These include anatomical, hormonal, environmental, and biomechanical (Griffin et al., 2000). Biomechanical risk factors include strength, body movement, skill level, and neuromuscular control and can be modified by altering an athlete's body position or increasing strength (Cochrane et al., 2007; Griffin et al., 2000). Lower extremity kinematics are frequently studied during at risk activities, such as landing or decelerating, to find alignments that put the body in an at risk position (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Cochrane et al., 2007; Ford, Myer, Toms, & Hewett, 2005; Hewett et al., 2005; Lephart, Abt, & Ferris, 2002; McLean, Neal, Myers, & Walters, 1999; Yu, Lin, & Garrett, 2006). Common lower extremity alignment seen during noncontact ACL injuries include decreased knee and hip flexion, increased knee valgus, increased hip internal rotation, and decreased hip abduction, and therefore is considered to be an at risk body position (Cochrane et al., 2007; Ireland, 1999; Lephart et al., 2002).

In an attempt to decrease the risk of ACL injury, recent research has focused on instructing athletes on their proper lower extremity alignment during jump-landing activities as-well-as increasing strength and balance (Chimera, Swanik, Swanik, & Straub, 2004; Herman et al., 2008; Hewett, Stroupe, Nance, & Noyes, 1996; Holm et al., 2004; Irmischer et al., 2004). These programs have succeeded in proving that an athlete's biomechanics can be altered, although strength and balance programs have not revealed as much improvement as those that incorporate plyometrics and the use of instruction (McNair, Prapavessis, & Callender, 2000; Wilkerson et al., 2004; Wojtys, Huston, Taylor, & Bastian, 1996). ACL prevention programs have also been created to see if diminishing risk factors actually equates to a reduction in ACL injuries (Mandelbaum et al., 2005; Myklebust et al., 2003; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005; Pfeiffer, Shea, Roberts, Grandstrand, & Bond, 2006; Scase, Cook, Makdissi, Gabbe, & Shuck, 2006). The prevention programs vary, including plyometrics, balance, and instruction, but all focus on improving technique while performing landing or decelerating activities (Mandelbaum et al., 2005; Myklebust et al., 2003; Olsen et al., 2005; Scase et al., 2006). Overall, these prevention programs successfully reduced the number of ACL injuries that occurred during a season, as well as over a two year span (Mandelbaum et al., 2005; Myklebust et al., 2003; Olsen et al., 2005; Scase et al., 2006)

The use of augmented feedback has recently been utilized in an attempt to decrease the biomechanical risk factors associated with ACL injuries (Cowling, Steele, & McNair, 2003; McNair et al., 2000; Onate et al., 2005; Onate, Guskiewicz, & Sullivan, 2001; Prapavessis & McNair, 1999). The use of verbal and video feedback has been shown to decrease ground reaction forces from a box-drop landing. Also, the combination of self and expert video feedback has been shown to improve knee flexion angles at peak knee flexion during a running-stop jump (McNair et al., 2000; Onate et al., 2005; Onate et al., 2001). Although these studies have shown improvements in some lower extremity kinetics and kinematics, further research needs to be conducted to determine a simple, clinical feedback tool that is effective at improving risk factors associated with jump landing activities.

Purpose Statement

The purpose of this study is to determine whether instruction (combo or self) will have a long term effect on box-drop, running-stop jump, and side-step maneuver lower extremity kinematics (knee flexion, knee valgus, hip flexion, hip abduction) over time in healthy college age female athletes.

Research Question

Will the combination of expert and self instructional feedback on jump landing technique have a long-term effect on box-drop, running-stop jump, and side step lower extremity kinematics?

Main Null Hypothesis

There will be no significant difference in lower extremity kinematics (knee flexion, knee valgus, hip flexion, hip abduction) between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, and one month retention test).

The following kinematic changes are expected to be significant at two time instances, initial contact and maximum knee flexion, for all research hypotheses (Chappell et al., 2007; Hewett et al., 2005; McLean, Huang, & van den Bogert, 2005; Pollard, Sigward, & Powers, 2007).

- Greater Knee Flexion
- Less Knee Valgus
- Greater Hip Flexion
- Greater Hip Abduction

Null Hypothesis (Knee Flexion at Initial Contact)

At initial contact, there will be no significant difference in knee flexion between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, and one month retention test).

Null Hypothesis (Knee Valgus at Initial Contact)

At initial contact, there will be no significant difference in knee valgus between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, and one month retention test).

Null Hypothesis (Hip Flexion at Initial Contact)

At initial contact, there will be no significant difference in hip flexion between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, and one month retention test).

Null Hypothesis (Hip Abduction at Initial Contact)

At initial contact, there will be no significant difference in hip abduction between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, and one month retention test).

Null Hypothesis (Maximum Knee Flexion)

There will be no significant difference in maximum knee flexion between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, one month retention test).

Null Hypothesis (Knee Valgus at Maximum Knee Flexion)

At maximum knee flexion, there will be no significant difference in knee valgus between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, one month retention test).

Null Hypothesis (Hip Flexion at Maximum Knee Flexion)

At maximum knee flexion, there will be no significant difference in hip flexion between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, one month retention test).

Null Hypothesis (Hip Abduction at Maximum Knee Flexion)

At maximum knee flexion, there will be no significant difference in hip abduction between feedback groups (combo, self, control) when performing jump-landing tasks (box-drop jump, running-stop jump, side step maneuver) measured over time (pretest, immediate posttest, one month retention test).

Research Hypothesis 1

At initial contact and maximum knee flexion during immediate posttest measurements, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) while performing the box-drop task (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 2

At initial contact and maximum knee flexion during one month retention test measurements, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) while performing the box-drop task (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 3

At initial contact and maximum knee flexion, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) when performing the box-drop task measured over time (pretest, immediate posttest and one month retention test) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 4

At initial contact and maximum knee flexion, both feedback groups (combo and self) will have significant kinematic changes when compared to the control group while performing the box-drop task over time (pretest, immediate posttest, one month retention test) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 5

At initial contact and maximum knee flexion during immediate posttest measurements, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) while performing the initial transfer test (running-stop jump) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 6

At initial contact and maximum knee flexion during one month retention test measurements, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) while performing the initial transfer test (running-stop jump) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 7

At initial contact and maximum knee flexion, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) when performing the initial transfer test (running-stop jump) over time (immediate posttest and one month retention test) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 8

At initial contact and maximum knee flexion during immediate posttest and one month retention test measurements, both feedback groups will have significant kinematic changes when compared to the control group while performing the initial transfer test (running-stop jump) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 9

At initial contact and maximum knee flexion during one month retention test measurements, the combo feedback group will have significant kinematic changes when compared to other feedback groups (self and control) when performing the delayed transfer test (side-step maneuver) (Cowling et al., 2003; Onate et al., 2005).

Research Hypothesis 10

At initial contact and maximum knee flexion during one month retention test measurements, both feedback groups will have significant kinematic changes when compared to the control group while performing the delayed transfer test (side-step maneuver) (Cowling et al., 2003; Onate et al., 2005).

Independent Variables

The independent variables of this study include feedback groups (3), testing time (3), and task (3). The feedback group has three levels which includes combo, self, and control. The testing time has three levels consisting of pretest, immediate posttest, and one month retention test. The task has three levels which includes box-drop jump, running-stop jump, and side-step maneuver.

Dependent Variables

The dependent variables for this study are knee and hip kinematics at initial contact and maximum knee flexion. This includes knee flexion, knee valgus, hip flexion, and hip abduction angles.

Operational Definitions

1. Healthy Recreational Female Athletes – College age female athletes (between ages 18 and 25) that exercised a minimum of three times per week for a minimum of 20 minutes.
2. Self Feedback Group – The self feedback group viewed the first four of five trials of their own videotaped box-drop jump trials (Onate et al., 2005).
3. Combo Feedback Group – The combo feedback group viewed two videotaped trials of an expert performing a box-drop jump and then their first two trials of their own videotaped box-drop jump trials (Onate et al., 2005).
4. Control Group – The control group did not receive any form of instruction on landing technique.

5. Dominant Leg – The dominant leg was determined by asking the subjects which leg they would choose to kick a ball as far as possible (Hewett et al., 2005; Van Lunen, Roberts, Branch, & Dowling, 2003).
6. Box-drop Task – The box-drop task consisted of subjects dropping from a 30-cm high box, landing with each foot on the corresponding 40cm x 60cm force plates, and immediately jumping upward for maximal jump height. (Fagenbaum & Darling, 2003; Nagano, Ida, Akai, & Fukubayashi, 2007).
7. Running-Stop Jump – A three to four step approach run at a minimum speed of 3 m/s, landing with each foot on the corresponding force plate. After making contact with the force plate they immediately jumped up for maximum height (Cowling et al., 2003).
8. Side-Step Maneuver – A sidestep cutting maneuver consisted of a forward run at a ca minimum speed of 3 m/s, and then a side step or change of direction of approximately 45 degrees to the opposite side of the contact foot. The contact foot was the subject's dominant leg (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Huang et al., 2005; McLean et al., 1999; Sigward & Powers, 2007).
9. Retention Test – A retention test is a test that a learner performs, of a practiced skill, after a period of time of no practice (Magill, 2004).
10. Transfer Test – A test in which a person performs a skill that has similar components of a skill he or she practiced (Magill, 2004). It is designed to see if the original task transfers over to other sport specific tasks.

11. Initial Contact – The point at which vertical ground reaction forces exceed 10 N (Borotikar, Newcomer, Koppes, & McLean, 2008; Yu et al., 2006).
12. Landing Error Scoring System (LESS) – The LESS is a qualitative assessment tool used for identifying potentially faulty movement patterns and poor technique during a jump-landing task, in which a sagittal plane camera and a frontal plane camera capture the jump-landing movement. An investigator then reviews the footage and scores the jump-landing based on the criteria of the LESS (Boling, Thigpen, Padua, & Marshall, 2005; Padua, Marshall, Beutler et al., 2004; Padua, Marshall, Onate et al., 2004). High scores are considered poor (Appendix 2).

Assumptions

1. The testing equipment (VICON – 3D Motion Analysis) used was reliable and valid.
2. All participants of the study complied with the guidelines set forth in the pre-participation agreement. This includes that they would not discuss which form of instruction they were assigned with other participants or receive outside instruction on proper cutting biomechanics while taking part in the study.
3. Participants had previously learned and executed all three jump-landing tasks while involved with recreational athletics.
4. Modeling cues were solely responsible for immediate posttest and one month retention test results; no external factors were involved.

5. There was a minimal practice effect from the testing sessions on knee and hip kinematic (knee flexion, knee valgus, hip flexion, hip abduction) values.
6. The clothing or type of sneakers worn by the subjects did not significantly influence the results of the study.

Limitations

1. The box-drop jump, running-stop jump, and side-step maneuver used to evaluate knee and hip kinematics did not simulate real game like speed or variety.
2. The population was not randomly selected due to the availability of subjects; it was a sample of convenience.
3. Athletic shoes worn were not standardized across the subjects.

Delimitations

1. This study was delimited to healthy female recreational and varsity athletes who were 18 to 25 years old. These athletes exercised a minimum of three times per week for a minimum of 20 minutes. They did not have a history of lower extremity injury in the past two months that limited them from activity for more than one day, no current self-reported history of lower extremity instability, or history of any lower extremity surgery within the past two years. To participate, subjects also had no history of ACL injury or reconstructive surgery. Subjects could have no history of jump-landing technique training.

CHAPTER II

REVIEW OF LITERATURE

The following is a review of literature of the risk associated with anterior cruciate ligament (ACL) injury and the relationship between the kinematics of the knee and hip, jump landing tasks, and intervention programs. With the increasing rate of ACL injuries among a young female athletic population, a growing amount of research has been devoted to not only identifying risk factors associated with the injury but has now turned to preventing this injury. There is a need for the identification of a clinically helpful, evidence based tool to easily instruct athletes on proper landing technique. Clinical screening and prevention of ACL injuries is the next step in reducing the growing number of ACL injuries. A number of studies have determined that biomechanical risk factors can be altered through the use of instruction, strength, plyometric, and balance training. The implementation of these strategies may be used in a warm-up, preseason, or in addition to regular training regimens. Although the use of instruction has been found to be effective in changing an athlete's biomechanics, it has largely been used in combination with other interventions to reduce injuries. Few researchers have evaluated how individual instructions influence lower extremity kinematics and the retention of these changes past the initial instruction.

Anatomy of Anterior Cruciate Ligament

The ACL is one of two important cruciate ligaments of the knee. The ACL's primary purpose is to prevent anterior tibial translation relative to the femur (Dienst et al., 2002; Karmani & Ember, 2003; Zantop et al., 2005). It is the only structure in the knee that prevents this translation generated by the quadriceps contraction and external forces producing joint compressive loads (Dienst et al., 2002; Karmani & Ember, 2003). The ACL also acts as a secondary restraint to internal rotation of the weightbearing and non-weightbearing knee (Dienst et al., 2002; Zantop et al., 2005). As a restraint for internal rotation, it helps guide the screw-home mechanism (Karmani & Ember, 2003). The screw-home mechanism involves a coupled internal tibial rotation as the femur flexes and external tibial rotation as it extends (Moglo & Shirazi-Adl, 2005).

The typical attachment of the ACL runs from the posterior, medial portion of the lateral femoral condyle to a fossa between the medial and lateral tibial spine (Dienst et al., 2002; Karmani & Ember, 2003; Zantop et al., 2005). The tibial attachment fans out to form a "foot" region, which allows the ACL to tuck under the roof of the intercondylar notch. When the knee is in full extension the anterior fibers of the ACL then turn around the anterior edge of the intercondylar notch (Zantop et al., 2005). In order to attach to the tibia, some fibers of the ACL must pass beneath the transverse meniscal ligament. As this occurs, a few fibers attach to the anterior and posterior horns of the lateral meniscus (Dienst et al., 2002; Karmani & Ember, 2003).

Most researchers agree that the ACL can be divided into two bundles, or bands, called the anteromedial (AMB) and the posterolateral (PLB) bundles. Some researchers include a third bundle called the intermediate, but it can only be identified in some specimens and therefore is included with the AMB (Dienst et al., 2002; Karmani & Ember, 2003; Takahashi, Doi, Abe, Suzuki, & Nagano, 2006). The anteromedial bundle originates from the posterior and proximal aspect of the femoral attachment and inserts into the anteromedial tibial attachment. The posterolateral bundle originates at the distal femoral attachment and inserts into the posterolateral tibial attachment (Dienst et al., 2002; Karmani & Ember, 2003; Zantop et al., 2005). When the knee is extended the PLB becomes tight where the AMB is moderately lax. As the knee flexes, the PLB becomes lax and the AMB is now taut (Dienst et al., 2002; Karmani & Ember, 2003; Zantop et al., 2005). When the knee is in extreme flexion, the femoral attachment of the ACL becomes more horizontally oriented resulting in almost all the fibers becoming parallel. This parallel orientation of fibers is considered the resting position of the ACL (Karmani & Ember, 2003).

Epidemiology of Anterior Cruciate Ligament Injuries

The Injury Surveillance System (ISS) was developed by the NCAA in 1982 to help track injuries in a wide variety of collegiate sports. It was not until 1989, however, that they added the option of identifying individual structures in the knee that were injured (Mihata, Beutler, & Boden, 2006). Also, in 2003 there was an addition of the mechanism of injury for ACL injuries. All of these changes have allowed for more detailed and accurate documentation and analysis of injuries (Mihata et al., 2006). Since 1989, a series of articles have been published over this 15 year period evaluating the incidence of knee injuries, particularly ACL injuries, in participating NCAA sports.

A five year review conducted by Arendt and Dick reported the incidence of knee injuries in basketball and soccer from 1989 to 1993 (Arendt & Dick, 1995). It was found that women, regardless of the sport, had a greater rate of ACL injuries. In soccer, they were over two times more likely to injure their ACL than men, and in basketball women were over four times more likely to injure their ACL than men. Also, the most common mechanism of injury regardless of sport for women was "no apparent contact" where as men had a greater rate of player contact as the mechanism of injury (Arendt & Dick, 1995). In a 13 year follow-up review of data, the rate of ACL injuries for male and female basketball and women's soccer all remained stable over the years (Agel et al., 2007). Regardless of the sport, females still continued to have a greater rate of ACL injury and non-contact was the primary mechanism of injury; an average of 67% of female ACL injuries were noncontact and 58% of male ACL injuries were noncontact (Agel et al., 2007). Finally, Hootman et al. examined injury trends in 15 sports over 15 years and found that 50% of all reported injuries were to the lower extremity with the knee and ankle accounting for the majority (Hootman, Dick, & Agel, 2007). Of the four sports with the highest ACL injury rate, three of them were women's sports. These include gymnastics, basketball, and soccer; football was the fourth sport. Their findings were consistent with past studies, citing that the ACL injury rate was steady and only rising 1.3% average annually. Although ACL injuries only accounted for 3.5% of all injuries, 88% of them required 10+ days of time loss (Hootman et al., 2007).

Through all of these studies mentioned, and many more that have analyzed the ISS data, it has been found that female athletes over the past 15 years have continued to have a greater rate of ACL injuries than males in similar sports (Agel et al., 2005; Agel et al., 2007; Arendt & Dick, 1995; Dick et al., 2007; Hootman et al., 2007; Mihata et al., 2006). Some researchers have suggested that this may be due to females playing organized sports for a shorter time and are less fit than males (Arendt & Dick, 1995). However, current research shows that females are now participating in sports at a younger age and have increased fitness levels and yet no downward trend in ACL injury among females has been observed (Ireland, 1999; Leininger, Knox, & Comstock, 2007; Mihata et al., 2006).

It has also been found that over the past 15 years the two sports in which ACL injuries are more common are soccer and basketball (Agel et al., 2005; Agel et al., 2007; Arendt & Dick, 1995; Dick et al., 2007; Hootman et al., 2007; Majewski, Susanne, & Klaus, 2006; Mihata et al., 2006; Mountcastle, Posner, Kragh, & Taylor, 2007). In games, soccer participants are nine times more likely to injure their ACL than in practices and basketball participants are three times more likely to injure their ACL than in practices (Arendt & Dick, 1995). Over a 15 year period it was found that the rate of ACL injuries in soccer was 3 times higher for women than men (Mihata et al., 2006). Over this same 15 year period, in basketball the rate of ACL injury in women was 4 times higher than men (Mihata et al., 2006).

With the majority of ACL injuries occurring in a young, athletic population, many athletes opt to have ACL reconstruction; ACL reconstruction is effective in creating a stable knee which allows athletes to return to their previous level of competition (Bonsell, 2000). In 2006, it was estimated that the annual health care cost of ACL injuries was approximately $625 million dollars (Hewett, Ford, & Myer, 2006). Although surgical reconstruction has been found to be more expensive than a non-operative treatment, the quality of life improvement makes it a more effective treatment option (Gottlob, Baker, Pellissier, & Colvin, 1999). When comparing the two autograft options, hamstring tendon and bone-patellar-bone, the bone-patellar-bone surgery cost $1,015 significantly more than the hamstring tendon surgery (Bonsell, 2000). Also when comparing the cost of an autograft versus an allograft, the autograft had a significantly greater operation cost than the allograft (Cole et al., 2005).

In addition to the financial cost of an ACL injury, other short-term consequences may include emotional burden and identity loss, potential loss in participation of entire seasons, and a reduction in academics (Freedman, Glasgow, Glasgow, & Bernstein, 1998; Hewett et al., 2006). Long-term consequences may also result from ACL injury. Osteoarthritis (OA) is a painful, life-long disability that is normally present in an older population (Lohmander et al., 2007; Lohmander et al., 2004; Roos et al., 1995). It is characterized by varying degrees of osteophyte formation and a loss of articular cartilage in synovial joints (Lohmander et al., 2007). If a knee injury occurs at a young age, a person's risk of developing knee OA by the age of 65 increases threefold (Lohmander et al., 2007). Roos et al. have found that patients with an isolated or combined ACL tear show radiologic signs of OA at a younger age than those with only a meniscus tear (Roos et al., 1995). The first radiographic signs of OA have been shown to appear as early as 10 years after the trauma occurred, with patients of an ACL injury showing early stage changes at a mean age of 40 years (Lohmander et al., 2007; Roos et al., 1995).

Mechanism of Injury of Anterior Cruciate Ligament

There are two types of ACL injuries, contact and noncontact. The noncontact mechanism has been recorded as accounting for 56 to 72% of ACL injuries, with the contact mechanism accounting for the remaining 28 to 32% (Boden et al., 2000; Cochrane et al., 2007). Contact injuries occur due to a direct force to the body while participating in a sport or recreational activities. The most common situation in which a contact ACL injury occurs is when a direct force is applied to the lateral aspect of the leg or knee causing a valgus collapse (Boden et al., 2000). Other mechanisms may include a direct force while changing direction or decelerating and a direct force that causes a hyperextension of the knee (Boden et al., 2000).

Noncontact ACL injuries are more frequently reported than noncontact ACL injuries (Boden et al., 2000; Cochrane et al., 2007; Ireland, 1999). The situations in which noncontact ACL injuries commonly occur are jump landing tasks or decelerating tasks (Boden et al., 2000; Cochrane et al., 2007). When analyzing videotapes of ACL injuries it was found that 47.4% of the noncontact injuries during jump landing tasks gave way in the valgus direction and 42.1% of the noncontact injuries gave way in the internal direction (Cochrane et al., 2007). When observing non-landing noncontact ACL injuries, 70% occurred when the athlete was decelerating, while only 30% occurred when accelerating (Cochrane et al., 2007).

Lower extremity alignment that is commonly seen during a noncontact ACL injury includes hip internal rotation and adduction, knee valgus, and tibia external rotation on a pronated foot. A decrease in hip and knee flexion are also observed right before failure of the ACL (Ireland, 1999). In a study conducted by Cochrane et al. it was observed that 91.7% of all noncontact ACL injuries occurred at initial foot contact with all noncontact ACL injuries having a knee flexion angle of 30 degrees or less (Cochrane et al., 2007).

Risk Factors of Anterior Cruciate Ligament Injuries

A number of potential risk factors have been identified for noncontact ACL injuries. These risk factors can be classified into four main categories. These include anatomical, hormonal, environmental, and biomechanical risk factors (Griffin et al., 2000). An alternative way of classifying ACL risk factors is modifiable and nonmodifiable, or intrinsic and extrinsic (Anderson, Dome, Gautam, Awh, & Rennirt, 2001; Orchard, Seward, McGivern, & Hood, 2001). Intrinsic factors include ligament laxity, hormones, and anatomical measurements such as femoral notch width. Extrinsic factors are those that are outside of the body, such as weather, training regimen, and biomechanics (Anderson et al., 2001; Orchard et al., 2001).

Anatomical

An anatomical risk factor is an alignment or characteristic of the body that puts an individual at an increased risk for ACL injury (Anderson et al., 2001; Griffin et al., 2000; Orchard et al., 2001). Some studies and researchers also classify anatomical risk factors as intrinsic risk factors or nonmodifiable factors (Anderson et al., 2001; Uhorchak et al., 2003). Examples of anatomical risk factors include knee or hip angle, lower extremity alignments, joint laxity, femoral notch width, and ACL width (Anderson et al., 2001; Bonci, 1999; Griffin et al., 2000; Ireland, Ballantyne, Little, & McClay, 2001; Uhorchak et al., 2003).

One anatomical risk factor that has frequently been studied is the femoral notch and its associated width. Regardless of shape or gender, smaller or narrower notch width indices were found in ACL injured athletes when compared to non-injured ACLs (Ireland et al., 2001; Uhorchak et al., 2003). As males' height increase so does their notch size and size of ACL. However, as females' height increases their notch size and ACL size do not (Anderson et al., 2001). The size of the ACL, however, does not predict the size of the intercondylar notch (Anderson et al., 2001).

Lower extremity alignments may also play a role in an increased risk for ACL injury, however many of them have not been researched as much as femoral notch width or ACL size (Griffin et al., 2000). Excessive foot pronation may contribute by preloading the ACL. If the foot remains in an excessive pronated position past the first half of the stance phase then the tibia undergoes additional internal rotation. When the tibia internally rotates, the ACL tightens and the excessive pronation produces forces up through the kinetic chain (Bonci, 1999). Therefore, the ACL is preloaded and already in a compromised position (Bonci, 1999). Genu recurvatum, or knee hyperextension, may also place extra strain on the ACL with each degree of deformation (Bonci, 1999). In addition to placing strain on the ACL, genu recurvatum can indicate joint laxity in an individual (Bonci, 1999).

Regardless of whether these anatomical risk factors significantly predict a greater risk of ACL injury, none of them can be modified to reduce this risk. A person cannot change the size of their ACL or the width of their intercondylar notch. Also, no anatomical risk factor has been directly correlated to an increase risk of ACL injury (Griffin et al., 2000). Therefore, these risk factors may be useful in identifying an at risk individual, but do not provide any information on how to reduce this risk.

Hormonal

In 1996, a study by Liu et al found that receptor sites for estrogen and progesterone were present in the ACL (Liu et al., 1996). Since then, much research has been devoted to finding the role of estrogen and progesterone on the ACL. Some researchers have found that sex hormones can influence the mechanical properties of the ACL (Liu et al., 1996). However, it is still unclear if hormone fluctuation during the menstrual cycle leads to an increased rate of ACL injury. Hormonal risk factors, like anatomical, are also considered intrinsic or nonmodifiable because even if estrogen does play a role in the risk of ACL injury, very little can be done to eliminate this risk (Anderson et al., 2001; Uhorchak et al., 2003). Although some argue that hormones can be modified through the use of oral contraceptives, particularly estrogen, it is still unclear if this modification is effective in reducing the risk of an ACL injury (Chaudhari et al., 2007; Martineau, Al-Jassir, Lenczner, & Burman, 2004).

There is currently conflicting conclusions as to the actual role of estrogen and ACL injury (Griffin et al., 2000). Slauterbeck et al. found that the load at failure of a ligament was significantly less in rabbits who had increased levels of circulating estrogen than those who did not, suggesting that estrogen may alter ligament strength (Slauterbeck, Clevenger, Lundberg, & Burchfield, 1999). In contrast, Chaudhari et al. concluded that neither hormonal cycling nor oral contraceptives were significant in the loading of the knee or hip in three jumping activities (Chaudhari et al., 2007).

In respect to ACL laxity, Martineau et al. found that the use of oral contraceptives significantly decreased knee laxity and in-turn may decrease the risk of ACL injury (Martineau et al., 2004). In addition, Van Lunen et al. found that the amount of laxity of the ACL did not change between the phases of the menstrual cycle, including the follicular, near-ovulation, and midluteal phases (Van Lunen et al., 2003). It appears that during passive and active displacement, athletes have significantly less knee joint laxity than non-athletes (Bowerman, Smith, Carlson, & King, 2006).

Environmental

A third category of risk factors related to ACL injury is environmental risk factors (Anderson et al., 2001; Griffin et al., 2000; Milburn & Barry, 1998; Orchard, Seward, McGivern, & Hood, 1999). Environmental risk factors are considered extrinsic factors because they are not within the body (Anderson et al., 2001; Orchard et al., 2001). Examples of environmental risk factors include equipment involved with the sport, shoe-surface interactions, and climate issues (Anderson et al., 2001; Milburn & Barry, 1998; Orchard et al., 1999).

Weather conditions have been found to influence the rate of ACL injury (Griffin et al., 2000; Orchard et al., 1999, 2001). There appears to be a relationship between drier playing surfaces and the rate of ACL injuries (Agel et al., 2005; Griffin et al., 2000; Orchard et al., 2001). Long term weather conditions, including rainfall and water evaporation, of a region have been found to be more relevant to the amount of injuries that occur than the short term, day before, weather conditions (Orchard et al., 1999). Therefore in sports such as soccer, higher rainfall and low water evaporation may significantly decrease the risk of noncontact ACL injuries (Orchard et al., 1999).

One reason to explain why drier conditions may increase the risk of ACL injury is the drier surface conditions increases the friction between the shoe-surface interaction (Griffin et al., 2000; Milburn & Barry, 1998; Orchard et al., 2001). Too little or too much friction between the shoe and surface may cause injury (Milburn & Barry, 1998). If the resistance is too low it may cause slipping too occur and therefore may cause injuries (Milburn & Barry, 1998). If the friction is too high, however, it will cause more acute injuries due to the excessive loads and force transmission on the leg (Milburn & Barry, 1998; Orchard et al., 2001). Although a higher level of friction is sometimes associated with better sport performance it is also associated with a higher risk of injury (Griffin et al., 2000).

Biomechanical

Finally, biomechanical risk factors can include muscular strength, body movement and forces, skill level, muscular activation, and neuromuscular control (Bonci, 1999; Cochrane et al., 2007; Griffin et al., 2000; Lephart et al., 2002). These risk factors are also considered extrinsic or modifiable factors, in which most can be changed more easily than the other three categories (Anderson et al., 2001; Uhorchak et al., 2003). Kinematics, kinetics, and muscle activation are all interrelated in the fact that if a joint angle is increased or decreased the forces and muscle activation times at that joint are also changed. Kinematics is the description of motion without concern of the force or cause of the motion (McGinnis, 1999). One of the most frequently studied kinematics is knee flexion angle and its relationship to ACL injury (Griffin et al., 2000; Lephart et al., 2002). On average the knee flexion angle at the time of an ACL injury has been found to be 22 degrees, although we do not know the exact degree at which injury can occur (Lephart et al., 2002). A decreased knee flexion angle while landing causes the hamstrings to be less effective in protecting the ACL from anterior tibial translation caused by the quadriceps exerting maximal anterior shear force at the small knee flexion angle (Cochrane et al., 2007; Griffin et al., 2000). Kinetics is defined as the role of force as a cause of motion (McGinnis, 1999). A decrease in knee flexion also leads to an increase in ground reaction forces, increasing the risk of injury (Cochrane et al., 2007).

An imbalance between the strength of the hamstrings and quadriceps, known as the hamstring-to-quadriceps ratio, is also a likely risk factor for ACL injuries (Anderson et al., 2001; Bonci, 1999; Bowerman et al., 2006; Lephart et al., 2002). The hamstrings counteract the force created by the quadriceps, compress the joint, and help reduce anterior tibial translation (Bowerman et al., 2006; Hewett, 2000). All of these functions decrease anterior shear forces, which in turn reduces the load on the ACL, playing a key role in preventing ACL injuries (Hewett, 2000). Athletes have been found to be 1.6 times more likely to injure their ACL if their hamstring-to-quad ratio is less than 0.75 (Bonci, 1999). Females have been found to have significantly lower hamstring-to-quadriceps muscle ratio than males, indicating that their hamstrings are weaker than males even when adjusted for body weight (Anderson et al., 2001). It has been proposed that an athlete could be predisposed to an ACL injury if their hamstring-to-quadriceps ratio is lower than 0.60 (Hewett, 2000).

Kinematics of Jump Landing Tasks

Due to the biomechanical risk factor being the only risk factor that can be easily modified, recent investigation and research has focused on lower extremity kinematics, kinetics, and muscle activation in hopes that it will reveal at-risk positions for ACL tears (Landry, McKean, Hubley-Kozey, Stanish, & Deluzio, 2007; Malinzak et al., 2001; Sigward & Powers, 2006; Yu et al., 2006). By identifying at risk positions and factors that contribute to ACL injury, athletes may be able to change their biomechanics and in turn reduce their risk of injury. The most common kinematics investigated include knee flexion, knee valgus, hip flexion, hip abduction, and hip internal rotation angles (Chappell, Yu, Kirkendall, & Garrett, 2002; McLean, Huang et al., 2005; Salci, Kentel, Heycan, Akin, & Korkusuz, 2004; Yu et al., 2005).

A large amount of research has focused on the kinematics of athletes while decelerating and performing jump-landing activities, due to its relationship as a common mechanism of injury for noncontact ACL injuries (Ford, Myer, & Hewett, 2003; McLean et al., 1999; Pollard, Heiderscheit, van Emmerik, & Hamill, 2005; Yu et al., 2006).

Initial contact and maximum knee flexion have been used as two points in which lower extremity kinematics can be evaluated (Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; James, Sizer, Starch, Lockhart, & Slauterbeck, 2004; Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007). It is believed that when injuring the ACL, the angle of the knee just prior to injury is an important factor (Cochrane et al., 2007). The maximum knee flexion angle is also an important factor in the injury of the ACL because if an athlete remains in an extended knee position throughout the duration of a landing their chances of an ACL injury are greatly increased (Boden et al., 2000; Cochrane et al., 2007; Ireland, 1999). Therefore maximum knee flexion is also a valuable reference point in many studies.

Knee Flexion at Initial Contact/Maximum Knee Flexion

Decreased knee flexion during jump landing tasks has been shown to increase proximal tibial anterior shear force which contributes to anterior tibial translation and in turn places excessive strain on the ACL (Chappell et al., 2007; Sell et al., 2007). The ACL acts as the primary restraint of anterior tibial translation from 0 to 90 degrees of flexion (Moglo & Shirazi-Adl, 2003). Along with the ACL, the hamstrings act as a restraint for anterior tibial translation; however, if the knee flexion angle is too small the line of pull of the hamstrings is inadequate to resist the increased force produced by the quadriceps (Hirokawa & Tsuruno, 2000; Kirkendall & Garrett, 2000; Lephart et al., 2002). When the knee flexion angle is less than 20 degrees, the amount of anterior tibial force is at its greatest placing dangerous loads on the ACL (Lephart et al., 2002; Markolf et al., 1995). Therefore to reduce ACL loading, knee flexion angles during jump landing tasks must be increased.

Females tend to have smaller knee flexion angles when performing jump landing and decelerating activities, such as a running stop jump or side-step cut (Chappell et al., 2007; Chappell et al., 2002; Chaudhari et al., 2007; Decker et al., 2003; Malinzak et al., 2001; McLean, Walker, & van den Bogert, 2005; Salci et al., 2004; Yu et al., 2006; Yu et al., 2005). These females range from youth to collegiate age athletes, and may be recreational or collegiate athletes (Chappell et al., 2002; Decker et al., 2003; Malinzak et al., 2001; McLean, Walker et al., 2005; Salci et al., 2004; Yu et al., 2005). When comparing male and female landing techniques females have been found to land with 5 to 8 degrees of less knee flexion compared to males (Chappell et al., 2007; James et al., 2004; Malinzak et al., 2001). When dropping from a height of 40 cm, men land with almost two times greater knee flexion at initial contact than females (Huston, Vibert, Ashton-Miller, & Wojtys, 2001).

At initial contact, decreased knee flexion angles have been found in a variety of populations including volleyball, soccer, and basketball (Decker et al., 2003; James et al., 2004; McLean, Walker et al., 2005; Pappas et al., 2007; Yu et al., 2006; Yu et al., 2005). Yu et al. (2005) found that at initial contact and maximum knee flexion age and gender significantly affected the knee flexion angle when comparing male and female youth recreational soccer players performing a stop-jump. Male subjects' knee flexion angle remained the same as age increased, but females' knee flexion angle decreased as age increased (Yu et al., 2005). Specifically, at age 12 there was a significant difference in knee flexion angle when comparing gender. At age 14 this difference appeared to become even more prominent (Yu et al., 2005).

Some studies have also evaluated maximum knee flexion during jump landing tasks and have found that a gender difference also exists (James et al., 2004; McLean et al., 1999; Pappas et al., 2007; Yu et al., 2005). It appears that when females land in an extended position they tend to maintain that extended position throughout all of the loading phase (James et al., 2004). In conjunction with maintaining an extended knee position throughout landing, females also achieve maximum knee flexion at a faster rate (McLean et al., 1999). Men achieved maximum flexion significantly later in the stance phase and therefore may spend more time controlling the knee than women (McLean et al., 1999).

A change in direction or the direction of a jump following the landing phase of a stop-jump can also significantly affect the knee flexion angle (Sell et al., 2006). When jumping medially from the stance leg, the maximum knee flexion angle has been found to be significantly less than a vertical jump (Sell et al., 2006). In addition to a smaller knee flexion angle, a greater knee valgus and proximal anterior tibia shear force are also associated with jumping to the medial aspect of the stance leg (Sell et al., 2006).

In contrast to the majority of studies, Fagenbaum et al. (2003) found that while performing a single leg drop landing women landed with approximately 10 to 14 degrees of greater knee flexion at initial contact than men (Fagenbaum & Darling, 2003). Women were also found to land with greater knee flexion acceleration than men. Because females landed with greater knee flexion angles, an increased acceleration in the flexion direction, and had similar hamstring activation levels as men it was determined that women would be less likely to injure their ACL during a jump landing task (Fagenbaum & Darling, 2003). One major limitation to this study that may have influenced the data is that the sample size was low and not randomized. All subjects were from the same institution and may have already shared similar landing technique training (Fagenbaum & Darling, 2003). This may be one reason that explains the contradicting findings to other studies.

Knee Valgus at Initial Contact/Maximum Knee Flexion

An increase in knee valgus angle may also significantly increase the risk of noncontact ACL injuries (Bendjaballah, Shirazi-Adl, & Zukor, 1997; Chaudhari & Andriacchi, 2006). It has been shown that a shift as small as two degrees from neutral alignment toward valgus can reduce the injury threshold of the ACL; this means that even the slightest valgus position places the ACL at an increased risk of injury (Chaudhari & Andriacchi, 2006). When a valgus position is combined with anterior tibial force of the knee, it produces the highest amount forces through the ACL (Markolf et al., 1995). Increased activity in the lateral musculature of the thigh has also been associated with increased knee valgus angles (Palmieri-Smith, Wojtys, & Ashton-Miller, 2007). This valgus position is due to the medial musculature's inability to offset the larger activity of the lateral musculature, producing an abducted knee (Palmieri-Smith et al., 2007). The valgus moment of the knee is also increased during a side-step cut when the torso leans in the opposite direction of the cut and the stance foot is placed wide or away from the body (Dempsey et al., 2007).

Females tend to display a greater amount of knee valgus during landing tasks than males (Chappell et al., 2002; Ford et al., 2003; Ford et al., 2005; Malinzak et al., 2001; McLean, Huang et al., 2005; Sigward & Powers, 2007; Yu et al., 2005). Women also tend to have a greater maximum knee valgus angle on their dominant side than males

(Ford 2003). In a study comparing three different athletic tasks, Malinzak et al. found that females were consistently in valgus through the entire movement for all three tasks (Malinzak et al., 2001). In particular, they found that women had 11 degrees more valgus at their knee than males (Malinzak et al., 2001). This is a very significant difference when considering that even a small difference of 2.4 degrees of increase in knee valgus can increase the tensile forces of the ACL by more than threefold (Bendjaballah et al., 1997). Females also display a significantly greater maximum knee valgus angle on their dominant leg compared to males (Ford 2003).

When performing specific jump landing tasks, the knee at initial contact tends to be in a greater valgus position (Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Ford et al., 2003; Ford et al., 2005; Hewett et al., 2005; McLean, Walker et al., 2005; Yu et al., 2005). Specifically, both soccer and basketball players have been found to have a greater knee valgus angle when performing a side step cut compared to a drop vertical jump (Cowley et al., 2006). During sidestepping, the peak knee valgus moment has been found to be dependent on the initial contact angle (McLean, Huang et al., 2005). As the knee moves into maximum flexion, the knee appears to remain in a valgus position (Cowley et al., 2006; Hewett et al., 2005; Yu et al., 2005). Female youth soccer players tend to continue to have a valgus knee angle at max knee flexion, where as male youth soccer players move from a valgus to a varus knee angle (Yu et al., 2005).

Hewett et al. conducted a study in which they prescreened adolescent soccer, basketball and volleyball players' biomechanics while performing a drop vertical jump (Hewett et al., 2005). They then recorded which subjects went on to injure their ACL. When comparing the knee valgus angles of the injured versus uninjured, those females who went on to injure their ACL had 8.4 degrees more knee valgus at initial contact than uninjured. This same group also had 7.6 degrees more knee valgus at maximum knee flexion than the uninjured females (Hewett et al., 2005). This shows that females who display greater knee valgus angles may be at a greater risk of tearing their ACL.

Hip Flexion at Initial Contact/Maximum Knee Flexion

Similar to knee flexion, hip flexion also plays a major role in lower extremity kinematics (Griffin et al., 2000; Salci et al., 2004; Yu et al., 2005). If there is a decrease in hip flexion during athletic tasks involving landing, the quadriceps large knee extensor torques, in addition to large ground reaction forces, may excessively accelerate the tibia anteriorly beneath the femur (Salci et al., 2004). The hips may influence or be associated with other at risk joint positions due to its influence on the lower extremity (Griffin et al., 2000). A higher peak valgus moment has been associated with a larger initial contact hip flexion angle during a side-step maneuver (McLean, Huang et al., 2005). There appears to be a direct association between hip neuromuscular control and knee valgus moments during a side-step task (McLean, Huang et al., 2005).

During landing tasks, females have been found to have a decrease in hip flexion angles (Chappell et al., 2007; McLean, Lipfert, & van den Bogert, 2004; McLean, Walker et al., 2005; Salci et al., 2004; Yu et al., 2006; Yu et al., 2005). Chappell et al. found that when performing a vertical stop-jump, men and women had similar hip flexion angles at the beginning of the flight phase, but at landing women had 48 degrees of hip flexion whereas men had 56 degrees of hip flexion (Chappell et al., 2007). When landing from a 40 cm block landing task, male volleyball players have also been found to display significantly greater hip flexion angles than female volleyball players (Salci et al., 2004).

In youth soccer players, the hip flexion angle at initial contact and maximum knee flexion were found to be significantly different between males and females (Yu et al., 2005). As age increased from 11 to 16 male hip flexion angles remained the same, while female hip flexion angles decreased after age 13 (Yu et al., 2005). Due to the fact that female youth soccer players landed with both a decreased hip and knee flexion angles compared to males, it suggests that females land with their lower extremities in a more extended position. After the age of 12 this gender difference increases as age increases (Yu et al., 2005).

Hip Abduction at Initial Contact/Maximum Knee Flexion

A decrease in hip abduction has been found to play a role in a variety of jump-landing tasks (Chappell et al., 2007; McLean et al., 2004; Pollard, Davis, & Hamill, 2004; Pollard et al., 2007). Females tend to be in a more adducted position than males, particularly during a side-step maneuver (Pollard et al., 2004). It has been suggested that knee valgus and hip adduction are directly related (Pappas et al., 2007; Sigward & Powers, 2007). Hip adduction in a closed-kinetic chain activity can lead to knee valgus and in turn place strain on the ACL (Pappas et al., 2007). Pappas et al. expected to see hip adduction during a unilateral, right leg landing due to the pelvis dropping to the left side, however they found that at 40 degrees of knee flexion subjects had 7 degrees of greater hip abduction (Pappas et al., 2007). After further investigation they found that unilateral landing produced 13.6 degrees of hip abduction at initial contact, but hip abduction at initial contact during a bilateral landing was only 1.2 degrees (Pappas et al., 2007). Furthermore, although the hip was abducted 13.6 degrees at initial contact it quickly moved to 3.2 degrees of adduction at maximum knee flexion (Pappas et al., 2007).

The role of the hip musculature in deceleration tasks is still not clear as it has been suggested that hip abductor weakness may be a cause of decreased hip abduction (Pappas et al., 2007; Pollard et al., 2004). Injury threshold of the ACL has been found to increase when hip stiffness was increased 50%. Similarly, injury threshold decreased when hip stiffness was decreased 50% (Chaudhari & Andriacchi, 2006). By increasing the strength of hip musculature, dynamic stiffening of the hip joint could be accomplished (Chaudhari & Andriacchi, 2006). Increasing dynamic abduction/adduction stiffening would in turn improve the stability of the knee (Chaudhari & Andriacchi, 2006).

In contrast to the other studies, Chappell et al. found that at the beginning of the flight phase of landing during a running stop-jump females had 9 degrees of hip abduction compared to males who had 13 degrees of hip abduction (Chappell et al., 2007). At landing, females had 10 degrees of abduction as males had 12 degrees (Chappell et al., 2007). Although neither gender was in an adducted position, the male participants still had achieved greater abduction than the females (Chappell et al., 2007). Sigward and Powers also found that during a side-step maneuver the valgus moment group demonstrated greater hip abduction at initial contact than the normal frontal plane moment group (Sigward & Powers, 2007). This was in contrast to what they hypothesized, but may be due to reaching farther laterally with their foot at initial contact (Sigward & Powers, 2007).

Hip Internal Rotation at Initial Contact/Maximum Knee Flexion

Although hip internal rotation angles have not been studied as frequently as knee flexion or knee valgus angles, it is still an important component of the lower extremity kinematics when performing athletic tasks (Chappell et al., 2007; McLean, Huang et al., 2005; McLean et al., 2004; Pollard et al., 2004; Sigward & Powers, 2007; Yu et al., 2005). An increase in hip internal rotation while performing functional activities, such as a stop-jump or side-step, can alter the alignment of the lower extremity, and therefore predispose an individual to ACL injury (Pollard et al., 2004). Female athletes tend to display an increase in hip internal rotation (Chappell et al., 2007; Pollard et al., 2004). Chappell et al. found that women had 9 degrees of hip internal rotation at the beginning of the flight phase of a stop jump. The male subjects' hips in the same study were externally rotated 14 degrees (Chappell et al., 2007). Females also displayed greater hip internal rotation and decreased hip flexion during the early deceleration phase of side-step cutting (Pollard et al., 2004; Pollard et al., 2007).

There appears to be an important connection between knee valgus moment and hip internal rotation angles (McLean, Huang et al., 2005; Sigward & Powers, 2007). In a study conducted by Sigward and Powers, youth female soccer players performing a sidestep cut were divided into excessive and normal peak valgus moment groups (Sigward & Powers, 2007). The excessive valgus moment group displayed significantly greater hip internal rotation at initial contact than the normal valgus moment group (Sigward & Powers, 2007). The increase in hip internal rotation at initial contact may then compromise the ability of the medial muscle groups to support knee valgus loads (McLean, Huang et al., 2005).

Prevention of Anterior Cruciate Ligament Injury

In an attempt to reduce the number of ACL injuries among the athletic population, recent research has begun to focus on improving lower extremity kinematics and kinetics during sport related movements (Herman et al., 2008; Hewett et al., 2006; Myklebust et al., 2003; Onate et al., 2001). A variety of methods of prevention have been explored, including strength training, balance or proprioception training, plyometric training, and the use of visual and verbal instruction. These prevention strategies attempt to reduce some of the risk factors associated with ACL injuries (Hewett et al., 2006). Some prevention programs have not only attempted to change athletes' biomechanics but have also tracked the reduction of ACL injuries across seasons (Mandelbaum et al., 2005; Myklebust et al., 2003; Olsen et al., 2005; Pfeiffer et al., 2006; Scase et al., 2006).

Strength

The hamstring-to-quadriceps ratio has been strongly suggested to be a factor in the injury of the ACL and therefore increasing lower extremity strength has been suggested as a prevention strategy (Anderson et al., 2001; Bonci, 1999; Herman et al., 2008; Wojtys et al., 1996). Herman et al. found that although a 9 week strengthening program of the lower extremity did in fact cause significant strength gains, compared to the control group, it did not change the lower extremity motion patterns, kinematics or kinetics, measured in the study (Herman et al., 2008). Knee laxity does not appear to be affected by isokinetic strengthening, isotonic strengthening, or agility training either. In fact, isotonic strengthening significantly increased anterior tibial translation, when stress with the muscles relaxed, by 0.83 mm (Wojtys et al., 1996). Although strength improvements have been seen through the use of strengthening programs, it appears that it should not be used as the lone strategy for altering lower extremity biomechanics in an attempt to prevent ACL injuries (Herman et al., 2008; Wojtys et al., 1996).

Balance

There is currently a limited amount of research on the effect of balance and proprioception training in a healthy population (Orchard et al., 2001). Paterno et al. found that through the use of a six week neuromuscular training program, young female athletes' total and AP direction single-limb postural stability were significantly improved (Paterno, Myer, Ford, & Hewett, 2004). After a 7 week training program, including balance and technique training, involving female handball players no difference in static balance, proprioception, or muscle strength was observed. However, dynamic balance did significantly improve (Holm et al., 2004). This improvement was probably a result of the study being directed to improve dynamic stability, which included landing and jumping activities (Holm et al., 2004). It appears that balance training alone may not be sufficient enough to decrease the risk of ACL injury, but may be better when utilized in combination with other prevention strategies (Hewett et al., 2006).

Plyometrics/Neuromuscular Training

While some programs have focused on one element, such as balance or strength alone, others have incorporated a combination of prevention modalities (Hewett et al., 2006). This includes plyometrics that incorporate jump landing technique training and neuromuscular training (Chimera et al., 2004; Hewett et al., 2006; Hewett et al., 1996; Irmischer et al., 2004; Wilkerson et al., 2004). Plyometric training has been found to significantly improve preactivation of the adductor muscles as well as coactivation of the adductor and abductor muscles (Chimera et al., 2004). The increase of co-activation of the adductors and abductors may lead to a more neutral frontal-plane position and in turn place the knee at less risk of injury (Chimera et al., 2004). Following a seven week neuromuscular training program, females who may be considered "high-risk" due to an increase in knee abduction loads, were able to reduce their peak knee abduction torque by 13% (Myer, Ford, Brent, & Hewett, 2007). A significant decrease in abduction and adduction moments at the knee have also been seen following plyometric landing training, reinforcing the assumption that neuromuscular training including plyometrics may improve the muscular control of the knee (Hewett et al., 1996; Myer et al., 2007).The hamstrings may also see an improvement from plyometric training. Wilkerson et al. observed an increase in hamstring peak torque in female collegiate basketball players after a six week plyometric training program was implemented (Wilkerson et al., 2004).

Plyometric training programs have also explored the decrease in force production at landing (Hewett et al., 1996; Irmischer et al., 2004). The amount of force dissipated through the lower extremity may be decreased at landing with proper landing technique and reduce the risk of injury (Irmischer et al., 2004; Lloyd, 2001). Plyometric training, focused on landing technique and joint stabilization, has been found to significantly reduce the impact force and rate of force development in female population while performing a step land (Irmischer et al., 2004). At landing, an average reduction of 26.4% of peak impact force can be seen following plyometric training (Irmischer et al., 2004). With the decrease in force production and increase in muscle co-activation observed following plyometric training programs, there may be a justification for the implementation of plyometrics as a form of ACL prevention (Chimera et al., 2004;

Irmischer et al., 2004; Wilkerson et al., 2004). However, knee flexion angles and flexion/extension moments at landing have been found not to increase, indicating that there are some risk factors not improved following plyometrics (Hewett et al., 1996).

The PEP, Prevent Injury and Enhance Performance, injury prevention program was integrated into three high school aged soccer teams in-season training in an attempt to improve knee and hip kinematics in landing tasks (Pollard, Sigward, Ota, Langford, & Powers, 2006). PEP is a 20 minute program that replaces the traditional warm-up and focuses on proper technique and landing during plyometrics and agilities (Pollard et al., 2006). After a season of practice combined with injury prevention training, females had significantly greater hip abduction and less hip internal rotation (Pollard et al., 2006). Although no significant knee kinematic changes were observed, PEP was effective in improving lower extremity kinematics (Pollard et al., 2006).

Instruction

The use of instruction, both verbal and visual, has also been employed in an attempt to reduce the impact of biomechanical risk factors (Cowling et al., 2003; McNair et al., 2000; Onate et al., 2005; Onate et al., 2001). The use of simple verbal instruction or visual feedback may allow simple clinical tools to be implemented in ACL prevention programs. Augmented feedback, or knowledge of performance, often emphasizes information about movement patterns and performance through the use of verbal or visual feedback (Magill, 2004; Onate et al., 2001). When comparing athletes who receive augmented feedback to those who used internal or sensory feedback, augmented feedback significantly reduced their impact forces (Onate et al., 2001; Prapavessis & McNair, 1999). This decrease in jump landing impact forces was also present one week later when performing a retention test, indicating that the benefits of augmented feedback are not only immediate but also exist one week later (Onate et al., 2005; Onate et al., 2001).

When comparing landing performance after technical instruction, auditory cues, and imaginary rehearsal, it has been found that imagery rehearsal did not significantly change peak vertical ground reaction forces compared to the control group; however, both instruction and auditory cues showed a significant decrease in peak vertical ground reaction forces (McNair et al., 2000). The imagery rehearsal consisted of visualizing statements such as, "feathers floating down to the ground" and "bubbles floating down to the ground" (McNair et al., 2000). In an effort to land as soft as possible, the instruction group focused on the kinematics of the lower limb which lead to a 13% reduction in forces (McNair et al., 2000). Similarly, the auditory group used external cues, such as listening to the sound of their landing, to aid them in landing more softly (McNair et al., 2000). Due to no significant difference in peak vertical ground reaction forces while landing, it appears that imagery rehearsal is not an effective tool in a program designed to decrease landing forces (McNair et al., 2000).

During an abrupt deceleration task, similar to a running-stop jump, the use of instruction focused on simple verbal cues related to knee angle significantly reduces landing forces compared to instruction regarding muscle activity (Cowling et al., 2003). Specifically, the peak anteroposterior (braking) forces are significantly less than the other conditions, suggesting that instruction may reduce the amount of anterior tibial translation and in turn reduce the load that the ACL has to withstand (Cowling et al., 2003). In fact, the muscle activation instruction had an adverse effect, in which it altered the quadriceps synchronization that resulted in decreased protection of the ACL (Cowling et al., 2003). Therefore, the use of muscle activation instruction without additional training is not recommended during dynamic landing (Cowling et al., 2003).

In addition to verbal feedback, the use of video feedback has also been employed in an effort to reduce kinematic risk factors during a running-stop jump (Onate et al., 2005). Overall, the use of videotape augmented feedback has been found to significantly improve maximum knee flexion angles, as well as decrease peak vertical ground reaction forces (Onate et al., 2005). This effect has not only been seen in immediate post-testing but is still present one week later during retention testing (Onate et al., 2005; Onate et al., 2001). When providing video feedback, using either self videotape model or a combination of expert and self videotape models are effective in significantly increasing maximum knee flexion angles and reducing peak vertical ground reaction forces (Onate et al., 2005).

Anterior Cruciate Ligament Injury Prevention Programs

Knowing that some training programs have been successful in altering an athlete's biomechanics, several researchers have taken the next step by implementing a variety of prevention programs during teams' seasons. The injury rates during those seasons are then monitored for a reduction in ACL injury (Hewett et al., 2006). These programs used have a combination of strategies or neuromuscular training, including technique, balance, strength and plyometric training (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Mandelbaum et al., 2005; Myklebust et al., 2003; Olsen et al., 2005; Scase et al., 2006).

Some studies have reported preventing lower extremity injuries in general, and not directly at ACL injuries (Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Olsen et al., 2005; Petersen et al., 2005; Scase et al., 2006). As part of a warm-up program, an injury prevention program can be effective in reducing the rate of injuries, specifically severe ankle and knee injuries (Olsen et al., 2005). Although Petersen et al. did not find a statistically significant reduction in lower extremity injury rates, they did find a tendency toward a lower rate of noncontact ACL injuries; one ACL injury in the intervention group compared to five in the control group (Petersen et al., 2005). Prevention programs can also be effective when implemented during preseason as part of a team's training regimen (Myklebust et al., 2003; Scase et al., 2006). When focused on landing, falling, and recovery skills, subjects in the intervention group have been shown to be significantly less likely to become injured (Scase et al., 2006). In an injury prevention program implemented in high school female soccer players, Heidt et al. did find a significant decrease in injuries in the trained group compared to untrained (Heidt et al., 2000). The trained group only suffered one ACL tear compared to eight ACL tears in the untrained group (Heidt et al., 2000).

Hewett et al. were some of the first to look at implementing an ACL prevention program, consisting of six weeks of jump landing training in three phases: technique, fundamental, and performance (Hewett et al., 1999). During the season, the untrained group had significantly more injuries than the trained, including a significantly greater amount of noncontact ACL injuries (Hewett et al., 1999). Overall, this study showed that a neuromuscular training program could reduce the amount of serious knee injuries, including ACLs, in young female athletes (Hewett et al., 1999).

Some studies have looked at a decrease in ACL injuries over two seasons of intervention (Mandelbaum et al., 2005; Myklebust et al., 2003). Mandelbaum et al. implemented a plyometric warm-up program previously discussed called PEP; a prevention program focused on soft landing and deep hip and knee flexion in young female soccer athletes (Mandelbaum et al., 2005). The PEP had already been shown to improve hip abduction and decrease hip internal rotation (Pollard et al., 2006). This program was implemented into female, high school aged soccer teams (Mandelbaum et al., 2005). After the first season of intervention, the incidence rate of ACL injuries/athlete/1000 exposures for the intervention group was .05 compared to .47 for the control group; the second season was 1.3 compared to 5.1 respectively (Mandelbaum et al., 2005). Overall, the two years of intervention lead to a 74% reduction of ACL injuries in the intervention group (Mandelbaum et al., 2005). Myklebust et al. also established a two year neuromuscular training program in female handball players (Myklebust et al., 2003). Although not significant, over the two intervention seasons it also reduced the total number of ACL injuries in the intervention group compared to the control (Myklebust et al., 2003).

Gilchrist et al. also took the PEP program and implemented into NCAA Division I female soccer teams (Gilchrist et al., 2008). Although not statistically significant, the intervention group overall had 7 ACL injuries and the control group reported 18 (Gilchrist et al., 2008). The number of noncontact ACL injuries was 2 for the treatment group versus 10 for the control group (Gilchrist et al., 2008). The number of ACL injuries occurring at practice was significantly lower for the intervention group compared to the control (Gilchrist et al., 2008). Also statistically significant was the number of

ACL injuries occurring in the last six weeks of the season; the intervention group had none compared to five in the control group (Gilchrist et al., 2008). The PEP program appears to be effective in reducing the number of ACL injuries when regularly incorporated into a warm-up (Gilchrist et al., 2008).

In contrast, Pfieffer et al. found no significant decrease in the rate of noncontact ACL injuries in high-school female athletes (Pfeiffer et al., 2006). A program called KLIP, Knee Ligament Injury Prevention Program, was implemented in two consecutive seasons for female soccer, volleyball, and basketball high school athletes (Pfeiffer et al., 2006). KLIP had previously been found to improve landing mechanics and was designed to last twenty minutes and could be incorporated into the beginning or end of a practice (Pfeiffer et al., 2006). After the two year period, three noncontact ACL injuries occurred in the treatment group and three occurred in the control group (Pfeiffer et al., 2006). Therefore, they were unable to show a difference in injury rates between the treatment versus control group (Pfeiffer et al., 2006).

Motor Learning

A basic definition of motor learning is the learning of a skilled behavior; however, noted authors have defined it as involving three important aspects (Magill, 2004; Rose, 1997; Schmidt, 1988). First, motor learning involves an internal capability for producing skilled actions that leads to a permanent change in the capability for the performance of skilled motor actions. Secondly, the learning process that leads to change is internal and is not observable. It must be inferred that learning has occurred based on the changes in the observed behavior. Finally, learning is a result of practice and experience (Magill, 2004; Rose, 1997; Schmidt, 1988). A more accurate definition of motor learning, involving the previously stated aspects, is defined by Magill, "A change in the capability of a person to perform a skill that must be inferred from a relatively permanent improvement in performance as a result of practice or experience" (Magill, 2004).

Motor Control Theories

Motor control can be controlled by two different systems: the open-loop and closed-loop control systems (Magill, 2004; Rose, 1997). The open-loop system occurs when all information is planned and included in the initial instructions needed to initiate the action (Magill, 2004). The closed-loop system involves the incorporation of feedback during the action to correct movements during the action (Magill, 2004). This feedback can come from the effectors, or the muscles and joints involved in the movement, or from visual and auditory receptors (Magill, 2004). The instructions that are given by the control center also differs depending on which control system is being used (Magill, 2004). During an open-loop system, all the information that is needed for movement is contained in the instructions (Magill, 2004). The closed-loop theory, however, only provides enough instructions to initiate movement and then relies on the feedback to update the movement (Magill, 2004).

Transfer Test of Learning

Transfer of learning refers to the learning and practice of one skill and its influence on the learning of a new one (Magill, 2004; Rose, 1997). The transfer of learning can either be positive, negative, or neutral (Magill, 2004; Rose, 1997; Schmidt, 1988). A positive transfer is when a previously learned skill aids in the acquisition of the new skill (Magill, 2004; Rose, 1997). An example of this would be using the knowledge of throwing a baseball could positively transfer of learning to throw a football. Negative transfer is the previous experiences interference on the ability to learn or perform a new skill (Magill, 2004). An example of negative transfer is if a swimmer used the previous understanding of the breaststroke in the learning of the butterfly stroke. Finally neutral transfer is when the familiarity of a previous skill has no bearing on learning of a new skill (Magill, 2004).

There are two key theories of transfer of learning. The first is the identical-elements theory which was developed by Thorndike and Woodworth (Magill, 2004; Rose, 1997). This theory states that transfer occurs because the underlying basics of the two skills are similar or identical (Magill, 2004; Rose, 1997). It assumes that the transfer occurs because of the nature of the skill not the extraction of the knowledge (Rose, 1997). The second theory is called transfer-appropriate processing (TAP) (Magill, 2004; Rose, 1997). TAP is based on the concept that the transfer of learning is due to the similarity of the cognitive processing that underlies the skills (Magill, 2004; Rose, 1997).

In a study conducted by Weigelt et al. (2000) subjects practiced juggling a soccer ball with their feet only for 10 minutes over a four week period (Weigelt, Williams, Wingrove, & Scott, 2000). It was found that at posttest the group who practiced juggling with their feet for four weeks significantly improved the number of juggles they could do in 30 seconds only using their feet compared to the control group (Weigelt et al., 2000). At posttest both groups skill of juggling with their knees was also tested (Weigelt et al., 2000). Results showed that the trained group performed significantly better than the untrained (Weigelt et al., 2000). The trained groups improvement in juggling a soccer ball with their knees indicated that a positive transfer occurred between the two similar tasks (Weigelt et al., 2000).

Retention Test

In order to test if a skill has been learned a retention test can be administered. A retention test is defined as a test in which a practiced skill is performed after a period of time after practice has ended (Magill, 2004; Rose, 1997). This is done to determine how much knowledge was retained after a length of time with no practice (Magill, 2004). Retention tests can be scored with an absolute retention score (Rose, 1997; Schmidt, 1988). The absolute retention score is the level of performance on the initial trials of the retention test (Rose, 1997; Schmidt, 1988). A relative retention score can also be used to measure how much retention took place (Rose, 1997; Schmidt, 1988). This is done by calculating the difference between the performance score of the last trial in the acquisition phase with the first trials of the retention test (Rose, 1997).

Feedback

While participating in athletic tasks, an athlete can receive many forms of feedback. Feedback, or performance related information, is divided into two categories. Intrinsic, or internal, feedback is the sensory information that is available while performing a task (Magill, 2004; Schmidt, 1988). This includes all three sensory systems; proprioception, visual, and auditory (Magill, 2004; Schmidt, 1988). Most intrinsic feedback is straightforward and requires no additional evaluation (Schmidt, 1988). An example of intrinsic feedback is seeing that a shot on goal did not go in the net. Auditory intrinsic feedback would include hearing the ball hit the goalie's gloves as the shot is blocked.

The second form of feedback is extrinsic, or external. Extrinsic feedback is in addition to or supplements the intrinsic feedback (Schmidt, 1988). This form of feedback is frequently referred to as augmented feedback (Magill, 2004; Rose, 1997). Augmented feedback is information from an external source that is provided to the learner (Rose, 1997). Augmented feedback can enhance information that the athlete's sensory system can detect on its own (Magill, 2004).

The guidance hypothesis referrers to the role that augmented feedback plays in guiding the correct performance during practice (Magill, 2004). This hypothesis states that if a learner receives feedback after every trial then they will be guided to perform the movement correctly (Magill, 2004; Maslovat, Brunke, Chua, & Franks, 2009; Pringle, 2004). There is a negative side to this hypothesis, however. If feedback is given too frequently the learner will learn to depend on it (Magill, 2004). This leads to a decrease in performance during later testing when feedback is no longer present (Maslovat et al., 2009).

The time at which augmented feedback is given can vary between concurrent or delayed (Ezekiel, Lehto, Marley, Wishart, & Lee, 2001; Magill, 2004). Concurrent augmented feedback is provided during a movement or skill (Ezekiel et al., 2001; Magill, 2004). An example of concurrent augmented feedback would include a patient with improper shoulder motion practicing shoulder flexion and abduction in front of a mirror. This provides immediate feedback as to how they are performing the task (Ezekiel et al., 2001). It has been shown however, that concurrent augmented feedback will aid in performance, but may degrade learning in retention tests (Ezekiel et al., 2001). This is because the learner begins to rely on the augmented feedback when it is available, instead of actually learning the movement (Ezekiel et al., 2001). This reliance on feedback then reduces performance when feedback is removed (Ezekiel et al., 2001).

Delayed or terminal augmented feedback is provided after a skill or movement (Ezekiel et al., 2001; Magill, 2004). Delayed feedback, specifically when summarized, has been shown to enhance learning (Ezekiel et al., 2001). Summary feedback delays the presentation of augmented feedback until after a number of trials has been performed as well as presents information about multiple trials together (Ezekiel et al., 2001). It has been shown that although participants who received concurrent feedback after every trial were more accurate during a task, the participants who received summary feedback of five trials were the most accurate on retention tests (Ezekiel et al., 2001).

Types of Augmented Feedback

Augmented feedback can be broken down into three different categories. These include knowledge of results (KR), knowledge of performance (KP), and biofeedback. Knowledge of results involves information about the outcome of performing a task (Magill, 2004; Rose, 1997; Schmidt, 1988). An example of this would be if a baseball coach informed their pitcher that the pitch was too high. Knowledge of results is not about the movement, but purely about the outcome of the movement. This form of feedback can also simply inform an athlete if they have achieved a goal or not (Magill, 2004; Schmidt, 1988).

In a study comparing KR and manual guidance (GD) subjects were told to place 70% of their body weight on a scale (Sidaway et al., 2008). There was a significant interaction between KR and the amount of feedback during the initial acquisition of the task (Sidaway et al., 2008). The group who received KR feedback following every trial had a decrease in error across the blocks of testing compared to the group who received KR feedback after every third trial (Sidaway et al., 2008). During the retention test however, the KR group did perform less errors than the GD, and the KR group who received feedback after every third trial significantly performed less errors than the group who received KR feedback following every trial (Sidaway et al., 2008). The results of this study support other studies' conclusions; showing that concurrent augmented feedback may be effective during the performance or immediately following a task, but delayed or summarized augmented feedback will improve learning and retention of a skill (Carnahan, Vandervoort, & Swanson, 1996; Ezekiel et al., 2001).

The second form of augmented feedback is knowledge of performance (KP), which includes information about the characteristics of a movement that led to an outcome (Magill, 2004; Schmidt, 1988). If the same baseball coach would tell the pitcher that they released the ball too early in the deceleration phase he would then be providing feedback of knowledge of performance. This form of feedback can be directed toward something that someone is vaguely aware of, as in the movement of a joint, or something that they cannot be aware of, such as heart rate and blood pressure (Schmidt, 1988).

Knowledge of performance may be provided by a number of forms. Verbal feedback tends to be the most common, particularly by coaches and teachers (Magill, 2004). Simple verbal cues are often utilized to decrease the amount of force someone lands with or change the position in which they land (Cowling et al., 2003; McNair et al., 2000; Prapavessis & McNair, 1999). Prapavessis and McNair analyzed augmented verbal feedback versus sensory feedback and its effect on ground reaction forces when landing from a box (Prapavessis & McNair, 1999). The augmented feedback group was told to, "Land on the balls of your feet with bent knees just prior to landing and lower the heels slowly to the ground, bending the knees until well after landing" (Prapavessis &

McNair, 1999). The sensory feedback group was told to use the experience of their first jump to land in a way that would reduce the stress of the next landing (Prapavessis & McNair, 1999). The augmented verbal feedback group significantly decreased their ground reaction force when landing from a jump compared to the sensory feedback group; indicating that verbal feedback is effective in altering lower extremity kinematics (Prapavessis & McNair, 1999).

Other forms of KP feedback include videotape feedback and kinematic measures. Videotape feedback can be influenced by verbal feedback, the time that the feedback is given, and the skill of the learner (Rose, 1997). Kinematic feedback can be a simple verbal reference to the movement of a joint, or can be shown or evaluated through complex software (Magill, 2004; Schmidt, 1988) In the attempt to improve distance and accuracy in a golf swing, expert golfers received either video, verbal, or self-guided feedback (Guadagnoli, Holcomb, & Davis, 2002). Immediate posttest showed no difference between groups, but a two week retention test revealed a significant increase in accuracy distance (Guadagnoli et al., 2002). Both instruction groups were greater than the self-guided, with the video instruction group improving greater than the verbal instruction group (Guadagnoli et al., 2002).

The combination of visual or video and verbal feedback has also been used as a means to learn and improve a skill (Janelle, Champenoy, Coombes, & Mousseau, 2003; Onate et al., 2001). In the retention of a new skill, it has been shown that combining video modeling and verbal and visual cues is an effective tool (Janelle et al., 2003). Onate et al. found that when provided augmented verbal and videotape feedback about landing techniques compared to sensory feedback, the augmented feedback group significantly decreased their peak vertical ground reaction forces (Onate et al., 2001). The augmented feedback group also had significantly less peak vertical ground reaction forces compared to sensory feedback during a one week retention test (Onate et al., 2001). The combination of video and verbal feedback has been shown to be an effective means of improving the acquisition of a skill or improving biomechanics (Janelle et al., 2003; Onate et al., 2001).

Visual and verbal feedbacks have also frequently been used to enhance or improve muscle strength (Campenella, Mattacola, & Kimura, 2000; Kim & Kramer, 1997). The use of visual feedback during isokinetic knee extension has been shown to produce greater torque than compared to no feedback (Kim & Kramer, 1997). This improvement in torque may be beneficial in learning a new task but may not be as effective for improving muscle torque over time (Kim & Kramer, 1997). Hamstring and quadriceps peak torque have also shown to be significantly greater with the use of visual feedback or the combination of verbal encouragement and visual feedback compared to verbal encouragement alone or no feedback (Campenella et al., 2000).

The third form of augmented feedback is biofeedback, although it is sometimes categorized under knowledge of performance (Magill, 2004; Rose, 1997). Biofeedback is also generally termed augmented sensory feedback (Rose, 1997). It involves feedback related to the activity of internal physiological events to help someone learn to control them (Magill, 2004; Rose, 1997). Biofeedback is commonly used in the clinical setting to provide feedback about muscle activity, center of mass, physiological processes, and joint displacement (Magill, 2004; Rose, 1997). This can be done as simply as placing someone in front of a mirror to allow them to view their movement or by using EMG feedback (Magill, 2004; Rose, 1997). EMG, electromyographic, feedback provides information about the activity of the muscle (Magill, 2004). This is commonly utilized for retraining the quadriceps following ACL surgery (Magill, 2004).

Modeling as Form of Motor Learning

Modeling is commonly used in observational learning, where a skill is demonstrated to impart important information about a skill (Magill, 2004; Rose, 1997). There are number of considerations when using a model or demonstration. These include the skill level of the model, the similarity and age of the model, augmented information, and the type of skill demonstrated (Rose, 1997). Augmented verbal information can be used to enhance the use of a visual model by highlighting the most important components of the movement (Rose, 1997). In a study conducted by Hebert and Landin (1994) augmented verbal feedback, learning model feedback, and the combination of augmented feedback and a learning model was used in the acquisition of a tennis volley (Hebert & Landin, 1994). It was determined that the use of a combination of a learning model and verbal augmented feedback was the most effective at improving the tennis skill (Hebert & Landin, 1994). This form of improvement was significantly greater than augmented verbal feedback and a learning model alone during both the acquisition of the skill as well as during a retention test 48 hours later (Hebert & Landin, 1994).

CHAPTER III

METHODOLOGY

A repeated measures design was used to analyze knee and hip kinematics of healthy college age female athletes during a box-drop, running-stop, and sidestep maneuver over time. Subjects were randomly assigned to three different feedback groups. These included video feedback of themselves performing a box-drop jump (self feedback), video feedback of an expert and themselves performing a box-drop jump (combo feedback), and a control group who received no instruction. The independent variables included the type of instruction (self feedback, combo feedback, and control), test time (pretest, immediate posttest, one month retention) and task (box-drop jump, running-stop jump, side-step maneuver). The dependent variables included the following kinematic variables: knee flexion, knee valgus, hip flexion, and hip abduction measured in degrees at initial contact and maximum knee flexion. A total of 64 statistical analyses were used to identify statistical differences in the four kinematic variables at initial contact and maximum knee flexion. This included a series of one-way and repeated measures ANOVAs used to evaluate box-drop jump, running-stop jump, and side-step maneuver. Change scores for each feedback group were also calculated.

Subject characteristics

Using data from the literature, a sample size was estimated for the different kinematic variables and ranged from 8 to 95 participants. A convenience sample of forty six healthy female recreational and varsity athletes between the ages 18 and 25 (mean age = 21.47 $\pm$ 1.55 years; height = 1.65 $\pm$ 0.08 m; weight = 63.78 $\pm$ 12 kg) voluntarily participated in the study. Inclusion criteria entailed that each subject must be physically active at least three times per week for a minimum of 20 minutes and have no history of ACL injury or reconstructive surgery. They could have no history of lower extremity injury in the past two months that limited them from activity for more than one day, no current self-reported history of lower extremity instability, or history of any lower extremity surgery within the past two years. They also could not have a history of jump-landing technique training. Each participant was required to sign an informed consent form approved by the Institutional Review Board before participating in the study (Appendix 1). Of the 46 subjects who participated, 44 were able to complete the study. Two subjects were unable to return for the retention portion of the study, and were excluded from the data analysis. A third subject was eliminated from statistical analysis due to discrepancy in their data. A total of forty-three subjects were used in the final analysis.

Instrumentation

The primary instrument used to attain kinematic measures of the various body segments was the VICON motion capture system (MX-F40, VICON Motion Systems Ltd., Oxford England). This system consisted of eight high-speed cameras with a sampling rate of 500 Hz. The cameras were positioned so that each reflective marker was detected by at least two cameras at the same time throughout the task. Each reflective marker was 14mm and light weight. The VICON system has been found to be reliable, both within-day repeatability and between-day repeatability (Kadaba et al., 1989). The between-day repeatability, however, may be affected by errors in marker reapplication (Kadaba et al., 1989). To increase the reliability, marker placement was minimized by standardizing marker placement on specific bony landmarks. The system was calibrated prior to each day's data collection. This was done by waving a 5-marker wand with a known distance between markers to determine the volume. An error up to 0.5mm was considered acceptable for data collection. Placing the wand in the right hand corner of the force plates set the volume origin (0, 0, 0).

In order to quantify the motion of the hip, knee, and ankle joints, a full body kinematic model was created from the standing trial. Visual 3D (C-motion, Rockville MD, USA) was used to create the model for each participant. To calculate the joint angles a Cardan angle sequence (x-y-z) was used which is comparable to a Joint Coordinate System. Kinematic and kinetic data were low-pass filtered with a 25 Hz cutoff frequency through a fourth-order Butterworth zero lag filter based on the power spectrum analysis of the camera system.

Two Bertec Force Plates, Model 4060-NC (Bertec Corporation, Columbus OH, USA), with a sampling rate of 500 Hz were utilized to collect kinetic data relating to ground reaction forces. These were used to determine the point at which initial contact occurred. The force plates were secured to a wooden runway platform for a combined area of 60cm x 80cm. The analog signal was amplified and sent to an Analog to Digital board to be converted to a digital signal. The measurements were obtained by Nexus (VICON Motion Systems Ltd., Oxford England) computer-based software acquisition program. All of the pretest and posttest box-drop trials were also recorded on two Sony DCR-HC40 digital mini-DV camcorders (Sony Electronics, INC. San Diego, CA, USA). The sagittal view was placed on the side of each subject's dominant leg and the frontal camera was placed at the end of the runway facing the force plates.

To monitor the approach speed for both the running-stop jump and the side step maneuver, a Speed Trap I timing system (Brower Timing Systems, Draper, UT, USA) was used. The first speed trap of the timing system was placed toward the end of the runway, three meters from the other speed trap. The finish sensor of the timing system was located 30 cm from the force plates. Normal approach speeds for a side-step maneuver typically fall between 5.5 and 7.0 m/s in a game like situation (McLean et al., 1999). However, due to the restriction of the runway length all subjects were required to have an approach speed of at least 3 m/s for all trials.

Box-Drop Jump Task

The box-drop landing task is a tool commonly used to evaluate landing biomechanics (Cowley et al., 2006; Hewett et al., 2005; Myer et al., 2007). This task simulates common landing maneuvers employed while played a variety of sports, such as basketball, soccer, and volleyball (Cowley et al., 2006; Fagenbaum & Darling, 2003; Hewett et al., 2005; Salci et al., 2004). This task consisted of subjects standing on a box placed 30 cm from the force plates and 30 cm high. They then leaned forward with both feet at the edge of the box and fell forward off the box. They landed with each foot in the corresponding force plate and immediately jumped straight up in the air to achieve maximal jump height. When they landed, they had to land with each foot on the corresponding force plate again (Fagenbaum & Darling, 2003; Nagano et al., 2007). The initial landing phase of the jump, or the initial contact of dominant foot and the force plate to the time at which they left the ground, was analyzed. Trials were discarded if both feet were not in the corresponding force plates and/or the subject lost their balance.

Running-Stop Jump Task

The running-stop jump is an athletic maneuver frequently performed in a variety of sports (Chappell et al., 2002; Sell et al., 2007; Yu et al., 2005). The task involved the subjects running down a platform at a comfortable speed. They took a three to four step approach run, followed by a two-footed landing with each foot landing in the corresponding force plate. The landing was followed by an immediate takeoff (vertical jump) for maximum height and landing back onto force plates (Cowley et al., 2006). The landing phase of the jump landing task was analyzed. A trial was discarded if a subject did not reach a speed greater than 3 m/s on the approach run, both feet did not land in their corresponding force plate, and/or they took an extra step forward or backwards.

Sidestep Maneuver Task

A sidestep maneuver is a regularly performed task for many athletes, particularly soccer and basketball players, in both game and practice situations (Landry et al., 2007; Pollard et al., 2004; Pollard et al., 2005; Sigward & Powers, 2007). The sidestep maneuver that the subjects performed in the lab was between 35 to 55degrees, which put them approximately at 45degrees. This angle was determined by the platform that the subjects performed the task on. This task consisted of a running approach, at a comfortable speed, and then contact with the corresponding force plate of their dominant leg with a change of direction to the non-dominant side. Subjects were instructed to follow the sidestep maneuver with a few steps (Malinzak et al., 2001; McLean et al., 1999). For example, if the subject was left leg dominant, they would cut to the right by having their left foot make contact with the left force plate. They then pushed off with the left and lead with the right foot in the direction of the non-dominant limb. The initial contact of their dominant leg to the take off of the same foot was analyzed. Trials were discarded if the subject did not have an approach run speed greater than 3 m/s, their dominant foot did not land in the force plate, and/or they lost their balance.

Landing Error Scoring System Criteria

The Landing Error Scoring System (LESS) criteria was used as a feedback tool instead of an assessment tool. The LESS is a clinical motion analysis tool that is used to identify errors in jump landing technique (Padua, Marshall, Onate et al., 2004). It has also been found to be both a reliable and valid clinical motion analysis tool, with both excellent intra-session and intra-rater reliability (Padua, Marshall, Onate et al., 2004). The LESS criteria include analysis of the ankle, knee, and hip at both initial contact and maximum knee flexion (Appendix 2). A grading sheet based off of the LESS criteria was used by the subjects (Appendix 3). They circled yes or no to indicate whether or not they met the stated criterion for that trial; a majority of yes's was desired. A high score, or all no's, equaled a poor jump landing technique.

Testing Procedure

Participants reported to the Sports Medicine Research Lab at Old Dominion University for testing. Subjects were required to wear spandex shorts and a sports bra. All participants wore running shoes that they regularly trained in. Before being allowed to participate, they had to sign an informed consent form.

After consent was received, pre-screening measurements were taken. These measurements included height, weight, and anatomic measurements: leg length, knee width, and ankle width. Their dominant leg was also determined at this time. This was done by asking them which leg they would choose to kick a ball as far as possible (Agel et al., 2005; Hewett et al., 2005; Van Lunen et al., 2003). Following these measurements, subjects were allowed five minutes to warm-up on the bike and five minutes of self-directed stretching. During this time the pre-screening measurements were inputted into the VICON system. After the ten minutes of warm-up and self-directed stretching, reflective markers were placed on the pelvis and lower extremities of the subject using double-sided tape, surgical tape, PowerFlex athletic tape, and Tuf Skin adhesive spray.

The pelvis was defined by placing one reflective marker on both the left and right posterior superior iliac crest and one on both the left and right anterior superior iliac crest. The lower limbs were defined using the same landmarks on both the left and right limbs. One reflective marker was placed on the lower lateral 1/3 surface of the thigh, the lateral epicondyle of the knee, the lower 1/3 of the shank, and the lateral malleolus along the imaginary line that passes through the transmalleolar axis. Both the left and right foot were defined by placing a reflective marker over the second metatarsal head, on the mid-foot side of the equines break between forefoot and mid-foot. A reflective marker was also placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker (Kadaba, Ramakrishnan, & Wootten, 1990).

Once the markers were placed on the subject, a static trial was taken. This involved the subject standing in a "static" position, with arms crossed, on the force plates (Appendix 4). After a static trial had been recorded, the box-drop task was explained to them. These instructions included: "Place both feet at the edge of the box and lean forward so that you fall off of the box; try not to jump off of the box. Land with one foot on each force plate and immediately jump up as high as you can. When you land again, make sure that one foot is on each force plate again." After the instructions, the subject were allowed two practice trials, or until they felt comfortable, to become familiar with the box-drop. Once they had time to become comfortable with the task, each subject performed five trials of the box-drop task with 30 seconds of rest time between trials to minimize the effect of fatigue.

After performing the box-drop trials, the subjects then received the intervention portion of the test. Each subject was randomly assigned to one of three instructional groups: self, combo, or control. This was done by having each subject select an envelope labeled A, B, or C which corresponded to a different feedback group. Each feedback group had to have a total of 15 subjects, therefore once all slots were filled in one group that group was no longer allowed to be selected. This process ensured that subjects were randomly assigned to feedback groups.

Intervention

After subjects were randomly assigned to a group, they received feedback on their box-drop trials. All subjects, combo and self groups, viewed four trials from both the frontal and sagittal views. The self feedback group viewed four of the five trials of the box-drop that they just performed. The combo feedback group viewed two trials of an expert performing a box-drop and then the first two trials of their own performance of the box-drop. During the viewing of all the trials, the film was freeze framed to allow adequate opportunity to view the trials. To analyze all trials, the subjects and researcher used a grading sheet based off of the LESS criteria, which included ankle, knee, and hip alignment and angles, as a standardized feedback tool. The instructor provided both visual and verbal feedback by evaluating the checklist criteria with the subject for all four trials viewed, frontal and sagittal (Onate et al., 2005). Finally, the control group received no feedback and was given the allotted time to read a magazine. A maximum of ten minutes was allotted for feedback.

Immediate Posttest

At the end of the allotted ten minutes, subjects then participated in the immediate posttest. At this time, the original set of instructions and explanation of the task was repeated. They were also allowed two practice trials. The subject then performed five trials of the box-drop, with 30 seconds rest between. After the data had been collected, the subjects were instructed to perform an initial transfer test of a running-stop jump task. These instructions included: "Run down the platform at a comfortable speed with a three to four step approach, land with each foot on a separate force plate and immediately jump up for maximum height, and land again with one foot on each force plate. Try not to jump onto the force plates, but run directly onto them and then jump up" (Chappell et al., 2007). After instructions had been given, subjects were allowed two practice trials and five recorded trials with 30 seconds rest in between each trial. For all trials, the subjects' running approach speed was recorded. At the end of testing, subjects were asked to report back to the Sports Medicine Research Laboratory after one month for a retention test.

One Month Retention Test

Subjects returned to the Sports Medicine Research Laboratory after at least one month of the original test date for a retention test. Each subject was required to wear the same type of clothing as well as the same shoes that they originally tested in. The same set of procedures as the original test was performed; subjects were allowed a five minute bike warm-up and five minutes of self-directed stretching. Reflective markers were placed in the same set of landmarks used in the first trials. The original set of instructions and explanation of the box-drop were also read to them. They were allowed two practice trials, or until they felt comfortable, and then five trials were recorded with 30 seconds of rest between trials.

After the box-drop trials had been recorded, the subjects performed the initial transfer test (running-stop jump) performed during the immediate posttest session. They received the same set of instructions given to them during the immediate posttest. After instructions had been read, they were given two practice trials, or until they felt comfortable, and then performed five trials with 30 seconds of rest in between trials, with all running approach speeds recorded. The running-stop jump was used as an initial transfer test and a retention test.

One Month Transfer Test

After the running-stop jump had been performed the subjects performed a delayed transfer test. A transfer test was designed to evaluate if teaching proper biomechanics of a box-drop and landing mechanics would result in improved biomechanics in other sport specific tasks. Subjects performed a side-step maneuver as the transfer task. Instructions for this included: "Run down the platform at a comfortable speed, when you get to the force plates plant with your dominant leg and side step to the opposite side of the contact leg. For example, if you are left leg dominant, cut to the right by having your left foot make contact with the left force plate. Then push off with your left foot and lead with the right foot in the direction of the non-dominant limb." Once instructions were read, subjects were allowed two practice trials, or until they became comfortable with the task and then five trials with 30 seconds rest between were be performed. For all trials, running approach speeds were also recorded.

Data Analysis

All data were reduced using Matlab 6.1 (The MathWorks, Inc, Natick MA, USA) software with the creation of a custom made program K2DS (Kinematic and Kinetic Data Simplification) to export into a Microsoft Excel spreadsheet. Each of the five trials were averaged and exported into SPSS version 16.0 (SPSS Inc, Chicago IL, USA) for data analysis. The average of all five trials was used to compare kinematic variables over time. Pretest box-drop jump data were analyzed using a total of eight one-way ANOVAs for all four kinematic variables at two time instances, initial contact and maximum knee flexion) to analyze if there was a significant difference between feedback groups at pretest. Pretest box-drop jump knee flexion at IC and hip flexion at IC were found to be significant between feedback groups. Therefore, two 2 (test time) x 3 (instruction) repeated measures ANOVAs, with the corresponding pretest box-drop jump variable as a covariate was used for knee flexion at IC and hip flexion at IC, and six 3 (test time) x 3 (instruction) repeated measures ANOVAs were conducted for the remaining variables for the box-drop jump task. For the running-stop jump task, eight 2 (test time) x 3 (instruction) repeated measures ANOVAs were conducted for all four dependent variables at initial contact and maximum knee flexion. Finally, for the side-step maneuver, eight one-way ANOVAs were performed for all four dependent variables at initial contact and maximum knee flexion. The same process was repeated with both self and combo feedback groups combined versus control group. The pretest box-drop jump one-way ANOVAs revealed no significant differences between feedback groups.

Therefore, eight 3 (test time) x 2 (instruction) repeated measures ANOVAs for box-drop jump over time, eight 2 (test time) x 2(instruction) repeated measures ANOVAs for running-stop jump over time, and eight one-way ANOVAs for side step maneuver were conducted. Mauchly's Test of Sphericity was utilized; sphericity was assumed unless Mauchly's was significant then Greenhouse-Geisser was used. A Tukey Post Hoc was conducted in conjunction with all of the above analyses to determine differences between feedback groups. A statistical significance of $p \leq 0.05$ was considered acceptable.

Change Scores were also conducted for the all eight variables for feedback group during the box-drop jump task. Change score one was defined as the change from pretest to posttest. Change score two was defined as the change from pretest to retention test. A total of eight multivariate ANOVAs were conducted to determine a significance difference between feedback groups.

CHAPTER IV

RESULTS AND DISCUSSION

Results

A total of 43 subjects were analyzed. The self and combo feedback group each had 15 subjects and the control consisted of 13 subjects. All subjects were right leg dominant. The average number of weeks between the first testing session (pre and posttest measurements) and the retention test was 5.49 ± 0.67 weeks.

Pretest Values

A significant difference was found between feedback groups at pretest for box-drop jump knee flexion at initial contact ($F_{2,40} = 6.68$, $p = 0.003$) and box-drop jump hip flexion at initial contact ($F_{2,40} = 3.40$, $p = 0.043$). Tukey's Post Hoc revealed that during pretest box-drop jump, the combo feedback group knee flexion at initial contact was significantly greater than the self feedback group ($p = 0.003$) and control group ($p = 0.049$) with associated effect sizes of $d = 0.94$, 0.67 respectively. It also revealed that during pretest box-drop jump, the combo feedback group had significantly higher hip flexion at initial contact than the self feedback group ($p = 0.034$) with an associated effect size of $d = 0.75$. When comparing both feedback groups versus control, no significant difference was found in kinematic variable during pretest box-drop jump.

Box-Drop Jump Over time (Pre to Immediate Posttest to Retention Test)

Knee Flexion at IC

There was a significant test time main effect for knee flexion at IC during the box-drop jump task ($F_{1,39} = 13.50$, $p = 0.001$). The total mean score for posttest knee flexion at IC was approximately 3 degrees (-22.49 ± 10.05) greater than the retention test knee flexion at IC (-19.46 ± 7.21) with an effect size of d = 0.29. There was no significant feedback group main effect for knee flexion at IC during the box-drop jump task ($F_{2,39} = 0.17$, $p = 0.844$). There was no significant test time and feedback group interaction for knee flexion at IC during the box-drop jump task ($F_{2,39} = 0.56$, $p = 0.576$).

Knee Valgus at IC

There was no significant test time main effect for knee valgus at IC during the box-drop jump task ($F_{1.45,58.17} = 0.06$, $p = 0.896$). There was no significant feedback group main effect for knee valgus at IC during the box-drop jump task ($F_{2,40} = 0.62$, $p = 0.541$). There was no significant test time and feedback group interaction for knee valgus at IC during the box-drop jump task ($F_{2.91,58.17} = 0.47$, $p = 0.702$).

Hip Flexion at IC

There was a significant test time main effect for hip flexion at IC during the box-drop jump task ($F_{1,39} = 15.57$, $p \leq 0.01$). The total mean score for immediate posttest hip flexion at initial contact was approximately 2 degrees (40.94 ± 9.27) greater than the retention posttest hip flexion at initial contact (39.17 ± 7.15) with a small effect size of d = 0.19. There was no significant feedback group main effect for hip flexion at IC during the box-drop jump task ($F_{2,39} = 0.59$, $p = 0.566$). There was no significant test time and feedback group interaction for hip flexion at IC during the box-drop jump task ($F_{2,39} = 0.59$, $p = 0.559$).

Hip Abduction at IC

There was no significant test time main effect for hip abduction at IC during the box-drop jump task ($F_{1.59,63.75} = 1.15$, $p = 0.315$). There was no significant feedback group main effect for hip abduction at IC for the box-drop jump task ($F_{2,40} = 0.20$, $p =$

0.823). There was no significant test time and feedback group interaction for hip abduction at IC during the box-drop jump task ($F_{3.19,63.75} = 1.28$, $p = 0.290$).

Peak Knee Flexion

There was a significant test time main effect for peak knee flexion during the box-drop jump task ($F_{2,80} = 3.29$, $p = 0.043$). Pairwise Comparisons showed that posttest peak knee flexion was significantly greater (-86.93 ± 12.97) when compared to pretest peak knee flexion (-83.54 ± 11.78) ($p = 0.012$) with an associated effect size of $d = 0.27$. It also showed that posttest peak knee flexion was significantly greater (-86.93 ± 12.97) when compared to retention test peak knee flexion (-83.86 ± 12.14) ($p = 0.054$) with an associated effect size of $d = 0.24$. There was a significant feedback group main effect for peak knee flexion during the box-drop jump task ($F_{2,40} = 4.15$, $p = 0.023$). Tukey Post Hoc revealed that the combo feedback group had significantly greater peak knee flexion (-91.03 ± 13.97) when compared to the self feedback group peak knee flexion (-82.57 ± 7.18) ($p = 0.03$) with an associated effect size of $d = 0.61$. There was no significant test time and feedback group interaction for peak knee flexion during the box-drop jump task ($F_{4,80} = 1.35$, $p = 0.26$).

Knee Valgus at PKF

There was a significant test time main effect for knee valgus at PKF during the box-drop jump task ($F_{1.20,48.15} = 6.10$, $p = 0.013$). Pairwise comparisons showed that pretest knee valgus at PKF was significantly less (1.42 ± 9.32) when compared to the retention test knee valgus at PKF (-2.10 ± 11.86) ($p = 0.033$) with an associated effect size of $d = 0.29$. It also showed that posttest knee valgus at PKF was significantly less (2.23 ± 9.142) when compared to retention test knee valgus at PKF (-2.10 ± 11.86) (p =

0.007) with an associated effect size of *d* = 0.36. There was no significant feedback group main effect for knee valgus at PKF during the box-drop jump task ($F_{2,40}$ = 0.10, p = 0.990). There was no significant test time and feedback group interaction for knee valgus at PKF during the box-drop jump task ($F_{2.41,48.15}$ = 0.33, p = 0.758).

Hip Flexion at PKF

There was a significant test time main effect for hip flexion at PKF during the box-drop jump task ($F_{2,80}$ = 6.04, p = 0.004). Pairwise comparisons showed that posttest hip flexion at PKF was significantly greater (80.85 + 12.17) when compared to pretest hip flexion at PKF (76.81 ± 12.10) (p = 0.001) with an associated effect size of *d* = 0.35. It also showed that retention test hip flexion at PKF was significantly greater (80.55 ± 11.43) when compared to pretest hip flexion at PKF (76.81 ± 12.10) (p = 0.013) with an associated effect size of *d* = 0.31. There was no significant feedback group main effect for hip flexion at PKF during the box-drop jump task ($F_{2,40}$ = 1.12, p = 0.335). There was no significant test time and feedback group interaction for hip flexion at PKF during the box-drop jump task ($F_{4,80}$ = 2.12, p = 0.085).

Hip Abduction at PKF

There was a significant test time main effect for hip abduction at PKF during the box-drop jump task ($F_{2,80}$ = 10.72, p ≤ 0.001). Pairwise comparisons showed that pretest hip abduction at PKF was significantly greater (-4.29 ± 6.45) when compared to posttest hip abduction at PKF (-6.90 ± 6.31) (p ≤ 0.001) with an associated effect size of *d* = 0.42. It also showed that pretest hip abduction at PKF was significantly greater (-4.29 ± 6.45) when compared to retention test hip abduction at PKF (-7.26 ± 6.10) (p ≤ 0.001) with an associated effect size of *d* = 0.47. There was no significant feedback group main effect for hip abduction during the box-drop jump task ($F_{2,40} = 0.37$, $p = 0.691$). There was no significant test time and feedback group interaction for hip abduction at PKF during the box-drop jump task ($F_{4,80} = 0.84$, $p = 0.496$)

Box-Drop Jump Over Time – Feedback Groups vs. Control

Knee Flexion at IC

When comparing feedback groups versus control group there was a significant test time main effect for knee flexion at IC during the box-drop jump task ($F_{1.42,58.10} = 4.95$, $p = 0.019$). Pairwise comparisons showed that pretest knee flexion at IC was significantly greater (-21.83 $\pm$ 9.87) when compared to retention test knee flexion at IC (-19.10 $\pm$ 7.21) ($p = 0.045$) with an associated effect size of $d = 0.28$. It also showed that posttest knee flexion at IC was significantly greater (-22.25 $\pm$ 10.05) when compared to retention test knee flexion at IC (-19.10 $\pm$ 7.21) ($p = 0.009$) with an associated effect size of $d = 0.30$. When comparing feedback groups versus control group there was no significant feedback group main effect for knee flexion at IC during the box-drop jump task ($F_{1,41} = 0.42$, $p = 0.520$). When comparing feedback groups versus control group there was no significant test time and feedback group interaction for knee flexion at IC during box-drop jump task ($F_{1.42,\ 58.10} = 0.15$, $p = 0.786$).

Knee Valgus at IC

When comparing feedback groups versus control group, there was no significant test time main effect for knee valgus at IC during box-drop jump task ($F_{1.46,59.64} = 0.06$, $p = 0.892$). When comparing feedback groups versus control group, there was no significant feedback main effect for knee valgus at IC during the box-drop jump task ($F_{1,41} = 0.21$, $p = 0.648$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for knee valgus at IC during the box-drop jump task ($F_{1.46,59.64} = 0.95$, $p = 0.368$).

Hip Flexion at IC

When comparing feedback groups versus control group, there was no significant test time main effect for hip flexion at IC during the box-drop jump task ($F_{1.42,58.12} = 0.70$, $p = 0.453$). When comparing feedback groups versus control group, there was no significant feedback group main effect for hip flexion at IC during the box-drop jump task ($F_{1,41} = 0.01$, $p = 0.908$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for hip flexion at IC during the box-drop task ($F_{1.42,58.12} = 0.43$, $p = 0.584$).

Hip Abduction at IC

When comparing feedback groups versus control group, there was no significant test time main effect for hip abduction at IC during the box-drop jump task ($F_{1.60,65.55} = 0.78$, $p = 0.438$). When comparing feedback groups versus control group, there was no significant feedback group main effect for hip abduction IC during the box-drop jump task ($F_{1,41} = 0.32$, $p = 0.575$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for hip abduction IC during the box-drop jump task ($F_{1.60,65.55} = 2.37$, $p = 0.112$).

Knee Flexion at PKF

When comparing feedback groups versus control group, there was no significant test time main effect for peak knee flexion during the box-drop jump task ($F_{1.92,78.52} = 1.96$, $p = 0.147$). When comparing feedback groups versus control group, there was no significant feedback group main effect for peak knee flexion during the box-drop jump task ($F_{1,41} = 2.89$, $p = 0.096$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for peak knee flexion during the box-drop jump task ($F_{1.92,78.52} = 1.90$, $p = 0.155$).

Knee Valgus at PKF

When comparing feedback groups versus control group, there was a significant test time main effect for knee valgus at PKF during the box-drop jump task ($F_{1.21,49.49} = 6.07$, $p = 0.013$). Pairwise comparisons showed that pretest knee valgus at PKF was significantly less (1.77 ± 9.32) when compared to retention test knee valgus at PKF (-2.25 ± 11.86) ($p = 0.024$) with an associated effect size of $d = 0.29$. It also showed that posttest knee valgus at PKF was significantly less (2.23 ± 9.14) when compared to retention test knee valgus at PKF (-2.25 ± 11.86) ($p = 0.009$) with an associated effect size of $d = 0.25$. When comparing feedback groups versus control group, there was no significant feedback group main effect for knee valgus at PKF during the box-drop jump task ($F_{1,41} = 0.02$, $p = 0.891$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for knee valgus at PKF during the box-drop task ($F_{1.21, 49.49} = 0.58$, $p = 0.479$).

Hip Flexion at PKF

When comparing feedback groups versus control group, there was a significant test time main effect for hip flexion at PKF during the box-drop jump task ($F_{1.86,76.08} = 3.24$, $p = 0.044$). Pairwise comparisons showed that posttest hip flexion at PKF was significantly greater (79.81 ± 12.17) when compared to pretest hip flexion at PKF (76.92 ± 12.10) ($p = 0.024$) with an associated effect size of $d = 0.35$. It also showed that retention test hip flexion at PKF was significantly greater (80.21 ± 11.43) when compared to pretest hip flexion at PKF (76.92 $\pm$ 12.10) ($p = 0.043$) with an associated effect size of $d = 0.31$. When comparing feedback groups versus control group, there was no significant feedback group main effect for hip flexion at PKF during the box-drop jump task ($F_{1,41} = 0.50$, $p = 0.485$). When comparing feedback groups versus control group, there was a significant test time and feedback group interaction for hip flexion at PKF during the box-drop jump task ($F_{1.85, 76.08} = 3.03$, $p = 0.054$). Interestingly though Tukey Post Hoc tests revealed no significant difference between the individual feedback groups and test times.

Hip Abduction at PKF

When comparing feedback groups versus control group, there was a significant test time main effect for hip abduction at PKF during the box-drop jump task ($F_{1.94,79.60} = 7.28$, $p = 0.001$). Pairwise comparisons showed that pretest hip abduction at PKF was significantly greater (-4.76 $\pm$ 6.45) when compared to posttest hip abduction at PKF (-7.01 $\pm$ 6.31) ($p = 0.002$) with an associated effect size of $d = 0.42$. It also showed that pretest hip abduction at PKF was significantly greater (-4.76 $\pm$ 6.45) when compared to retention test hip abduction at PKF (-7.45 $\pm$ 6.10) ($p = 0.002$) with an associated effect size of $d = 0.47$. When comparing feedback groups versus control group, there was no significant feedback group main effect for hip abduction at PKF during the box-drop jump task ($F_{1,41} = 0.64$, $p = 0.427$). When comparing feedback group versus control group, there was no significant test time and feedback group interaction for hip abduction at PKF during the box-drop jump task ($F_{1.94,79.60} = 1.13$, $p = 0.328$).

Running-Stop Jump Over Time (Pre to Posttest to Retention Test)

Knee Flexion at IC

There was no significant test time main effect for knee flexion at IC during the running-stop jump task ($F_{1,40} = 0.43$, $p = 0.509$). There was no significant feedback group main effect for knee flexion at IC during the running-stop jump task ($F_{2,40} = 1.14$, $p = 0.330$). There was a significant test time and feedback group interaction for knee flexion at IC during the running-stop jump task ($F_{2,40} = 3.80$, $p = 0.031$). Interesting though Tukey Post Hoc revealed no significant difference between the individual feedback groups and times.

Knee Valgus at IC

There was no significant test time main effect for knee valgus at IC during the running-stop jump task ($F_{2,40} = 1.54$, $p = 0.222$). There was no significant feedback group main effect of knee valgus at IC during the running-stop jump task ($F_{2,40} = 0.31$, $p = 0.734$). There was no significant test time and feedback group interaction for knee valgus at IC during the running-stop jump task ($F_{2,40} = 2.33$, $p = 0.111$).

Hip Flexion at IC

There was a significant test time main effect for hip flexion at IC during the running-stop jump task ($F_{1,40} = 5.96$, $p = 0.019$). Pairwise comparisons showed that posttest hip flexion at IC was significantly greater (53.12 ± 11.75) when compared to retention test hip flexion at IC (49.53 ± 9.69) ($p = 0.019$) with an associated effect size of $d = 0.31$. There was no significant feedback group main effect for hip flexion at IC during the running-stop jump task ($F_{2,40} = 2.60$, $p = 0.115$). There was no significant test time and feedback group interaction for hip flexion at IC during the running-stop jump task ($F_{2,40} = 0.49$, $p = 0.615$).

Hip Abduction at IC

There was no significant test time main effect for hip abduction at IC during the running-stop jump task ($F_{1,40} = 0.40$, $p = 0.529$). There was no significant feedback group main effect for hip abduction at IC during the running-stop jump task ($F_{2,40} = 0.90$, $p = 0.414$). There was no significant test time and feedback group interaction for hip abduction at IC during the running-stop jump task ($F_{2,40} = 0.83$, $p = 0.443$).

Knee Flexion at PKF

There was no significant test time main effect for peak knee flexion during the running-stop jump task ($F_{1,40} = 2.29$, $p = 0.138$). There was a significant feedback group main effect for peak knee flexion during the running-stop jump ($F_{2,40} = 3.22$, $p = 0.051$). Pairwise comparisons showed that the combo feedback group peak knee flexion was significantly greater (-76.37 $\pm$ 12.85) when compared to self feedback group peak knee flexion (-68.36 $\pm$ 9.66) ($p = 0.025$) with an associated effect size of $d = 0.62$. It also showed that the combo feedback group peak knee flexion was significantly greater (-76.37 $\pm$ 12.85) when compared to the control group peak knee flexion (-69.23 $\pm$ 8.03) ($p = 0.052$) with an associated effect size of $d = 0.56$. There was no significant test time and feedback group interaction for peak knee flexion during the running-stop jump task ($F_{2,40} = 0.71$, $p = 0.499$).

Knee Valgus at PKF

There was a significant test time main effect for knee valgus at PKF during the running-stop jump task ($F_{1,40} = 5.65$, $p = 0.022$). Pairwise comparisons showed that posttest knee valgus at PKF was significantly less (-2.50 $\pm$ 9.88) when compared to retention test knee valgus at PKF (-6.00 $\pm$ 12.72) ($p = 0.022$) with an associated effect size of $d = 0.27$. There was no significant feedback group main effect for knee valgus at

PKF during the running-stop jump task ($F_{2,40} = 0.86$, $p = 0.431$). There was no significant test time and feedback group interaction for knee valgus at PKF during the running-stop jump task ($F_{2,40} = 0.75$, $p = 0.479$).

Hip Flexion at PKF

There was a significant test time main effect for hip flexion at PKF during the running-stop jump task ($F_{1,40} = 4.38$, $p = 0.043$). Pairwise comparisons showed retention test hip flexion at PKF was significantly greater (66.11 $\pm$ 12.86) compared to posttest hip flexion at PKF (62.75 $\pm$ 12.53) ($p = 0.043$) with an associated effect size of $d = 0.25$. There was no significant feedback group main effect for hip flexion at PKF during the running-stop jump task ($F_{2,40} = 1.64$, $p = 0.076$). There was no significant test time and feedback interaction for hip flexion at PKF during the running-stop jump task ($F_{2,40} = 2.27$, $p = 0.116$).

Hip Abduction at PKF

There was no significant test time main effect for hip abduction at PKF during the running-stop jump task ($F_{1,40} = 1.88$, $p = 0.178$). There was no significant feedback group main effect for hip abduction PKF during the running-stop jump task ($F_{2,40} = 0.03$, $p = 0.975$). There was no significant test time and feedback group interaction for hip abduction at PKF during the running-stop jump task ($F_{2,40} = 0.62$, $p = 0.545$).

Running-Stop Jump Over Time – Feedback Groups vs. Control

Knee Flexion at IC

When comparing feedback groups versus control group, there was no significant test time main effect for knee flexion at IC during the running-stop jump task ($F_{1,41} = 0.34$, $p = 0.548$). When comparing feedback groups versus control group, there was no significant feedback group main effect for knee flexion at IC during the running-stop jump task ($F_{1,41} = 0.01$, $p = 0.921$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for knee flexion at IC during the running-stop jump task ($F_{1,41} = 0.01$, $p = 0.915$).

Knee Valgus at IC

When comparing feedback groups versus control group, there was no significant test time main effect for knee valgus at IC during the running-stop jump task ($F_{1,41} = 0.62$, $p = 0.436$). When comparing feedback groups versus control group, there was no significant feedback group main effect for knee valgus at IC during the running-stop jump task ($F_{1,41} = 0.26$, $p = 0.611$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for knee valgus at IC during the running-stop jump task ($F_{1,41} = 0.92$, $p = 0.344$).

Hip Flexion at IC

When comparing feedback groups versus control group, there was a significant test time main effect for hip flexion at IC during the running-stop jump task ($F_{1,41} = 3.77$, $p = 0.059$). Pairwise comparisons showed that posttest hip flexion at IC was significantly greater (53.33 ± 11.88) when compared to retention test hip flexion at IC (50.28 ± 9.79) ($p = 0.059$) with an associated effect size of $d = 0.31$. When comparing feedback groups versus control group, there was no significant feedback group main effect for hip flexion at IC during the running-stop jump task ($F_{1,41} = 0.78$, $p = 0.383$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for hip flexion at IC during the running-stop jump task ($F_{1,41} = 1.01$, $p = 0.321$).

Hip Abduction at IC

When comparing feedback groups versus control group, there was no significant test time main effect for hip abduction at IC during the running-stop jump task ($F_{1,41}$ = 1.04, p = 0.313). When comparing feedback groups versus control group, there was no significant feedback group main effect for hip abduction at IC during the running-stop jump task ($F_{1,41}$ = 1.80, p = 0.187). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for hip abduction at IC during the running-stop jump task ($F_{1,41}$ = 1.66, p = 0.205).

Knee Flexion at PKF

When comparing feedback groups versus control group, there was no significant test time main effect for peak knee flexion during the running-stop jump task ($F_{1,41}$ = 2.07, p = 0.158). When comparing feedback groups versus control group, there was no significant feedback group main effect for peak knee flexion during the running-stop jump task ($F_{1,41}$ = 0.91, p = 0.346). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for peak knee flexion during the running-stop jump task ($F_{1,41}$ = 0.02, p = 0.879).

Knee Valgus at PKF

When comparing feedback groups versus control group, there was a significant test time main effect for knee valgus at PKF during the running-stop jump task ($F_{1,41}$ = 6.06, p = 0.018). Pairwise comparisons showed that posttest knee valgus at PKF was significantly less (-2.69 $\pm$ 9.33) when compared to retention test knee valgus at PKF (-6.62 $\pm$ 12.72) (p = 0.018) with an associated effect size of *d* = 0.27. When comparing feedback groups versus control group, there was no significant feedback group main effect for knee valgus at PKF during the running-stop jump task ($F_{1,41} = 0.53$, $p = 0.472$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for knee valgus at PKF during the running-stop jump task ($F_{1,41} = 0.65$, $p = 0.424$).

Hip Flexion at PKF

When comparing feedback groups versus control group, there was a significant test time main effect for hip flexion at PKF during the running-stop jump task ($F_{1,41} = 4.65$, $p = 0.037$). Pairwise comparisons showed that retention test hip flexion at PKF was significantly greater (65.79 + 12.98) when compared to posttest hip flexion at PKF (61.90 + 12.40) ($p = 0.037$) with an associated effect size of $d = 0.25$. When comparing feedback groups versus control group, there was no significant feedback group main effect for hip flexion at PKF during the running-stop jump task ($F_{1,41} = 0.85$, $p = 0.363$). When comparing feedback groups versus control group, there was no significant test time and feedback group interaction for hip flexion at PKF during the running-stop jump task ($F_{1,41} = 0.76$, $p = 0.387$).

Hip Abduction at PKF

When comparing feedback groups versus control group, there was no significant test time main effect for hip abduction at PKF during the running-stop jump task ($F_{1,41} = 1.01$, $p = 0.320$). When comparing feedback groups versus control group, there was no significant feedback group main effect for hip abduction at PKF during the running-stop jump task ($F_{1,41} = 0.01$, $p = 0.921$). When comparing feedback groups versus control group, there was no test time and feedback group interaction for hip abduction at PKF during the running-stop jump task ($F_{1,41} = 0.62$, $p = 0.437$).

Side-Step Maneuver Retention Test

There was no significant difference between feedback groups for any of the dependent variables during the side-step maneuver task. A summary with all statistical results are presented in Appendix 6

Side-Step Maneuver Retention Test – Feedback Groups vs. Control

There was no significant difference between feedback groups versus control group for any of the dependent variables during the side-step maneuver task. A summary with all statistical results are presented in Appendix 7.

Change Scores

There was a significant feedback main effect for change score immediate of hip flexion at PKF during the box-drop jump task ($p=0.030$). Pairwise comparisons showed that combo feedback group had a significantly more positive change score value (6.62 ± 9.61) than the self feedback group (6.06 ± 6.99) ($p=0.025$). Pairwise comparisons also showed that the combo feedback group had a significantly more positive change score value of hip flexion at PKF (6.62 ± 9.61) than the control group (-0.55 ± 7.99) ($p = 0.016$). There was no significant difference between feedback groups for change score immediate for the remaining variables. All change score 1 graphs can be found in Appendix 8.

There was a significant feedback main effect for change score retention of hip flexion at IC during the box-drop jump task ($p = 0.055$). Pairwise comparisons showed that the self feedback group had a significantly more positive change score value of hip flexion at IC (1.80 ± 5.43) than the combo feedback group (-5.49 ± 9.28) ($p = 0.020$). There was no significant difference between feedback groups for change score retention for the remaining variables. All change score 2 graphs can be found in Appendix 9.

Table 1 – Box-Drop Jump Self Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Pretest	-17.34	5.34	-14.38	-20.29
Posttest	-17.17	5.52	-14.11	-20.23
Retention	-17.02	5.53	-13.96	-20.08
Knee Valgus IC				
Pretest	-2.34	2.72	-0.83	-3.85
Posttest	-1.98	2.44	-0.63	-3.33
Retention	-1.75	2.59	-0.31	-3.18
Hip Flexion IC				
Pretest	36.29	7.39	32.20	40.38
Posttest	37.99	8.52	33.27	72.71
Retention	38.09	5.13	35.25	40.93
Hip Abduction IC				
Pretest	-3.87	3.20	-5.64	-2.09
Posttest	-4.40	3.56	-6.37	-2.43
Retention	-5.01	3.49	-6.95	-3.08
Knee Flexion PKF				
Pretest	-80.71	6.25	-77.25	-84.17
Posttest	-84.19	7.00	-80.31	-88.07
Retention	-82.82	8.29	-78.23	-87.42
Knee Valgus PKF				
Pretest	0.81	10.33	-4.91	6.52
Posttest	1.77	8.89	-3.15	6.69
Retention	-1.62	11.91	-8.22	4.98
Hip Flexion PKF				
Pretest	73.45	10.30	67.75	79.16
Posttest	79.51	10.46	73.72	85.30
Retention	80.01	10.61	74.13	85.88
Hip Abduction PKF				
Pretest	-3.29	5.19	-6.17	-0.42
Posttest	-5.81	4.97	-8.56	-3.06
Retention	-6.74	7.59	-10.94	-2.53

Table 2 – Box-Drop Jump Combo Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Pretest	-28.72	12.11	-22.01	-35.42
Posttest	-28.55	11.34	-19.14	-34.83
Retention	-22.99	6.96	-19.14	-26.85
Knee Valgus IC				
Pretest	-3.61	4.66	-1.03	-6.19
Posttest	-3.38	4.41	-0.94	-5.82
Retention	-3.09	5.59	0.01	-6.19
Hip Flexion IC				
Pretest	44.81	11.40	38.50	51.12
Posttest	44.26	11.05	38.14	50.37
Retention	39.33	7.49	35.18	43.47
Hip Abduction IC				
Pretest	-4.07	4.32	-1.68	-6.46
Posttest	-5.16	2.89	-3.56	-6.76
Retention	-5.13	3.67	-3.09	-7.16
Knee Flexion PKF				
Pretest	-88.07	12.60	-81.09	-95.05
Posttest	-95.18	14.59	-87.10	-103.26
Retention	-89.83	14.73	-81.68	-97.99
Knee Valgus PKF				
Pretest	0.63	9.07	-4.39	5.66
Posttest	2.67	10.21	-2.99	8.32
Retention	-1.99	14.73	-10.15	6.16
Hip Flexion PKF				
Pretest	79.73	13.82	72.08	87.39
Posttest	86.35	13.10	79.09	93.61
Retention	82.44	11.87	75.87	89.02
Hip Abduction PKF				
Pretest	-3.42	5.31	-6.36	-0.48
Posttest	-7.57	4.70	-10.17	-4.97
Retention	-7.01	4.48	-9.49	-4.53

Table 3 – Box-Drop Jump Control Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Pretest	-20.62	7.16	-16.30	-24.95
Posttest	-21.65	9.27	-16.05	-27.25
Retention	-18.19	8.06	-13.32	-23.06
Knee Valgus IC				
Pretest	-1.68	4.09	0.79	-4.16
Posttest	-2.31	4.22	0.24	-4.86
Retention	-2.43	4.08	0.04	-4.89
Hip Flexion IC				
Pretest	40.51	7.24	36.14	44.89
Posttest	40.52	7.01	36.28	44.75
Retention	40.24	8.97	34.82	45.66
Hip Abduction IC				
Pretest	-5.43	4.95	-8.42	-2.43
Posttest	-5.73	4.35	-8.35	-3.10
Retention	-4.57	3.57	-6.73	-2.41
Knee Flexion PKF				
Pretest	-81.85	14.71	-72.96	-90.74
Posttest	-81.42	12.50	-73.87	-88.98
Retention	-78.92	10.49	-72.58	-85.27
Knee Valgus PKF				
Pretest	2.82	8.95	-2.59	8.23
Posttest	2.25	8.85	-3.10	7.60
Retention	-2.70	8.55	-7.86	2.47
Hip Flexion PKF				
Pretest	77.24	11.87	70.07	84.42
Posttest	76.69	11.48	69.75	83.62
Retention	79.19	12.42	71.69	86.70
Hip Abduction PKF				
Pretest	-6.16	8.69	-11.41	-0.91
Posttest	-7.33	9.09	-12.82	-1.83
Retention	-8.02	6.21	-11.77	-4.26

Table 4 – Running-Stop Jump Self Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Posttest	-25.51	10.35	-19.77	-31.24
Retention	-32.98	15.04	-24.65	-41.31
Knee Valgus IC				
Posttest	-3.46	4.19	-5.78	-1.14
Retention	0.58	5.27	-2.34	3.50
Hip Flexion IC				
Posttest	49.07	10.31	43.36	54.77
Retention	44.46	9.41	39.25	49.67
Hip Abduction IC				
Posttest	-3.66	3.87	-5.80	-1.52
Retention	-3.13	6.16	-6.54	0.28
Knee Flexion PKF				
Posttest	-66.31	10.76	-60.35	-72.27
Retention	-70.42	8.56	-65.68	-75.15
Knee Valgus PKF				
Posttest	-0.91	9.74	-6.30	4.48
Retention	-1.93	11.33	-8.21	4.34
Hip Flexion PKF				
Posttest	63.10	10.81	57.12	69.08
Retention	61.71	11.31	55.45	67.97
Hip Abduction PKF				
Posttest	-3.08	6.26	-6.55	0.39
Retention	-3.78	5.44	-6.80	-0.77

Table 5 – Running-Stop Jump Combo Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Posttest	-41.21	17.86	-31.32	-51.11
Retention	-30.53	15.17	-22.13	-38.93
Knee Valgus IC				
Posttest	-2.64	6.54	-6.26	0.98
Retention	-2.96	6.95	-6.81	0.89
Hip Flexion IC				
Posttest	56.30	14.19	48.44	64.16
Retention	51.63	9.89	46.16	57.11
Hip Abduction IC				
Posttest	-3.77	5.56	-6.84	-0.69
Retention	-3.74	6.12	-7.13	-0.35
Knee Flexion PKF				
Posttest	-76.37	11.06	-70.25	-82.50
Retention	-76.36	14.64	-84.47	-68.26
Knee Valgus PKF				
Posttest	-3.31	7.54	-7.49	0.86
Retention	-7.58	13.11	-14.84	-0.32
Hip Flexion PKF				
Posttest	65.80	15.59	57.17	74.43
Retention	71.81	15.30	63.34	80.28
Hip Abduction PKF				
Posttest	-2.82	4.70	-5.42	-0.22
Retention	-4.84	5.58	-7.93	-1.75

Table 6 – Running-Stop Jump Control Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC				
Posttest	-33.30	15.93	-23.68	-42.93
Retention	-31.00	15.16	-21.84	-40.16
Knee Valgus IC				
Posttest	-3.07	9.62	-8.88	2.74
Retention	-3.26	8.27	-8.25	1.74
Hip Flexion IC				
Posttest	53.98	10.08	47.89	60.07
Retention	52.50	8.44	47.41	57.60
Hip Abduction IC				
Posttest	-4.34	5.84	-7.87	-0.81
Retention	-6.75	5.07	-9.82	-3.69
Knee Flexion PKF				
Posttest	-67.96	8.08	-63.08	-72.84
Retention	-70.50	7.99	-65.67	-75.32
Knee Valgus PKF				
Posttest	-3.26	11.11	-9.97	3.45
Retention	-8.49	13.63	-16.73	-0.25
Hip Flexion PKF				
Posttest	59.36	9.72	53.48	65.23
Retention	64.82	10.04	58.75	70.88
Hip Abduction PKF				
Posttest	-3.72	6.94	-7.92	0.47
Retention	-3.89	6.03	-7.53	-0.25

Table 7 – Side-Step Self Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC	-19.9	5.96	-16.59	-23.2
Knee Valgus IC	-5.15	4.16	-2.84	-7.45
Hip Flexion IC	45.95	7.64	41.72	50.18
Hip Abduction IC	-4.70	4.86	-7.39	-2.01
Knee Flexion PKF	-47.92	6.22	-44.47	-51.36
Knee Valgus PKF	-4.95	8.19	-9.48	-0.41
Hip Flexion PKF	38.72	9.30	33.57	43.87
Hip Abduction PKF	-7.54	7.33	-11.59	-3.48

Table 8 – Side-Step Combo Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC	-18.14	6.22	-14.70	-21.59
Knee Valgus IC	-7.12	5.36	-10.09	-4.15
Hip Flexion IC	43.73	7.75	39.44	48.01
Hip Abduction IC	-7.91	6.76	-11.65	-4.17
Knee Flexion PKF	-47.06	6.26	-43.6	-50.53
Knee Valgus PKF	-5.44	7.41	-9.54	-1.33
Hip Flexion PKF	33.63	6.67	29.94	37.32
Hip Abduction PKF	-7.51	6.82	-11.28	-3.73

Table 9 – Side-Step Control Feedback Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
Knee Flexion IC	-18.93	5.75	-15.45	-22.4
Knee Valgus IC	-6.03	3.69	-8.27	-3.8
Hip Flexion IC	45.33	6.88	41.18	49.49
Hip Abduction IC	-7.49	5.92	-11.07	-3.91
Knee Flexion PKF	-46.32	6.41	-42.45	-50.19
Knee Valgus PKF	-5.44	8.17	-10.38	-0.51
Hip Flexion PKF	35.85	8.95	30.45	41.26
Hip Abduction PKF	-9.60	4.92	-12.58	-6.63

Table 10 - Pretest Box-Drop Jump Descriptives

	Mean	SD	95% CI: Lower	95% CI: Upper
BDJ Knee Flexion IC	-22.23	9.87	-19.26	-25.34
BDJ Knee Valgus IC	-2.58	3.89	-3.78	-1.39
BDJ Hip Flexion IC	40.54	9.46	37.63	43.45
BDJ Hip Abduction IC	-4.41	4.14	-5.68	-3.14
BDJ Knee Flexion PKF	-83.62	11.78	-79.99	-87.25
BDJ Knee Valgus PKF	1.36	9.32	-1.51	4.22
BDJ Hip Flexion PKF	76.79	12.10	73.06	80.51
BDJ Hip Abduction PKF	-4.20	6.45	-6.19	-2.22

Table 11 - Posttest Box-Drop Jump Descriptives

Posttest BDJ	Mean	SD	95% CI: Lower	95% CI: Upper
BDJ Knee Flexion IC	-22.49	10.05	-19.4	-25.58
BDJ Knee Valgus IC	-2.57	3.73	-3.72	-1.42
BDJ Hip Flexion IC	40.94	9.28	38.08	43.79
BDJ Hip Abduction IC	-5.06	3.57	-6.16	-3.97
BDJ Knee Flexion PKF	-87.19	12.97	-83.2	-91.18
BDJ Knee Valgus PKF	2.23	9.14	-0.59	5.04
BDJ Hip Flexion PKF	81.04	12.17	77.3	84.79
BDJ Hip Abduction PKF	-6.88	6.31	-8.82	-4.94

Table 12 - Retention Test Box-Drop Jump Descriptives

Retention BDJ	Mean	SD	95% CI: Lower	95% CI: Upper
BDJ Knee Flexion IC	-19.46	7.21	-17.24	-21.68
BDJ Knee Valgus IC	-2.42	4.21	-3.72	-1.12
BDJ Hip Flexion IC	39.17	7.16	36.97	41.37
BDJ Hip Abduction IC	-4.92	3.50	-6.00	-3.84
BDJ Knee Flexion PKF	-84.09	12.14	-80.35	-87.83
BDJ Knee Valgus PKF	-2.076	11.86	-5.73	1.57
BDJ Hip Flexion PKF	80.61	11.43	77.09	84.13
BDJ Hip Abduction PKF	-7.22	6.1	-9.20	-5.34

Table 13 – Posttest Running-Stop Jump Descriptives

Posttest RS	Mean	SD	95% CI: Lower	95% CI: Upper
RS Knee Flexion IC	-33.34	16.08	-28.39	-38.29
RS Knee Valgus IC	-3.06	6.83	-5.16	-0.96
RS Hip Flexion IC	53.08	11.88	49.42	56.73
RS Hip Abduction IC	-3.90	5.01	-5.45	-2.36
RS Knee Flexion PKF	-70.32	10.89	-66.97	-73.67
RS Knee Valgus PKF	-2.46	9.33	-5.33	0.41
RS Hip Flexion PKF	62.91	12.40	59.09	66.73
RS Hip Abduction PKF	-3.18	5.86	-4.99	-1.38

Table 14 – Retention Test Running-Stop Jump Descriptives

Retention RS	Mean	SD	95% CI: Lower	95% CI: Upper
RS Knee Flexion IC	-31.53	14.80	-26.97	-36.08
RS Knee Valgus IC	-1.81	6.93	-3.95	0.32
RS Hip Flexion IC	49.39	9.79	46.38	52.41
RS Hip Abduction IC	-4.44	5.91	-6.26	-2.62
RS Knee Flexion PKF	-72.51	11.05	-69.11	-75.92
RS Knee Valgus PKF	-5.89	12.72	-9.8	-1.97
RS Hip Flexion PKF	66.17	12.98	62.18	70.17
RS Hip Abduction PKF	-4.19	5.56	-5.89	-2.48

Table 15 – Retention Test Side-Step Maneuver Descriptives

Retention SS	Mean	SD	95% CI: Lower	95%CI: Upper
SS Knee Flexion IC	-18.99	5.89	-17.18	-20.81
SS Knee Valgus IC	-6.10	4.47	-7.48	-4.73
SS Hip Flexion IC	44.99	7.34	42.73	47.25
SS Hip Abduction IC	-6.67	5.94	-8.49	-4.84
SS Knee Flexion PKF	-47.14	6.17	-45.24	-49.04
SS Knee Valgus PKF	-5.27	7.73	-7.65	-2.89
SS Hip Flexion PKF	36.08	8.44	33.48	38.68
SS Hip Abduction PKF	-8.15	6.42	-10.13	-6.17

Figure 1: Peak Knee Flexion Means Over Time

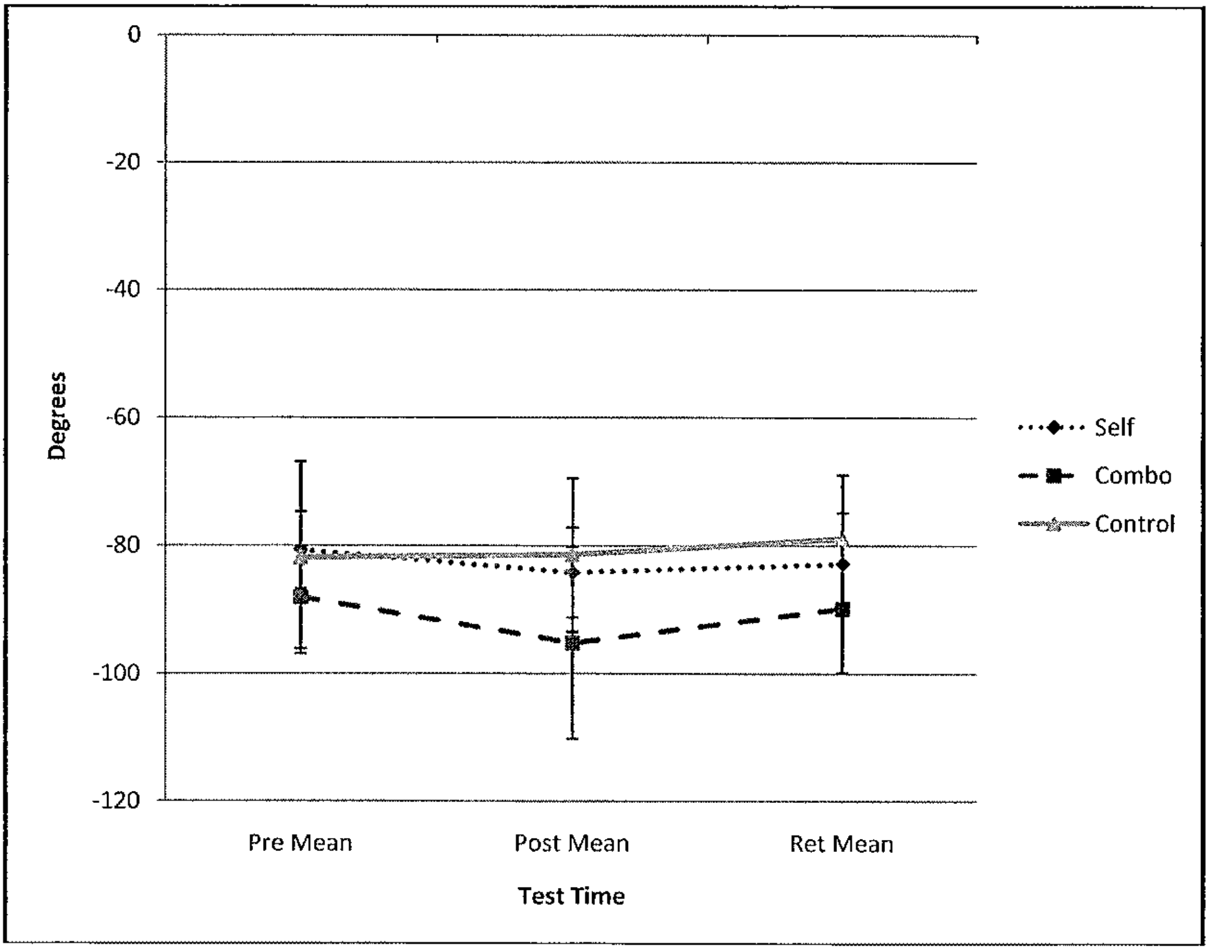


Figure 2: Hip Flexion at PKF Means Over Time

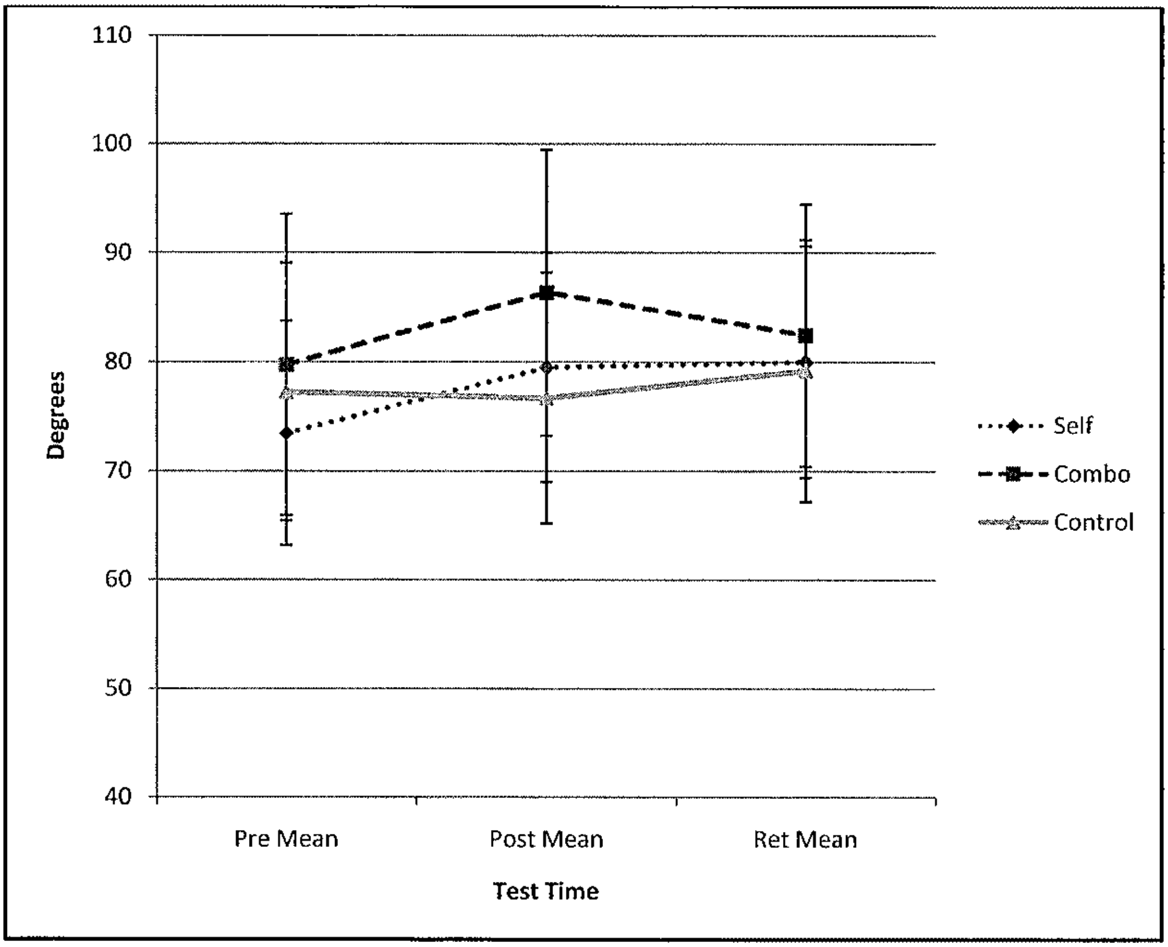
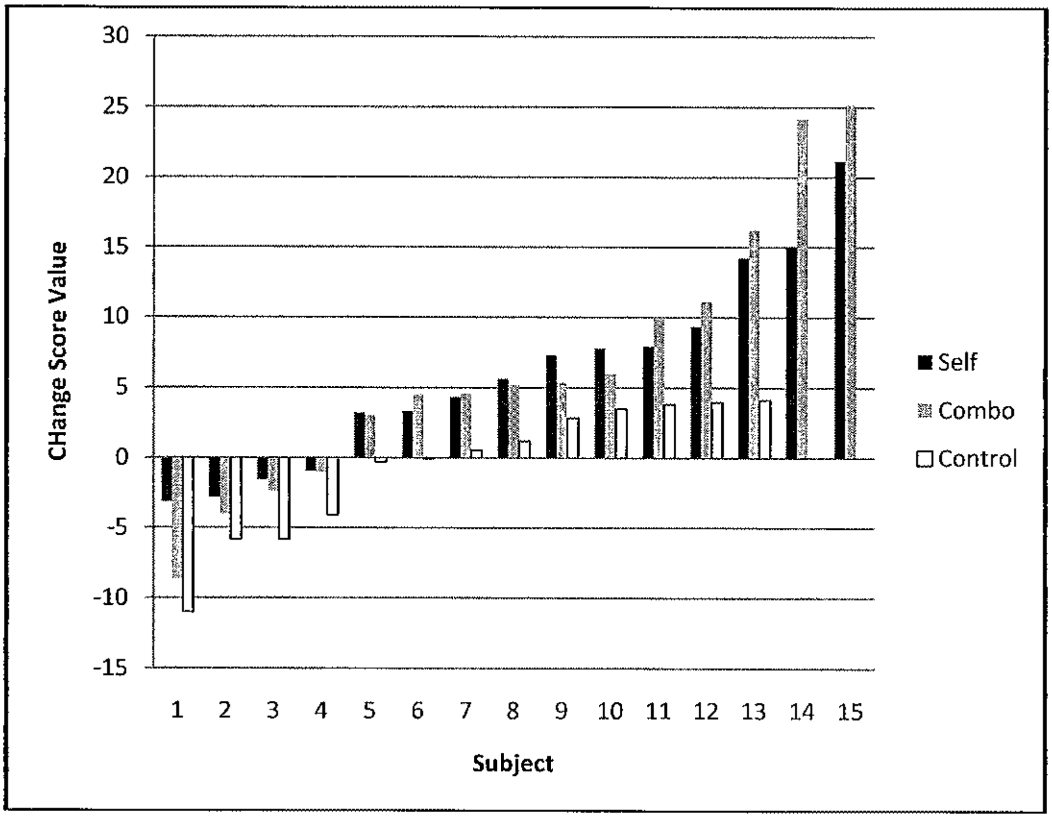
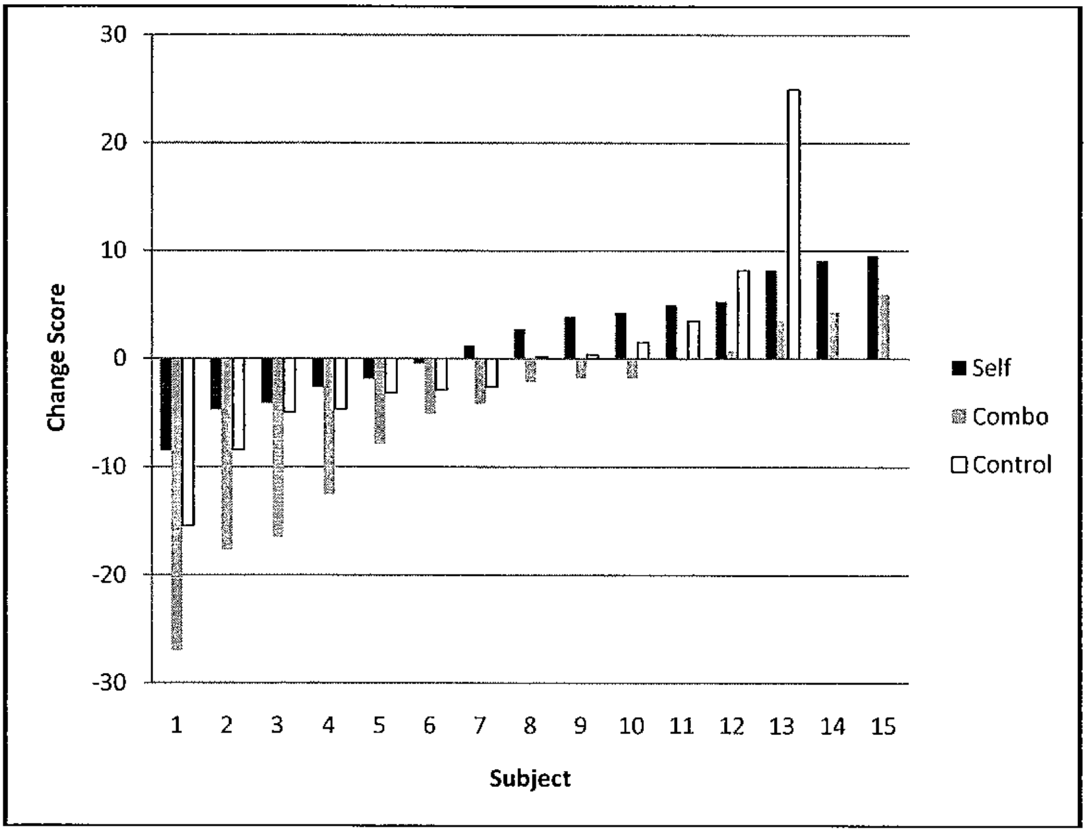


Figure 3: Change Score Immediate for Box-Drop Jump Hip Flexion at PKF



Negative change scores indicate a decrease in hip flexion at PKF between test sessions while a positive change score indicates an increase in hip flexion at PKF.

Figure 4: Change Score Retention for Box-Drop Jump Hip Flexion at IC



Negative change scores indicate a decrease in hip flexion at IC between test sessions while a positive change score indicates an increase in hip flexion at IC.

Discussion

The main purpose of this study was to determine if instruction (self or combo) improved lower extremity kinematics (knee flexion, knee valgus, hip flexion, hip abduction) over time while performing a box-drop jump, running-stop jump, and side-step maneuver in healthy college age female athletes. We hypothesized that the combo feedback group would show the greatest improvement on lower extremity kinematics during all three tasks compared to the self feedback and control group. We also hypothesized that when combining both feedback groups, feedback would improve lower extremity kinematics greater than no feedback (control group). Supporting our hypotheses, it was found that during both the box-drop jump and running-stop jump, there was a significant improvement for feedback group. The combo feedback group had greater peak knee flexion than the self-feedback group during both tasks, while the combo group also had greater peak knee flexion than the control group while performing a running-stop jump. Also supporting our hypotheses, it was found that for the box-drop jump task there was a significant improvement across test time. Subjects had significantly greater hip flexion at PKF during the posttest box-drop jump than the pretest box-drop jump. Also, the hip flexion angle at PKF during the box-drop jump task was significantly greater during retention testing than pretest. This may suggest that learning occurred and was maintained across the one-month time frame.

Box-Drop Jump

Feedback Group

It was hypothesized that the combo feedback group would have significantly greater peak knee flexion during the box-drop jump task compared to the self feedback and control group. The results confirmed what we initially hypothesized; the subjects who received combo (self and expert) feedback had significantly greater peak knee flexion than the self-feedback group. Only one other study has used similar feedback groups to provide instruction on a jump-landing task (Onate et al., 2005). This study did not give information related to a box-drop task, but instead provided feedback about a running-stop jump. Onate and associates (2005) found that a combination of self and expert feedback produced a significant improvement in knee flexion angles at maximum knee flexion compared to the control group at posttest and retention testing (Onate et al., 2005). Other studies have also shown that using a combination of verbal and visual or video feedback, is effective in the acquisition of a new skill as well as the retention of the skill (Guadagnoli et al., 2002; Janelle et al., 2003). Guadagnoli et al. (2002) found that although no groups improved accuracy of a golf swing during immediate posttest, the verbal and video groups showed a significant increase in accuracy two weeks after the initial test, with the video instruction group showing the greatest improvement (Guadagnoli et al., 2002). Verbal and visual feedback has also been utilized in an effort to reduce landing forces (McNair et al., 2000; Onate et al., 2001; Prapavessis & McNair, 1999). Onate et al (2001) used a simple jump-landing task in which subjects were instructed to stand directly behind the force plates and jump as high as they could touching a Vertec jumping instrument with their dominant hand (Onate et al., 2001). The group that received both verbal and self video feedback significantly reduced their peak vertical ground reaction forces compared to the sensory and control groups (Onate et al., 2001). Although this study did not look at the kinematics of the jump-landing task, it did provide evidence to the effectiveness of using verbal and video feedback and its ability to reduce lower extremity kinetics. In both studies conducted by Onate et al. instructions given to the subjects included the phrase, "land as soft as possible" (Agel et al., 2005; Onate et al., 2005; Onate et al., 2001). Commonly this phrase is intended to provide instruction and feedback related to ground reactions forces (McNair et al., 2000; Prapavessis & McNair, 1999). This is a distinguishable difference between the current study and previous research. Our study did not address ground reaction forces but solely evaluated joint angles and therefore this was not included in our instructions.

Contrary to our hypotheses, during the box-drop jump task all other lower extremity kinematic variables (knee valgus, hip flexion, and hip abduction) were not significant between feedback groups at initial contact (IC) or peak knee flexion. There was also no significant difference in kinematic variables when comparing both feedback groups to the control group at initial contact or maximum knee flexion during the box-drop task. Through our research, we have not found a study that has evaluated the rest of these kinematic variables, besides knee flexion at IC, with the same feedback groups. Onate et al. (2005) also analyzed knee flexion at IC following self, expert, and combination feedback but during a running-stop jump task. This study also found no significant difference between feedback groups for knee flexion angle at IC (Onate et al., 2005). One reason these variables, particularly knee flexion at IC, may not have been significant between the feedback groups may be due to the feedback provided. While the feedback tool used focused on both the knee and hip angles, it did not break the movement down into initial contact and maximum knee flexion time frames. Instead, the feedback was based on more global movements of the joints. An example of this feedback includes, was the knee angle greater than 30 degrees or was the trunk in front of the hips.

Although the only variable in which a significant difference between feedback groups was found was peak knee flexion. This is a relevant finding due to the important role knee flexion is thought to play in incidence of ACL injuries. Studies have found that females display decreased knee flexion angles when compared to males during jump landing activities (James et al., 2004; McLean et al., 1999; Pappas et al., 2007). Maximum knee flexion has already been found to increase following feedback from a running-stop jump task (Onate et al., 2005). Our study now shows that verbal and video feedback is also effective in improving peak knee flexion angles following simple box-drop jump instruction; in turn potentially placing the subject in a better body alignment position in the hopes of reducing the subjects' risk of an ACL injury.

Test Time

Our primary hypothesis regarding test time and kinematic values during the box-drop jump task was that subjects would improve their landing mechanics from pretest to posttest and would then retain those changes from posttest to retention test. Our results varied greatly across variables and time. Pretest to posttest showed improvement in two variables, particularly hip flexion at PKF and peak knee flexion. This improvement was only able to be retained during the retention test for hip flexion at PKF however.

Hip flexion at PKF was the only variable that significantly improved from pretest to posttest and then also significantly improved from pretest to retention test when comparing all three feedback groups and feedback versus control. This indicates that during the box-drop jump task subjects increased their hip flexion angle at PKF significantly more from pretest to posttest. Coinciding with this finding, there was a significant positive immediate change score for hip flexion at PKF during the box-drop jump task. The combo feedback group had significantly greater positive change scores for hip flexion at PKF compared to self feedback and control group from pretest to posttest. Although there was no significant feedback group and test time interaction for hip flexion at PKF, the significant change score values indicate that the combo feedback group had greater improvement in this angle than the other two groups from pretest to posttest and indicates that a learning effect occured. Subjects also retained this increased hip flexion angle at PKF during this retention test. To our knowledge no other studies using verbal and video feedback to improve lower extremity kinematics or kinetics have evaluated hip flexion at PKF. Research relating to gender differences has shown that females tend to land from a jump with a reduced hip flexion angle (Salci et al., 2004). This is noteworthy because when landing with a more erect posture, including a smaller hip flexion angle and smaller knee flexion angle an athlete could be a greater risk for an ACL injury (Griffin et al., 2000). Since subjects were able to improve their hip flexion at PKF from pretest to posttest as well as pretest to retention test is suggests that they learned and retained the feedback, leading to a better lower extremity alignment and hopefully a decreased risk of an ACL injury.

The only other variable to significantly improve during the box-drop task from pretest to posttest was peak knee flexion when comparing all three feedback groups and feedback versus control. However, peak knee flexion significantly decreased from posttest to retention test during the box-drop task when comparing all three feedback groups and feedback versus control. This suggests that subjects improved their peak knee flexion angle but were unable to retain this improvement during the retention test. Onate et al. (2005) also looked at the retention of peak knee flexion. An important difference between the methodologies of these two studies was the length of time from posttest to retention test. Onate et al. (2005) evaluated the retention of instruction after one week while the average time between posttest and retention test in our study was five and a half weeks. Like our study they found that there was an increase in peak knee flexion at immediate posttest. Although they found that subjects were able to retain this increase in maximum knee flexion at retention testing while the subjects in our study significantly decreased from posttest to retention. This difference in the length of time for retention testing may be a contributing factor as to why Onate et al. (2005) found a significant increase in peak knee flexion angles from baseline to retention while we found a significant decrease from posttest to retention.

Completely contradicting with what we hypothesized, hip abduction at PKF was significantly less during posttest compared to pretest and was also significantly less during the retention test compared to the pretest. This indicates that subjects went into more adduction at PKF during the posttest compared to pretest. Also, subjects had significantly less hip abduction at PKF during retention test box-drop jump than during the pretest. It has been suggested that hip abduction plays a role in the amount of valgus at the knee (Pappas et al., 2007). Pappas et al. (2007) reported that while performing a bilateral box-drop landing subjects initially landed with 1.2 degrees of hip abduction but at peak knee flexion they displayed 1.5 degrees of hip adduction (Pappas et al., 2007). The subjects' in our study were actually in considerably greater hip adduction than reported by Pappas et al (2007), with a mean hip adduction angle 7.22 during retention testing.

Also contradicting our hypotheses, during the box-drop jump task the knee valgus angle at PKF did not decrease but actually went into significantly greater valgus from both pretest to retention test and posttest to retention test. This suggests that subjects went into a more valgus position than varus throughout the testing sessions and were not able to learn or retain any information related to knee valgus position. Although no studies have looked directly at knee valgus at PKF during a running-stop jump following feedback, Hewett et al. (2005) evaluated lower extremity kinematics of high school female athletes who later went on to tear their ACL (Hewett et al., 2005). These authors found that females who tore their ACL had significantly greater knee valgus angles at maximum, 7.6 degrees greater, than non-injured females during a box-drop jump (Hewett et al., 2005). Due to the possible link between a valgus position of the knee and the incidence of ACL injuries, the finding that knee valgus angles at PKF actually increased from pretest and posttest to retention test is unfavorable. Rather, it may indicate a potentially dangerous jump landing position. Factors that may have caused the increase in valgus angles may be due to a possible lack of flexibility, decreased strength hindering their ability to control the movement, or they may have been over thinking the task.

Finally, during the box-drop jump task knee flexion angles at IC and hip flexion angles at IC significantly decreased from posttest to retention test, which also do not support what we hypothesized. There was no significant difference between test times for the remaining variables. There was a significant retention change score for hip flexion at IC during the box-drop jump task. The self feedback group had significantly more positive scores than the combo feedback group for hip flexion at IC from pretest to retention test. This indicates that the self feedback group actually improved their hip flexion angles at initial contact over time more than the combo feedback group and potentially had a greater retention of the skill. A decrease in knee flexion at initial contact has been linked to an increase risk of ACL injury (Cochrane et al., 2007; Ireland, 1999). In one study 91.7% of all noncontact ACL injuries occurred when the knee was flexion less than 30 degrees at initial contact (Cochrane et al., 2007). Although knee flexion at IC was not shown to decrease from pretest to posttest, the decrease from posttest to retention test is not ideal due to the mean value at retention test was -19.43 degrees. Regardless of feedback, the subjects knee flexion angles at initial contact are clearly below the preferred knee flexion angles at initial contact. This decreased knee flexion angle at IC from posttest to retention test may be in part due to the more global feedback given during the initial testing. Instead of distinguishing directly between how the subjects should be landing at initial contact and at peak knee flexion, the feedback focused on joint positions of the overall jump landing.

Summarizing our findings from box-drop jump test time, it has been found that subjects displayed a learning effect from pretest to posttest for hip flexion at PKF and peak knee flexion. These subjects were able to retain the learning effect of hip flexion at PKF from pretest to retention test, but did not retain peak knee flexion from posttest to retention test. Contradicting our hypotheses, hip abduction at PKF decreased from pretest to posttest as well as from pretest to retention test. Also contradicting what we hypothesized, knee valgus at PKF significantly increased from both pretest and posttest to retention test. Finally, knee flexion at IC and hip flexion at IC significantly decreased from posttest to retention test, indicating that any possibility of a learning effect was not retained.

Running-Stop Jump

Feedback Group

It was hypothesized that during the running-stop jump, initial transfer test, the combo feedback group would have greater peak knee flexion compared to the self feedback and control group. There was a main effect for feedback group during the running-stop jump for peak knee flexion, supporting our hypothesis that the combo feedback group would have greater peak knee flexion than both the self feedback and control group. To our knowledge only one other study conducted by Onate et al. (2005) provided instruction using similar feedback groups during a running-stop jump task (Onate et al., 2005). This study found comparable results to ours, demonstrating that a combination of self and expert video feedback was effective in increasing maximum knee flexion angles (Onate et al., 2005). It, however, used different methodology than ours. The subjects in their study performed a running-stop jump, simulating a jump ball in basketball. Subjects then received feedback on their jump landing from this task. In our study, the feedback was given about subjects' box-drop jump landing and not the running-stop jump task.

There was no significant difference between feedback groups for all other kinematic variables (knee valgus, hip flexion, and hip abduction) at initial contact or maximum knee flexion during the running-stop jump task when comparing all three feedback groups and feedback versus control. One similar study conducted by Onate et al. (2005) also found no significant difference between feedback groups for knee flexion at IC during a running-stop jump task (Onate et al., 2005). Although their feedback was given regarding a subjects landing following a running-stop jump task and ours was given about the landing from a box-drop task, it appears that both similar forms of feedback were not effective in providing feedback about initial contact. Contrary to our findings, Cowling et al. (2003) found that simple verbal instruction related to the bending of the knees before landing was effective in increasing knee flexion at IC and peak resultant ground reaction force during a running-stop jump task (Cowling et al., 2003). The authors may have significantly increased knee flexion at IC because the feedback that they provided was based simply on landing with their knees bent. Our feedback included visual as well as verbal feedback and was focused on multi-joint positions.

Corresponding with feedback group findings for box-drop jump, the only significant difference between feedback groups was peak knee flexion. It does, however, correspond with our hypothesis that a combination of self and expert feedback would show the greatest improvement in peak knee flexion angles. This is still a significant and important finding due to the important role that knee flexion angles play in the incidence of ACL injuries (Cochrane et al., 2007; Griffin et al., 2000; Ireland, 1999). Also, these results coincide with the results of Onate et al. (2005) finding that the combination of expert and self simple verbal and video feedback is effective at improving peak knee flexion angles.

Test Time

We hypothesized that during the running-stop jump task, kinematic variables would be improved from posttest to retention test. Our results varied greatly between variables. There was a significant main effect for hip flexion at PKF during the running-stop jump task when comparing all three feedbacks and also when comparing feedback versus control. The hip flexion angle at PKF was greater during the retention test than the posttest. This indicates that the subjects were able to improve their hip flexion angle at PKF between testing sessions. No other research has evaluated the improvement of hip flexion angles during a running-stop jump over time or as an initial transfer test. Research has found that a difference does exist post fatigue and between males and females for hip flexion at maximum knee flexion during a running-stop jump task (Orishimo & Kremenic, 2006; Yu et al., 2005). Yu et al. (2005) found that male youth soccer players had significantly greater hip flexion angles at maximum knee flexion when compared to females (Yu et al., 2005). Males actually maintained the same hip flexion angle at PKF from ages 11 to 16, whereas females hip flexion angle at PKF decreased starting at age 13 (Yu et al., 2005). Combining the results of our study that hip flexion at PKF increased from posttest to retention testing with the results of previous research findings that females display a decreased hip flexion angle at PKF compared to males, we can infer that the females in our study decreased the at risk position for an ACL during a running-stop jump task.

Contradicting what we hypothesized, there was a significant decrease in hip flexion angles at IC and knee valgus angles at PKF from posttest to retention test when we expected to see an increase in hip flexion at IC and a more varus position of the knee at PKF. This was found when comparing all three feedback groups and feedback versus control. There was no significant difference between test times for the remaining kinematic variables. As stated previously, there has been no prior research evaluating lower extremity kinematics while performing a running-stop jump over time. Other studies have shown that hip flexion at initial contact and maximum knee valgus angle differs between male and females during jump-landing tasks and is altered pre to post fatigue (Benjaminse et al., 2008; Chappell et al., 2007; Salci et al., 2004; Sell et al., 2006; Yu et al., 2006). Yu et al. (2006) and Chappell et al. (2007) have both found that when performing a running-stop jump, females hip flexion angle at initial contact is significantly less than males (Chappell et al., 2007; Yu et al., 2006). Although these authors have found a significant difference between genders for hip flexion at IC, indicating that females are landing in a stiffer hip joint position, our study actually found a decrease in hip flexion angles at initial contact over time following instruction.

The only variable that supported our hypotheses and significantly improved from posttest to retention test for the running-stop jump was hip flexion at PKF. Hip flexion at initial contact and knee valgus at PKF actually differed from out hypotheses. Knee valgus at PKF actually increased from posttest to retention test for the running-stop jump. Interestingly, the same variable increased from pretest to retention test for the box-drop jump task. Similarly, hip flexion at initial contact decreased for the running-stop jump from posttest to retention test, but also decreased from posttest to retention test for the box-drop jump task.

Side-Step Maneuver

Feedback Group

It was hypothesized that at initial contact and maximum knee flexion the combo feedback group would have significant kinematic changes during the side-step maneuver compared to the self feedback and control groups. It was also hypothesized that at initial contact and maximum knee flexion both feedback groups would have significant kinematic changes during the side-step maneuver compared to the control group. Our results contradicted what we initially hypothesized. There was no significant difference between feedback groups for any of the kinematic variables at initial contact or maximum knee flexion for the side-step maneuver. To our knowledge no other study has used the side-step maneuver as a delayed transfer test for box-drop jump instruction. Also, no other studies have provided feedback related to the performance of a side-step maneuver. However, one study has analyzed the difference between genders during three different athletic tasks (Malinzak et al., 2001). These tasks included running, side-cutting, and cross-cutting (Malinzak et al., 2001). For all three of these tasks Malinzak et al. (2001) found that females were in a greater valgus position and the knee flexion angle was generally smaller for females than males (Malinzak et al., 2001). These same females had an increased quadriceps and decreased hamstring muscle activation than males (Malinzak et al., 2001). All of these motion patterns appear to suggest that females are placing their bodies in a position of greater risk for a noncontact ACL injury than their male counterparts.

The lack of significance in our study may be due to the large difference in tasks. Landing from a box and jumping up is a very basic task that is not sport specific. Although it is the basic form of a landing task, many other components are involved in landing from a running-stop jump for a jump ball or cutting quickly to the left or right. This means that using a box-drop jump to screen and correct lower extremity kinematics may not be functionally transferable to improving side-step maneuver kinematics. Research has showed that females display at-risk lower extremity kinematics predictive of an ACL injury and therefore a form of feedback or intervention needs to focus on these sport specific tasks instead of simple box-drop jump kinematics.

Transfer

A positive transfer of improvement for peak knee flexion from box-drop jump to running-stop jump occurred during this study. The combo feedback group had significantly greater peak knee flexion angles during the box-drop jump as well as the running-stop jump compared to the self feedback group. During the running-stop jump the combo feedback group also had significantly greater peak knee flexion angles compared to the control group. In a study conducted by Weigelt et al. (2000) it was found that subjects who practiced juggling a soccer ball with their feet not only performed significantly better during posttest feet juggling but posttest knee juggling as well (Weigelt et al., 2000). Juggling a soccer ball with the knees is a similar task to juggling a soccer ball with the feet. It was therefore determined that a positive transfer effect occurred due to the improvement in both tasks after only practicing with the feet (Weigelt et al., 2000). The running-stop jump in our study was used as an initial transfer test. This is because although the tasks use different landing mechanics, they are similar in nature. Typically, the box-drop jump involves a toe first landing while the running-stop jump utilizes a heel first landing. Similarities include landing with both feet at the same time, a landing phase, and a take-off phase. Considering the fact that peak knee flexion was significantly greater for the combo feedback group compared to the self for both the box-drop jump and the running-stop jump it can be inferred that a positive transfer effect occurred. This indicates that the combination of self and expert feedback relating to the landing mechanics of a box-drop jump could have a positive transfer effect in the improvement of peak knee flexion angles during a similar task, such as the running-stop jump.

There was no transfer of improvement from the learning of box-drop jump landing mechanics to the performance of a side-step maneuver. No significant difference was found between feedback groups during the side-step maneuver for any of the kinematic variables. An improvement in peak knee flexion for both the box-drop jump and running-stop jump for the combo feedback group was found indicating a positive transfer. However, there no significant differences between feedback groups for the side-step maneuver suggesting that no transfer, or neutral transfer, occurred. This could be due to a number of reasons. First, when using the theory of identical-elements one could say that there were not enough similar elements between the tasks for a positive transfer to occur (Cox, 1997; Magill, 2004; Rose, 1997). Although the side-step maneuver involves a landing phase like the box-drop jump, the two tasks are not that similar. The box-drop jump is not sport-specific involving few outside influences. The side-step maneuver on the other hand is more complex and is influenced by other factors such as speed of approach, anticipatory versus unanticipatory, and direction of cut. Secondly, the side-step maneuver was performed during the retention test of the study while the running-stop jump was performed during the immediate posttest. The running-stop may have been influenced more by instruction because the feedback was fresh in their mind where the side-step maneuver was only performed one month after the feedback.

There were also similar results between the box-drop jump and running-stop jump task in regards to test time. Hip flexion at PKF was significantly greater at retention test compared to posttest for both the box-drop jump and running-stop jump tasks. Also, contradicting our hypothesis, hip flexion at IC significantly decreased and knee valgus at PKF significantly increased from posttest to retention test for both tasks. It is important to note that these results may not be a true positive transfer of task. The definition of transfer of learning is the learning and practice of one skill and its influence on the learning of a new one (Magill, 2004; Rose, 1997). The significant findings are related to test time and not feedback group. Therefore, instruction cannot be attributed to the significant results. Instead, this could be a transfer of learning due to repetitively performing the tasks over time or it may be that all subjects, regardless of feedback, displayed similar mechanics from posttest to retention.

Clinical Relevance

The box-drop jump is a simple clinical tool that can be easily implemented in a variety of clinical settings. Following a box-drop jump, quick and concise feedback can be given regarding lower extremity alignment using the LESS as a systematic feedback tool. The findings of this study support the use of verbal and visual feedback of a simple box-drop jump as a means to improve jump landing lower extremity kinematics. Particularly, the combination of self and expert video feedback following a box-drop jump can improve peak knee flexion angles during both a box-drop jump and a running-stop jump. However, providing feedback of a box-drop jump landing does not lead to the improvement of knee flexion angles during a side-step maneuver. This may be due to the complex, sport-specific nature of the task that differs greatly from the simple box-drop jump.

Having an athlete perform a box-drop jump is effective at simulating a jump in the clinical setting for evaluation or rehabilitation, but it is not a sport specific task. The basic jump land is similar to that of a running-stop jump, which may explain why there was a positive transfer of peak knee flexion improvement for combo feedback group during the running-stop jump. On the other hand the side-step maneuver, although still utilizing a decelerating and landing phase, is a very different task than a box-drop jump. When athletes perform the box-drop jump and running-stop jump the task involves a deceleration followed by a stop in movement, where as the side-step maneuver is a deceleration followed by acceleration with no actual stop in movement. Many things go into such a sport-specific task including timing, defensive opponent, speed, strength, and all external and internal stimuli. Therefore, it may be more beneficial for basketball athletes who frequently perform a running-stop jump to receive feedback following a box-drop jump than soccer athletes who tend to perform side-step maneuvers more often. Future research therefore needs to focus on creating a feedback tool that relates specifically to the biomechanics of a side-step maneuver or pivoting movement.

It appears that the feedback provided was more globally based, as hip flexion at PKF and peak knee flexion showed significant improvement between feedback groups as well as test time. These are two large joint motions that subjects may be able to understand and focus on easier than knee valgus or hip abduction. Initial contact, particularly knee flexion, is still an area that needs to be emphasized through feedback due to its important relationship with ACL injuries. During the box-drop jump and running-stop jump tasks, there was no significant difference between feedback groups for knee flexion at IC. This is also true of the study conducted by Onate et al. (2005) in which they found no significant difference in knee flexion at IC following feedback of a running-stop jump task (Onate et al., 2005). Future research and feedback protocols need to address initial contact, specifically knee flexion, due to its important role in which it plays in the incidence and prevention of ACL injuries. This can be done by using a system that allows the video feedback to be freeze framed at precise time instances, specifically initial contact and maximum knee flexion.

While the implementation of self and expert video and verbal feedback into a screening or prevention program may be indicated, the lack of retention of peak knee flexion from posttest to retention test may signify the use of more frequent feedback. Onate et al. (2005) found that subjects retained improvement in peak knee flexion angles one week post instruction. In our study subjects did not return until on average five and half weeks following initial testing. Therefore, the implementation of regular or weekly feedback may be more advantageous as athletes may not retain the information from one session of feedback a month later. In order to obtain greater retention of the learned task, it may be beneficial to provide more frequent and consistent feedback. This can be done not only weekly but also be reinforced by coaches, athletic trainers, and strength and conditioning coaches throughout all sport related activities.

A possible explanation for subjects not showing a significant improvement following feedback, particularly knee valgus and hip abduction, may be that they simply could not achieve the proper position. This could have been due to a number of factors, including decreased flexibility and decreased strength preventing them from properly controlling the movement. These subjects may have learned and knew the position in which they should be, but could not achieve it. Another reason may include that the subjects were overloaded with information, as the feedback provided was for multiple joints and movements. This may not have allowed them to focus on the smaller, finite movements such as knee valgus, but instead on the larger movements of knee and hip flexion.

In addition to solely using feedback as an ACL prevention tool, instruction may need to be used in conjunction with other intervention modalities, including strength, balance, and plyometric training. While there are a number of prevention programs in existence, evidence is lacking as to what the best form of each intervention modality is as well as the best combination of modalities. In order to implement a successful prevention program the underlying components of the program must have evidence as to their effectiveness in making a positive change. Future research needs to focus on the multiple combinations of intervention modalities with the purpose of determining the most effective means of preventing ACL injuries.

From the findings of our study and previous research, it appears that an appropriate clinical recommendation would include that video and verbal feedback of a box-drop jump be implemented in the form of a prevention program or as part of an existing strength and conditioning program. This could be done by screening athletes using the LESS to find those individuals who are at greater risk of injury. Feedback could then focus on this select group of athletes. A second method of implementation could include that all individuals on a team receive video and verbal feedback. Even though some of these athletes may not be "at-risk" they may still improve a few degrees in some of their landing mechanics. This small improvement may not be statistically significant but any improvement in landing mechanics, whether small or large, is still an improvement. Feedback should also be given weekly and reinforced throughout the many aspects of training.

Limitations

A major limitation of the study was that the video and verbal feedback for both the self and combo feedback groups emphasized more global movements than specific movements at initial contact and maximum knee flexion. This is in part due to the equipment involved. The video feedback from the self trials was replayed using the video camera hooked into the television. This did not allow frame-by-frame viewing of the trials, but it was instead stopped at the most suitable frame to provide appropriate feedback. The video on average was stopped closer to maximum knee flexion than at initial contact. This could explain why the majority of our results were significant for variables at peak knee flexion while those at initial contact were either not significant or contradicted what we hypothesized.

CHAPTER V

CONCLUSION

Female athletes have been shown to have a greater incidence of noncontact ACL injury which has now lead to an explosion of research trying to explain why. Biomechanical risk factors are the most easily modifiable and therefore, much emphasis in research has been placed in this area to find gender differences during jump-landing and deceleration tasks. Evidence has shown that females land with greater ground reaction forces, greater quadriceps versus hamstring activation patterns, and decreased knee and hip flexion and increased knee valgus and hip adduction angles.

While much research is still being conducted on the biomechanics of jump-landing activities, there has now been a shift toward finding a way to improve these risk factors and prevent ACL injuries. Researchers have investigated balance, strength, plyometrics, and instruction as a means to improve lower extremity kinematics and kinetics. There are also a number of ACL prevention programs currently being implemented, including PEP and KLIP, that incorporate all of these prevention strategies. While some of these programs have shown improvement in biomechanics or in a reduction in ACL injuries, the direct cause of this improvement is unknown due to the wide range of strategies all being used at once. These strategies on an individual level have limited evidence as to what is the most successful. The most effective form of each strategy needs to be determined as well as if one prevention strategy decreases the risk of ACL injuries greater than another. In a large number of these programs instruction, verbal or visual, is incorporated while the research remains limited as to its effectiveness in improving biomechanics. Simple verbal and visual/video feedback can easily be used to screen athletes for an increased risk of ACL injury or to improve lower extremity biomechanics in a wide variety of clinical settings. It can also be used in both rehabilitative and prevention programs. There are a number of forms of feedback ranging from verbal and/or visual, global versus specific, and expert versus self or a combination of the two.

Through our research, we found that the use of verbal and video feedback is successful in improving lower extremity biomechanics during jump-landing activities. Specifically, the combination of self and expert video feedback with verbal feedback following a box-drop jump significantly improved peak knee flexion angles. The instruction of box-drop landing also positively transferred to an improvement in running-stop jump peak knee flexion angles. Regardless of feedback, there was a learning effect for hip flexion at peak knee flexion for the box-drop jump task and this learning effect was retained one month later. Peak knee flexion was also learned from pretest to posttest, but subjects were unable to retain this knowledge during the one month posttest. Conversely, knee flexion at initial contact significantly decreased from posttest to retention test. This is unfavorable as the knee flexion angle at initial contact has been linked to the incidence of noncontact injuries.

Our results revealed significant differences at peak knee flexion that may be associated with a decreased risk of ACL injury, while initial contact variables revealed no significant difference or an undesirable kinematic position. The use of simple verbal and video feedback appears to be an easy and effective tool that could be used at almost all clinical settings to improve lower extremity kinematics, particularly peak knee flexion. While it is important to teach peak flexion angles there appears to be a need for more emphasis on initial contact landing mechanics in video and verbal feedback. In order to improve more sport-specific task biomechanics, such as the side-step maneuver, box-drop jump feedback may not be as appropriate. Overall, the combination of self and expert feedback is an effective tool in changing lower extremity kinematics. Future research now needs to focus on instructions that improve lower extremity kinematics at both initial contact and peak knee flexion. As our study revealed the learning effect was not retained one month following feedback for peak knee flexion, more research also needs to be done on the retention of learning and what is most effective at reinforcing the learning. The feedback tool utilized in our study was based solely on the kinematics of the lower extremity and had no references to kinetics. Therefore, future research should also focus on the use of the phrase "land as soft as possible" in conjunction with video feedback to evaluate its effectiveness in improving not only kinematics but kinetics over a long term period.

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INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: Effect of Instruction and Neuromuscular Fatigue on Jump Landing in Female Recreational and Collegiate Athletes

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The purpose of this project is to assess the effect of instruction and neuromuscular fatigue on jump landing.

RESEARCHERS

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Director- Graduate Athletic Training Program and Doctorate in Human Movement Science Program, Old Dominion University, ESPER Dept.

DESCRIPTION OF RESEARCH STUDY

Several studies have been conducted looking into the effect of instruction or neuromuscular fatigue on jump landing to assess the risk of ACL injury. However none of these studies have determined the effect of jump landing feedback of box-drop jump, running-stop jump, and side-step maneuver, or isolated hamstring fatigue on double leg drop box landing.

This study will involve your participation in two testing sessions. The first session will be followed by a second session two to three months later. Approximately a total of 2.5 hours of your time will be required. Upon arriving in the Sports Medicine Research Laboratory, your height, weight and body dimensions will be measured. Following those measurements, you will complete a brief warm up on a stationary bicycle and a self-directed stretch. After the brief warm up time you will perform jump landing tasks, that include a box-drop jump, a running-stop jump and a sidestep maneuver, and a fatigue task of the hamstrings. The fatigue task will only be utilized on the first session of testing.

- **Jump Landing (Box-drop Jump, Running-stop Jump, Side-step Maneuver):** These tasks involve using VICON, which entails reflective markers to be placed on various landmarks on the body. The cameras around the laboratory track the reflective marks to analyze movement during the tasks. Five test trials will be conducted for each test.
- **Hamstring Fatigue:** The Primus RS is used for this task to record the torque (force) produced during each repetition of knee flexion of the fatigue protocol. Continuous repetitions will be performed until hamstring fatigue is achieved.

Approximately 90 subjects will be participating in this study.

EXCLUSIONARY CRITERIA
In order for you to participate in this study, you must be a healthy female recreational or varsity collegiate athlete who exercises a minimum of three times per week for a minimum of 20 minutes. You must not have had a lower extremity injury in the past two months that limited you from activity for more than one day, no current self-reported history of lower extremity instability, or history of any lower extremity surgery within the past two years. You also should never have had an ACL injury or reconstructive knee surgery.

RISKS AND BENEFITS
RISKS: If you decide to participate in this study, then you may face a risk of ligament injury, muscle strains or delayed onset muscle soreness due to the hamstring fatigue activity. The fatigue activity may decrease muscular control, therefore affecting the body positioning during the landing activity and increasing the risk of injury to ligaments of the knee. To reduce this risk, the fatigue protocol and jump landing task are performed in a controlled lab environment without external stimuli and are supervised by trained and practiced researchers. The hamstring fatigue also requires full effort over a series of repetitions to elicit a decrease in maximum peak torque, which increases the likelihood of a strained muscle or delayed onset muscle soreness following the completion of the initial testing session. The researchers try to reduce these risks specifically by allowing a 10 minute warm-up, consisting of a stationary bike ride and self-directed static stretching, to assist in properly increasing the body temperature and elastic properties of the hamstring musculature. It is recommended that you refrain from strenuous exercise for one day after the initial testing session. There is also a possibility of slight discomfort of the Velcro strap at the testing station. Also, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: If you decide to participate in this study, you will receive points *equivalent to one extra credit assignment* if you are registered for any of the designated ESPER Department courses. Equivalent points may be obtained in other ways. Another benefit to you for participating in this study is learning how to properly position yourself during a jump-landing activity. The results of this study may benefit others and expand the knowledge in the profession of athletic training by drawing more precise and clearer conclusions on risk factors that predispose female athletes to risk of ACL injury.

COSTS AND PAYMENTS
The researchers are unable to give you any payment for participating in this study.

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

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

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

COMPENSATION FOR ILLNESS AND INJURY
If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm arising from this study, neither Old Dominion University nor the

researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. James A. Onate, ODU Sports Medicine Research Laboratory at 757-683-4351 or Dr. George Maihafer the current IRB chair at 757-683-4520 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them: Dr. James A. Onate, ODU Sports Medicine Research Laboratory at 757-683-4351

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

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

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

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

Investigator's Printed Name & Signature	**Date**

Landing Error Scoring System (LESS) Date: ________

Subject ID:__________ Rater:________________________________
Project: _________

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

1. Ankle Plantar-Flexion Angle at Initial Contact: Toe to Heel Trial #1 #2 #3

___|___|___

(+0) Yes
(+1) No

2. Knee Flexion Angle at Initial Contact: Greater than 30° Trial #1 #2 #3

___|___|___

(0) Yes
(+1) No

3. Trunk Flexion Angle at Initial Contact: Trunk in front of hips Trial #1 #2 #3

___|___|___

(+0) Yes
(+1) No

4. Knee Flexion ROM GREATER than 30° Trial #1 #2 #3

___|___|___

(0) Yes
(+1) No

5. Trunk Flexion at Max Knee Flexion Angle: Trunk in front of hips Trial #1 #2 #3

___|___|___

(0) Yes
(+1) No

6. Initial Foot Contact Trial #1 #2 #3

___|___|___

(0) Symmetric foot contact
(+1) Asymmetric foot contact

7. Foot Position at Initial Contact: Toes > 30 of ER Trial #1 #2 #3

___|___|___

(+1) Yes
(+0) No

8. Foot Position at Initial Contact: Toes > 30 of IR Trial #1 #2 #3

___|___|___

(+1) Yes
(+0) No

9. Stance Width at Initial Contact: LESS than shoulder width **Trial #1 #2 #3**

___|___|___

(+1) Yes
(+0) No

10. Stance Width at Initial Contact: GREATER than shoulder width **Trial #1 #2 #3**

___|___|___

(+1) Yes
(+0) No

11. Knee Valgus Angle at Initial Contact: Knees over mid-foot **Trial #1 #2 #3**

___|___|___

(+0) Yes
(+1) No

12. Lateral Trunk Flexion at Initial Contact **Trial #1 #2 #3**

___|___|___

(0) Sternum centered over hips
(+1) Lateral deviation of sternum over hips

13. Knee Valgus ROM: Greater than great toe **Trial #1 #2 #3**

___|___|___

(+1) Yes
(0) No

14. Joint Displacement: (Sagittal Plane) **Trial #1 #2 #3**

___|___|___

(+0) Large joint motion (quiet / soft)
(+1) Average joint motion
(+2) Small joint motion (loud / stiff)

15. Overall Impression **Trial #1 #2 #3**

___|___|___

(+0) Excellent (maintains frontal alignment, lands w/ > 30° of knee flexion, undergoes > 30° of displacement)
(+1) Average (small frontal motion, straight/stiff landing)
(+2) Poor (large frontal motion)

Total Score #1____ #2____ #3____

Video Feedback

Self / Combo

Front View

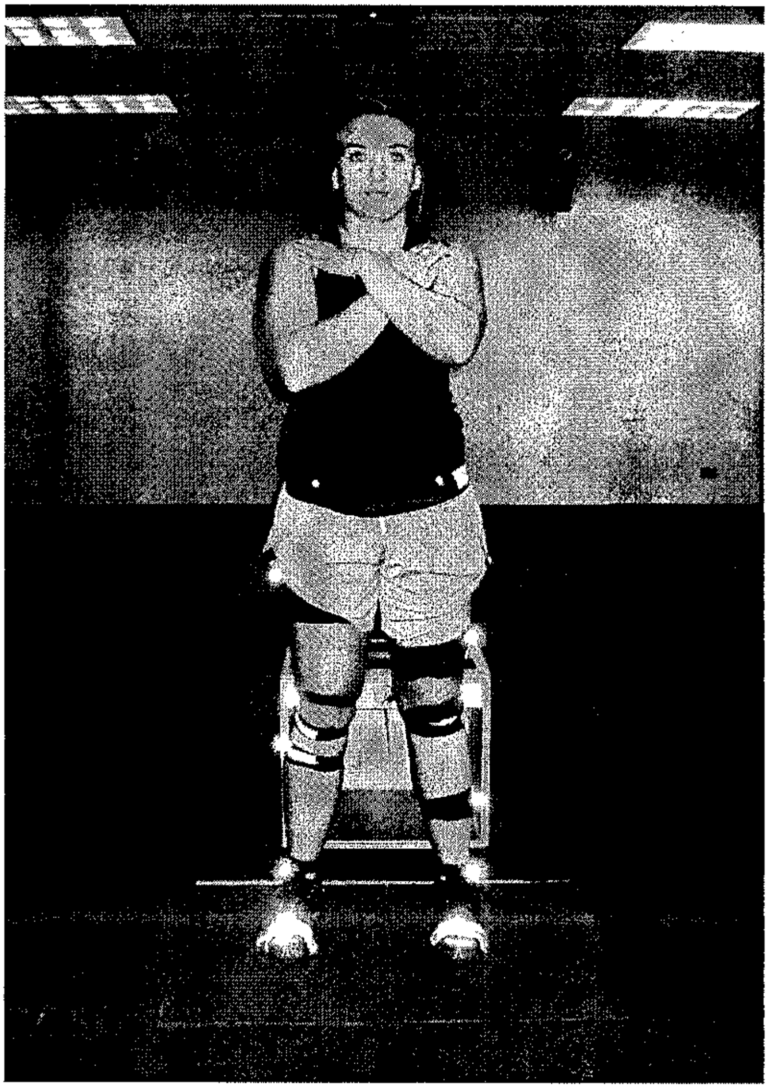
	Trial 1	Trial 2	Trial 3	Trial 4
1. Toe to heel landing	Y / N	Y / N	Y / N	Y / N
2. Feet land at same time	Y / N	Y / N	Y / N	Y / N
3. Stance shoulder width apart	Y / N	Y / N	Y / N	Y / N
4. Knees over mid-foot (no valgus)	Y / N	Y / N	Y / N	Y / N
5. No side bending	Y / N	Y / N	Y / N	Y / N

Side View

	Trial 1	Trial 2	Trial 3	Trial 4
1. Toe to heel landing	Y / N	Y / N	Y / N	Y / N
2. Feet land at same time	Y / N	Y / N	Y / N	Y / N
3. Knee angle > 30 degrees	Y / N	Y / N	Y / N	Y / N
4. Trunk in front of hips	Y / N	Y / N	Y / N	Y / N
5. Knee doesn't go farther in than great toe	Y / N	Y / N	Y / N	Y / N

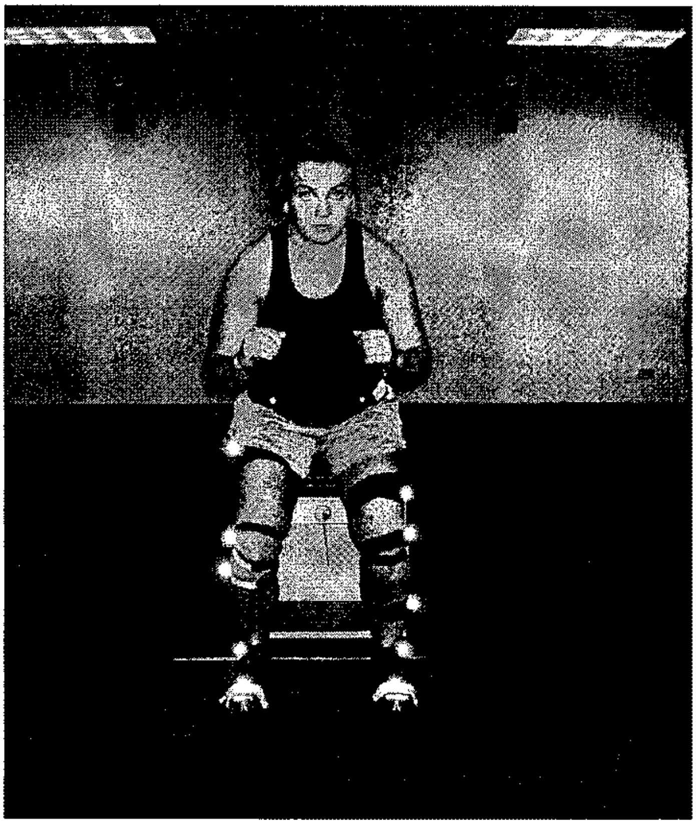
Key Points:

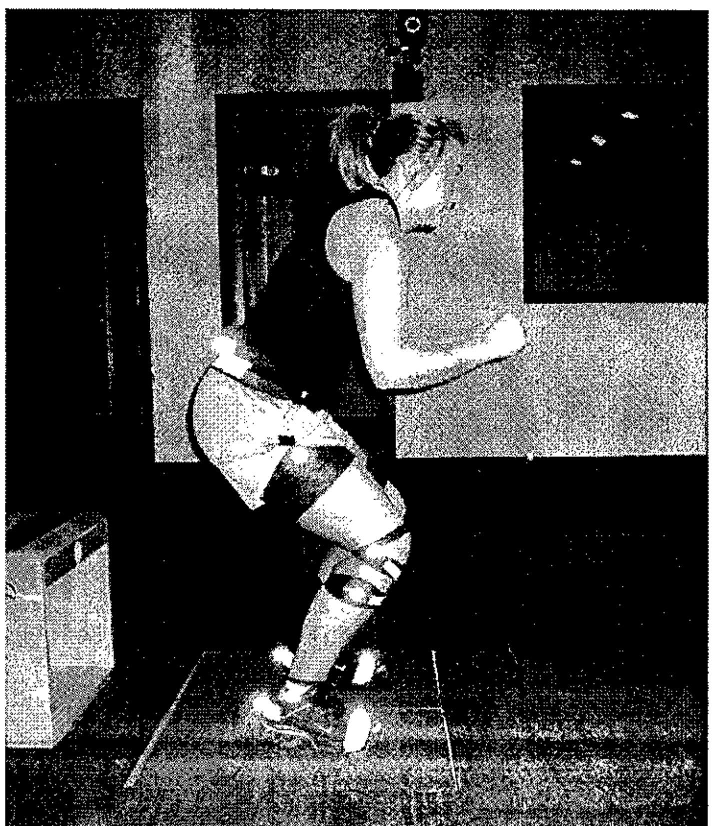
- Land with your knees bent
- Land with your trunk bent
- Keep knees over toes



APPENDIX 5

BOX-DROP JUMP EXPERT POSITION





APPENDIX 6

SIDE-STEP MANEUVER STATISTICAL RESULTS

Table – Side-step Maneuver Retention Test Statistical Results

	F	df	p
Knee Flexion IC	0.32	2	0.726
Knee Valgus IC	0.72	2	0.492
Hip Flexion IC	0.35	2	0.704
Hip Abduction IC	1.29	2	0.286
Knee Flexion PKF	0.23	2	0.799
Knee Valgus PKF	0.02	2	0.098
Hip Flexion PKF	1.40	2	0.259
Hip Abduction PKF	0.47	2	0.632

APPENDIX 7

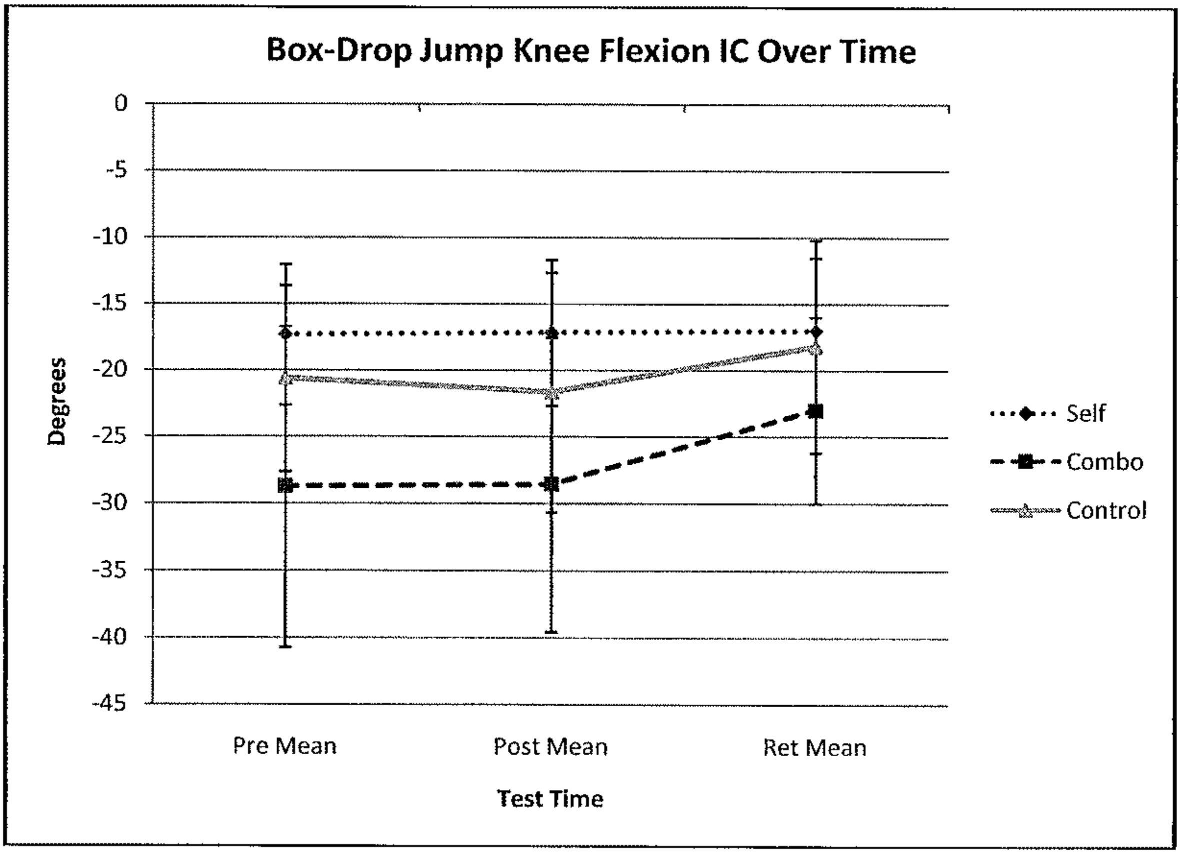
SIDE-STEP MANEUVER (COMBINED FEEDBACK) STATISTICAL RESULTS

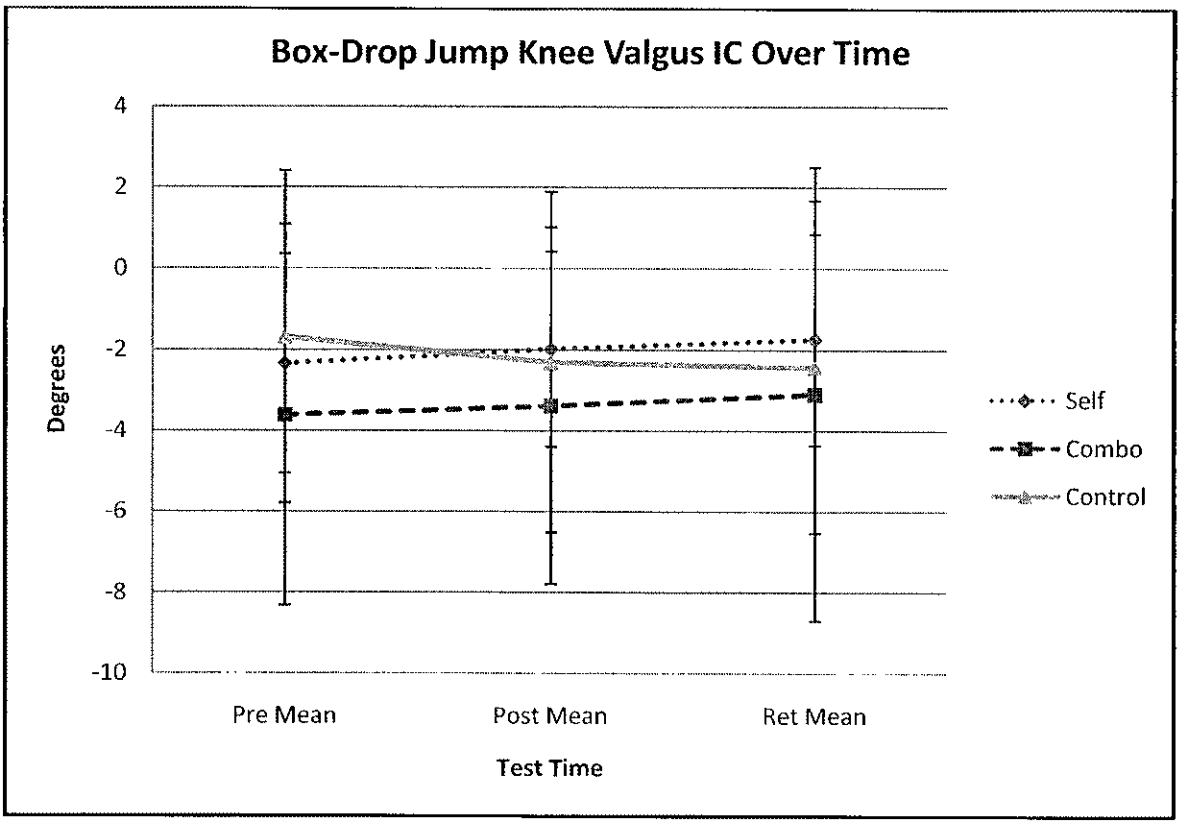
Table – Side-step Maneuver Retention Test (Feedback Groups vs. Control) Statistical Results

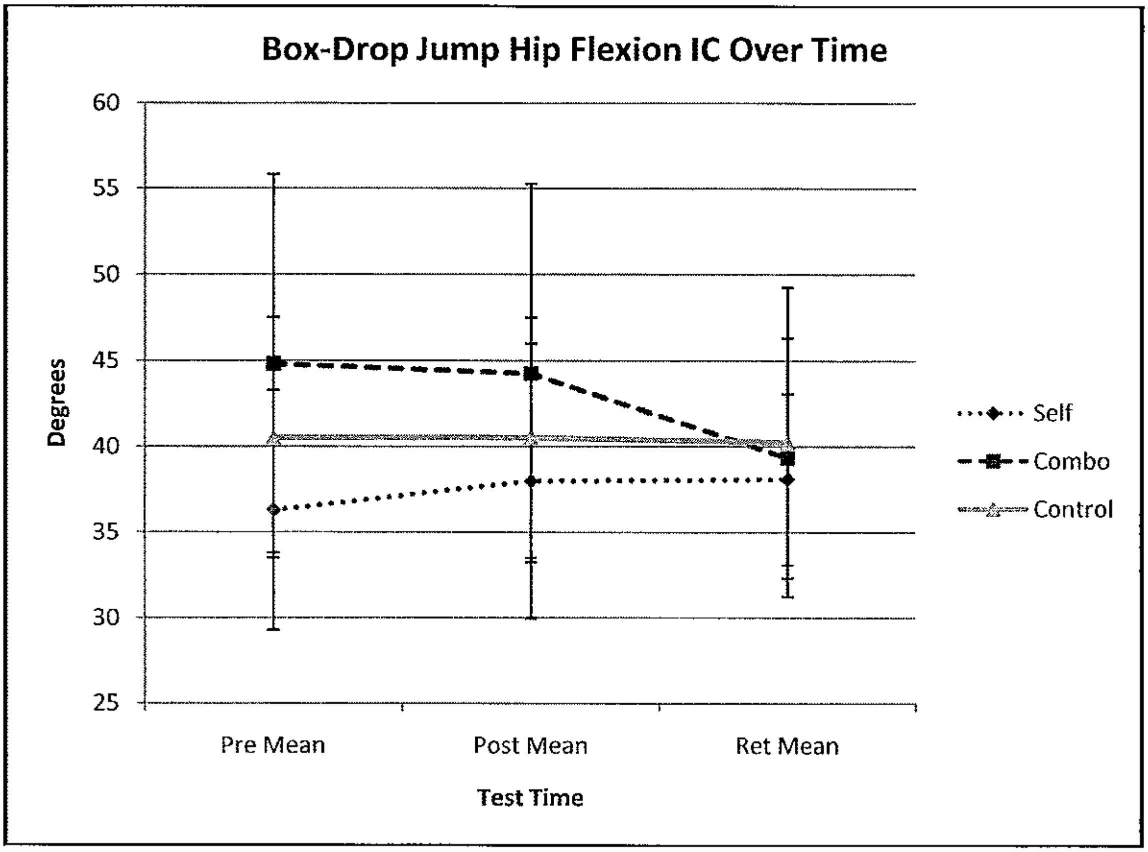
	F	df	p
Knee Flexion IC	0.002	1	0.963
Knee Valgus IC	0.004	1	0.948
Hip Flexion IC	0.04	1	0.842
Hip Abduction IC	0.36	1	0.554
Knee Flexion PKF	0.32	1	0.575
Knee Valgus PKF	0.01	1	0.923
Hip Flexion PKF	0.01	1	0.910
Hip Abduction PKF	0.95	1	0.335

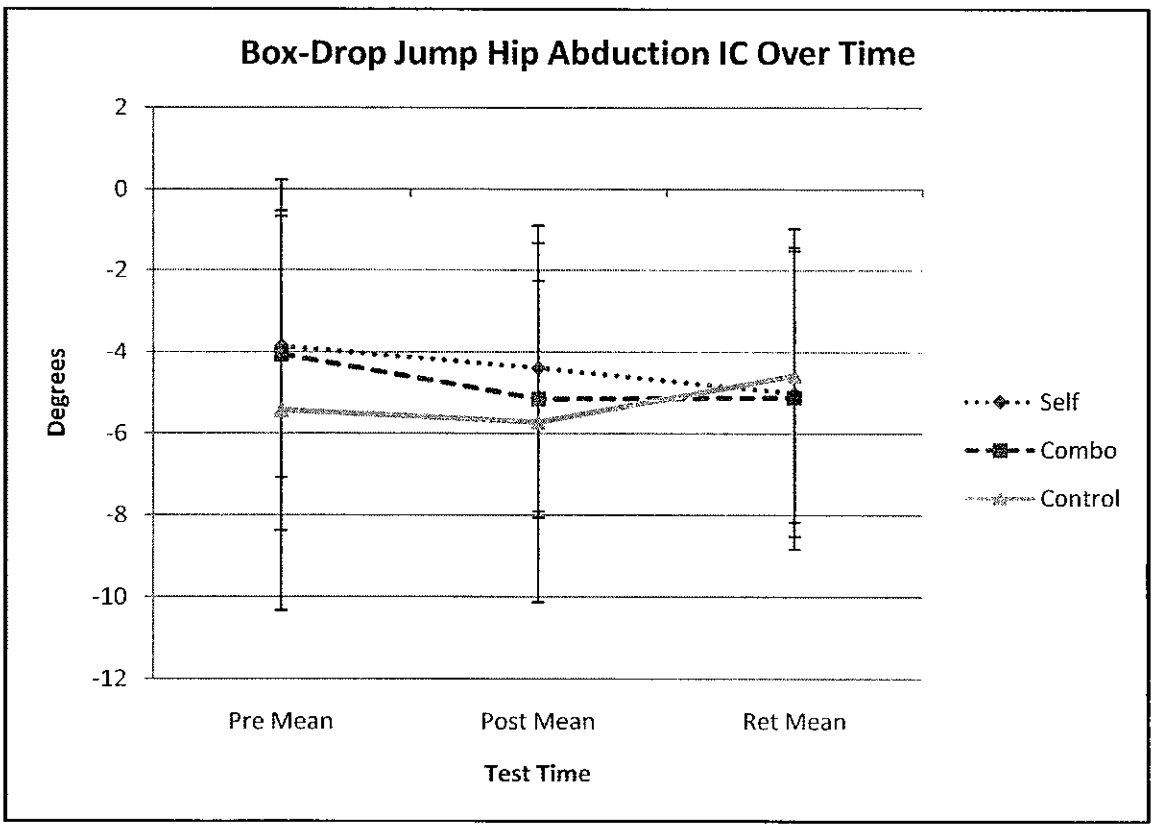
APPENDIX 8

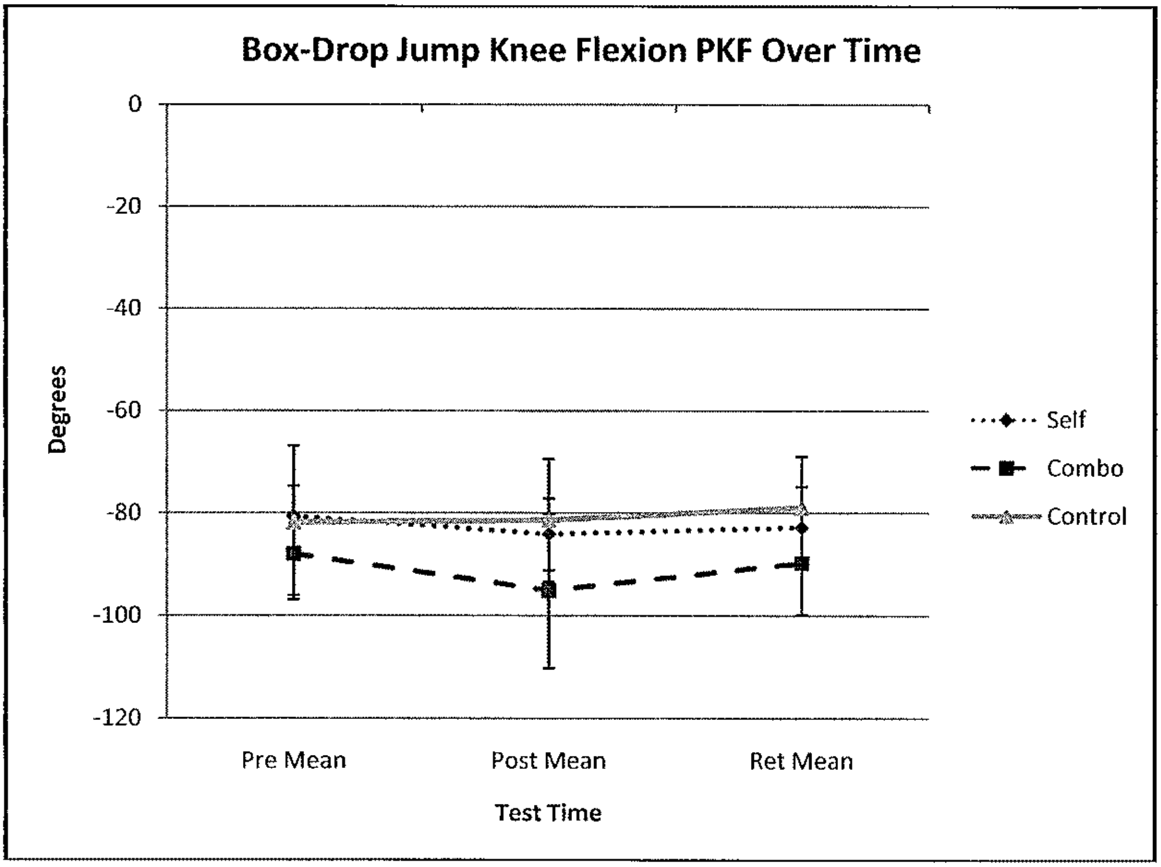
BOX-DROP JUMP GROUP MEANS OVER TIME

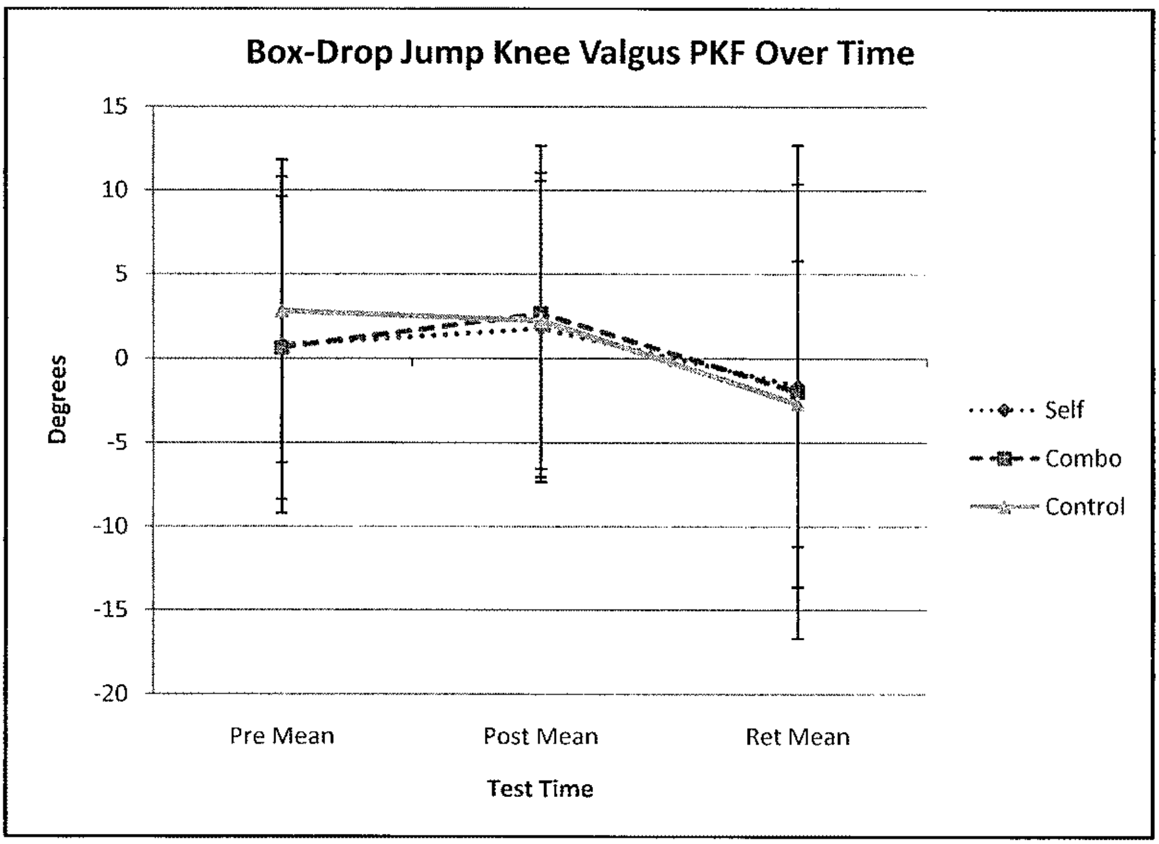

Box-Drop Jump Knee Flexion IC Over Time
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control

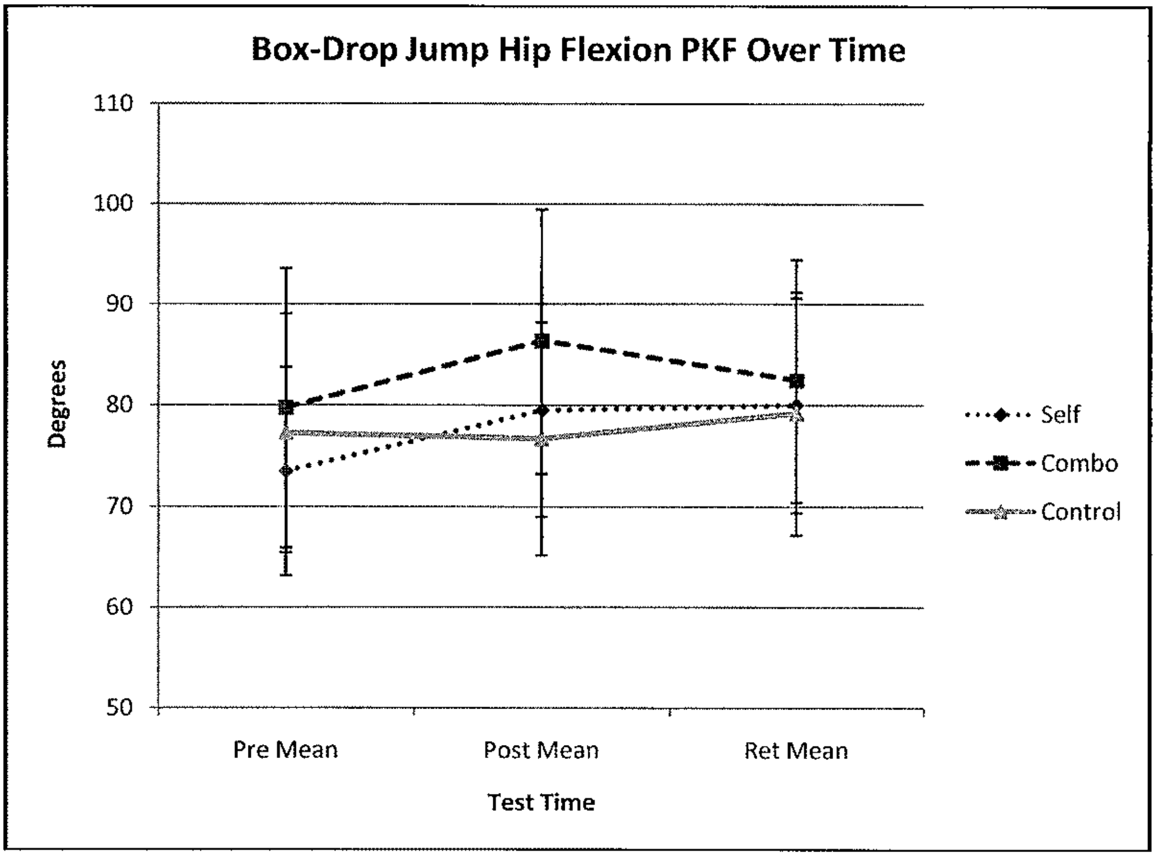

Box-Drop Jump Knee Valgus IC Over Time
4
2
0
-2
-4
-6
-8
-10
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control

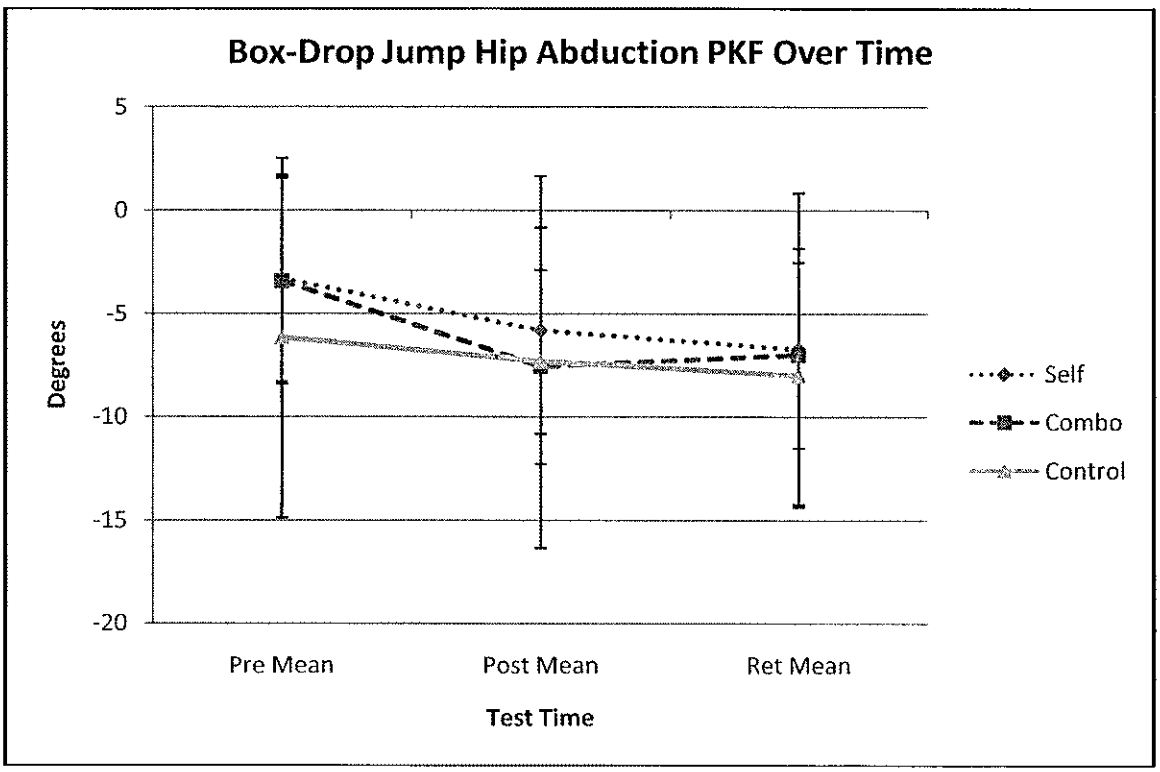

Box-Drop Jump Hip Flexion IC Over Time
Degrees
60
55
50
45
40
35
30
25
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control

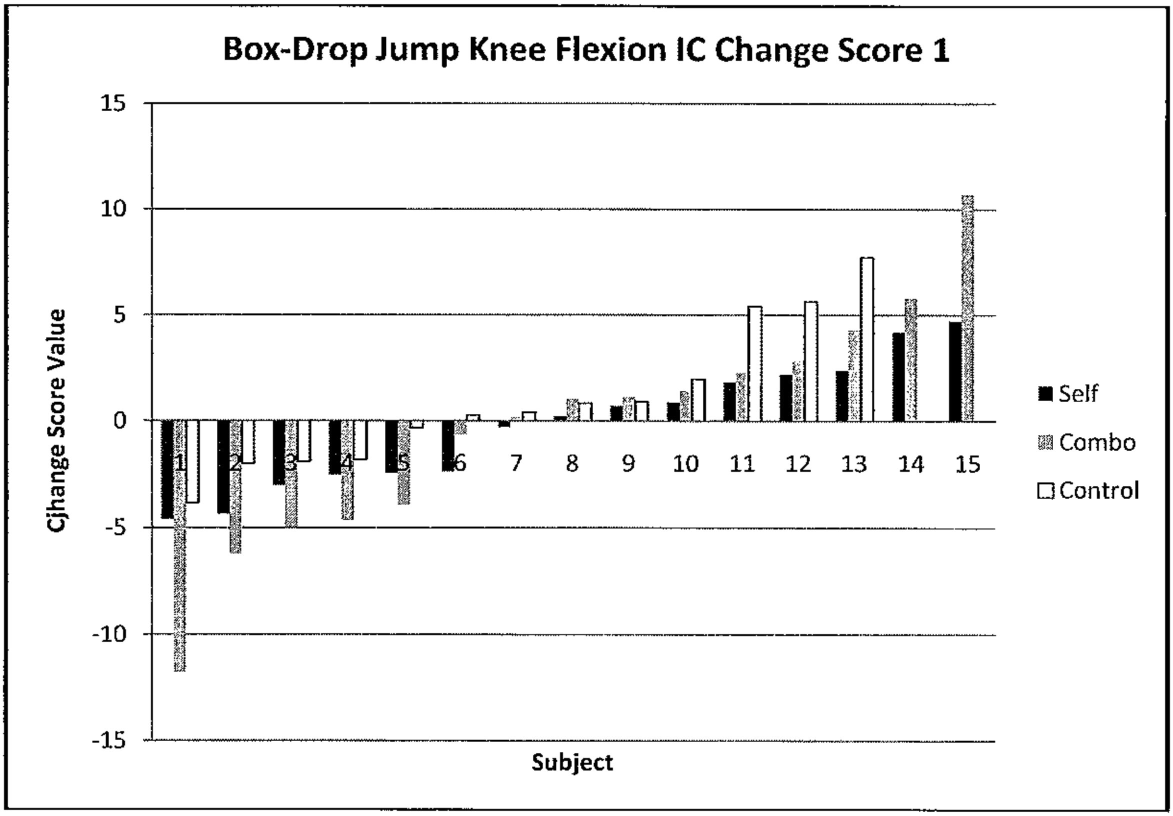

Box-Drop Jump Hip Abduction IC Over Time
Degrees
2
0
-2
-4
-6
-8
-10
-12
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control


Box-Drop Jump Knee Flexion PKF Over Time
0
-20
-40
-60
-80
-100
-120
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control

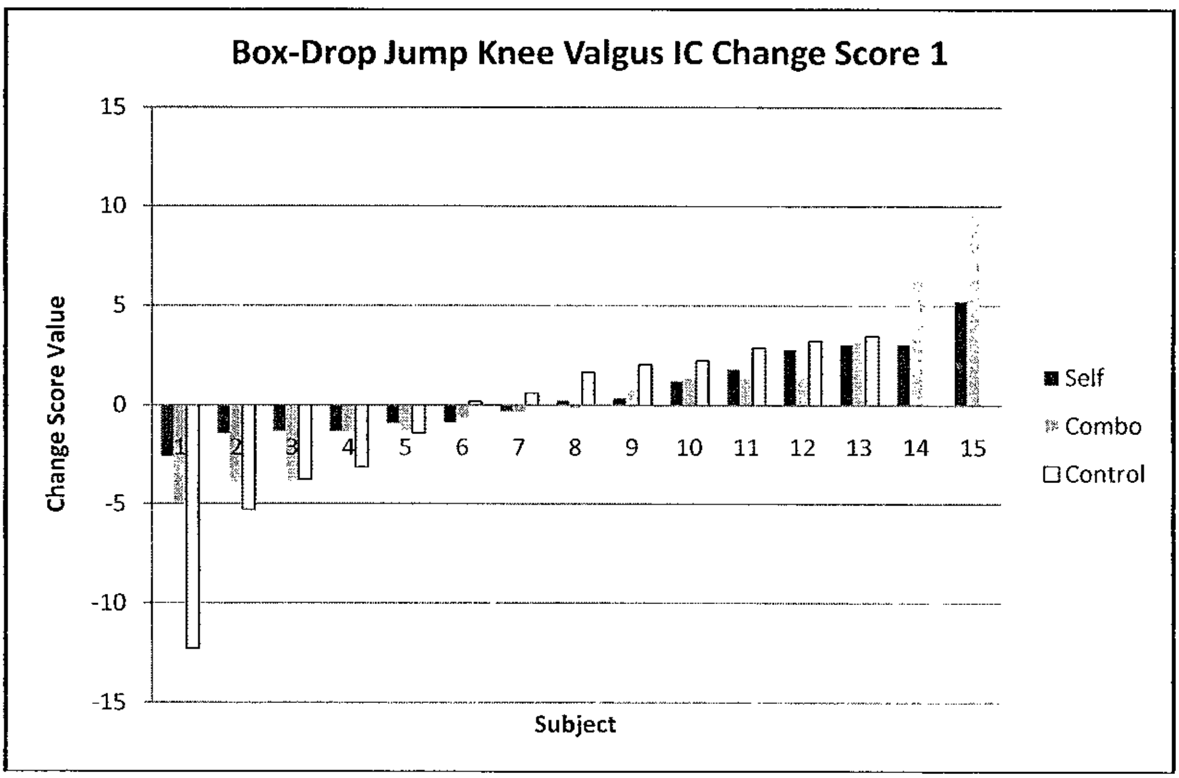

Box-Drop Jump Knee Valgus PKF Over Time
15
10
5
0
-5
-10
-15
-20
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control


Box-Drop Jump Hip Flexion PKF Over Time
110
100
90
80
70
60
50
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control


Box-Drop Jump Hip Abduction PKF Over Time
5
0
-5
-10
-15
-20
Degrees
Pre Mean
Post Mean
Ret Mean
Test Time
Self
Combo
Control



Box-Drop Jump Knee Flexion IC Change Score 1
15
10
5
0
-5
-10
-15
Cjhange Score Value
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Subject
Self
Combo
Control



Box-Drop Jump Knee Valgus IC Change Score 1
15
10
5
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Change Score Value
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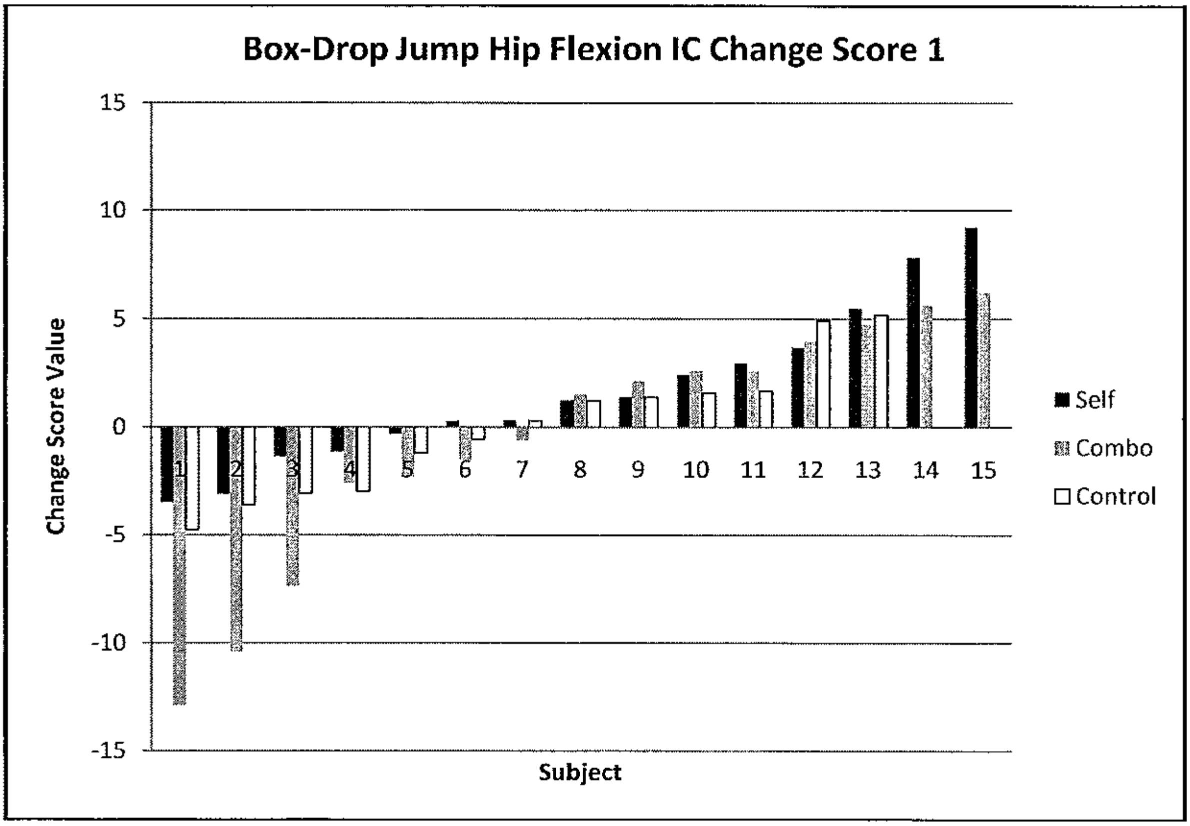
Subject
Self
Combo
Control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5
0
-5
-10
-15
Change Score Value
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Combo
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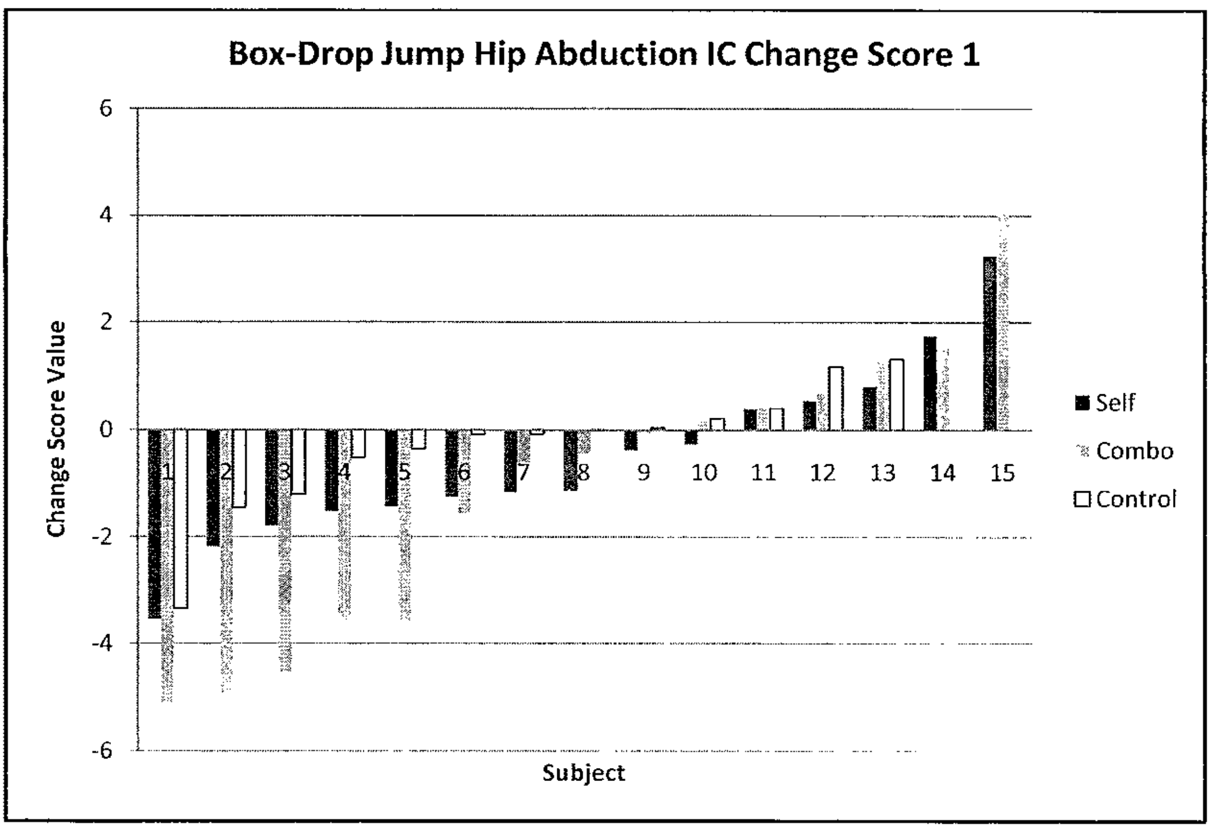
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-2
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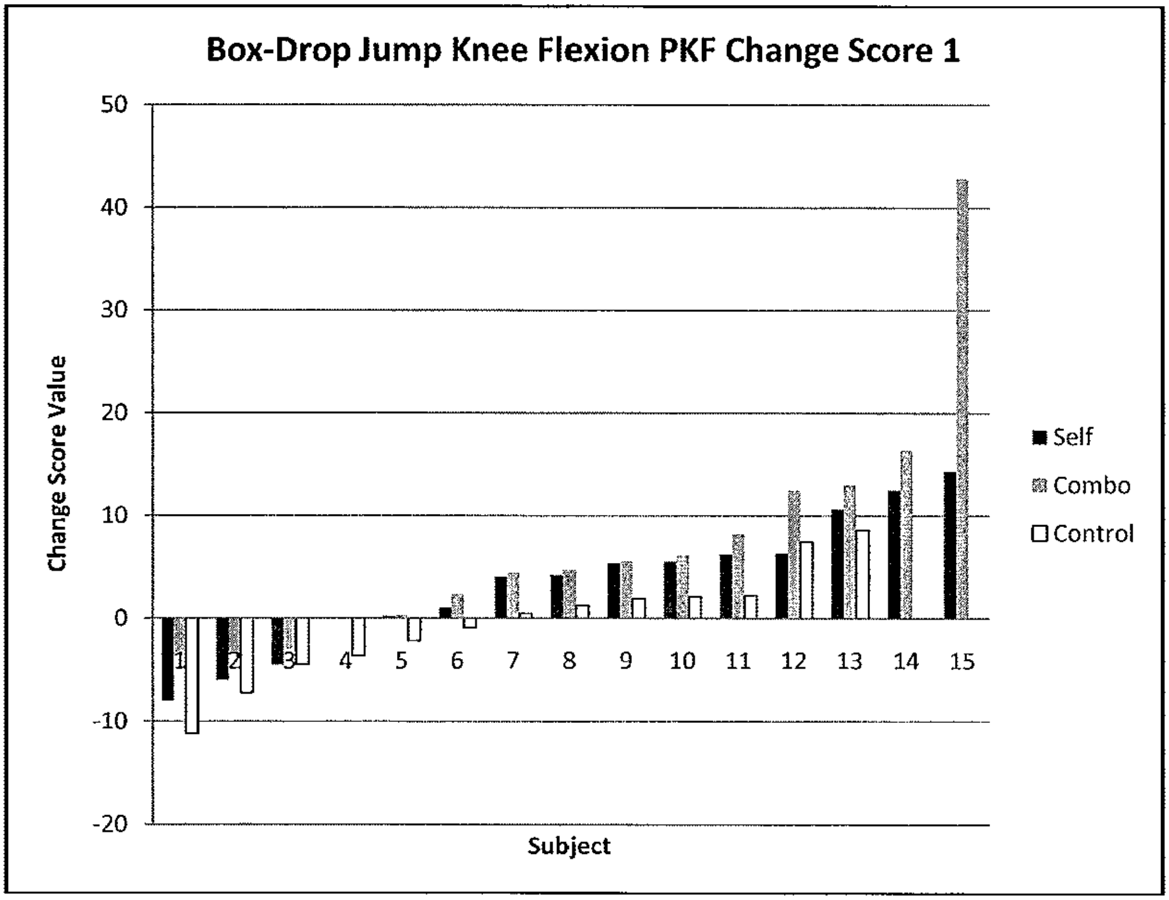
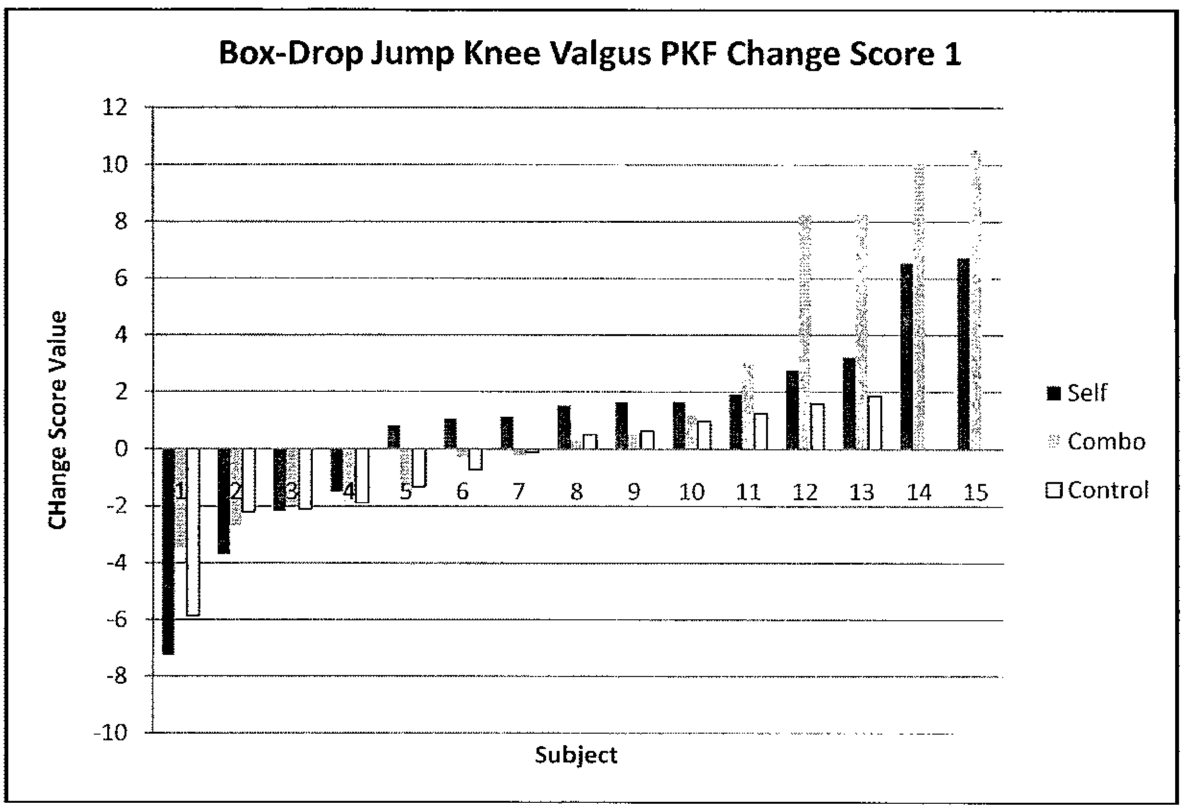
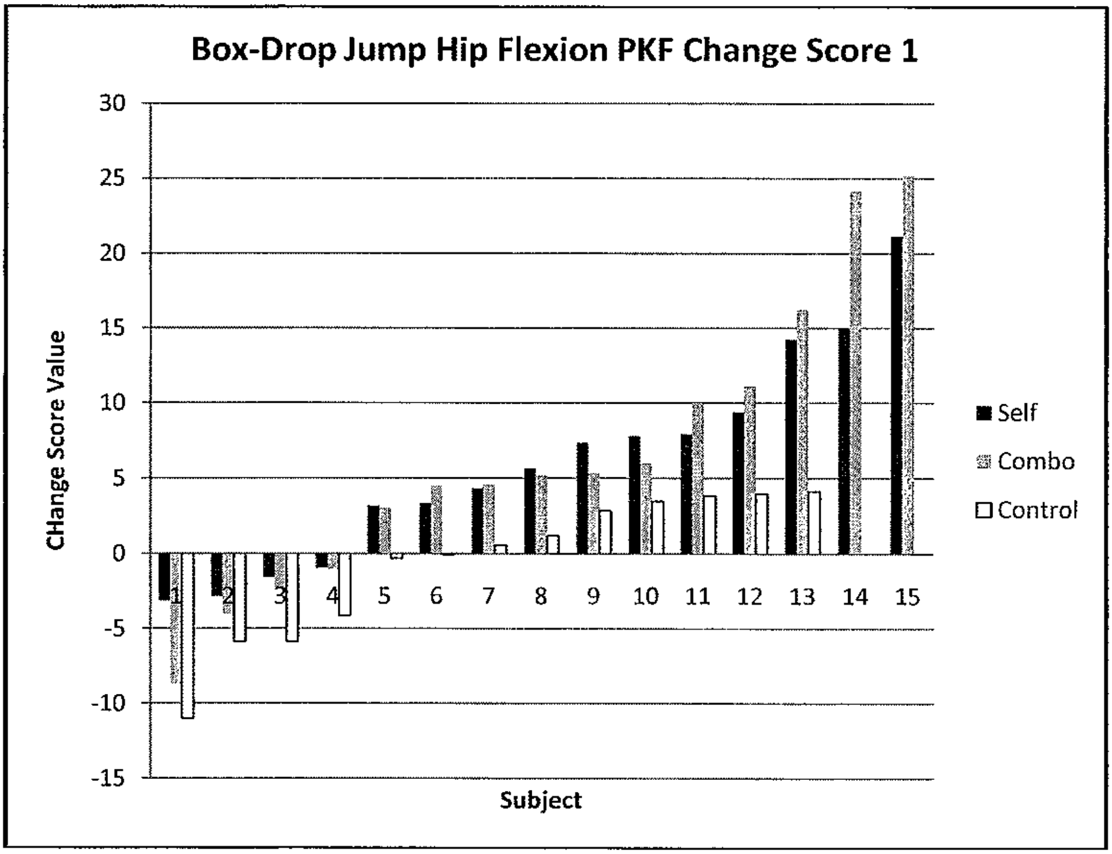
Subject
Self
Combo
Control


Box-Drop Jump Knee Flexion PKF Change Score 1
50
40
30
20
10
0
-10
-20
Change Score Value
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Subject
Self
Combo
Control


Box-Drop Jump Knee Valgus PKF Change Score 1
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
CHange Score Value
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Subject
Self
Combo
Control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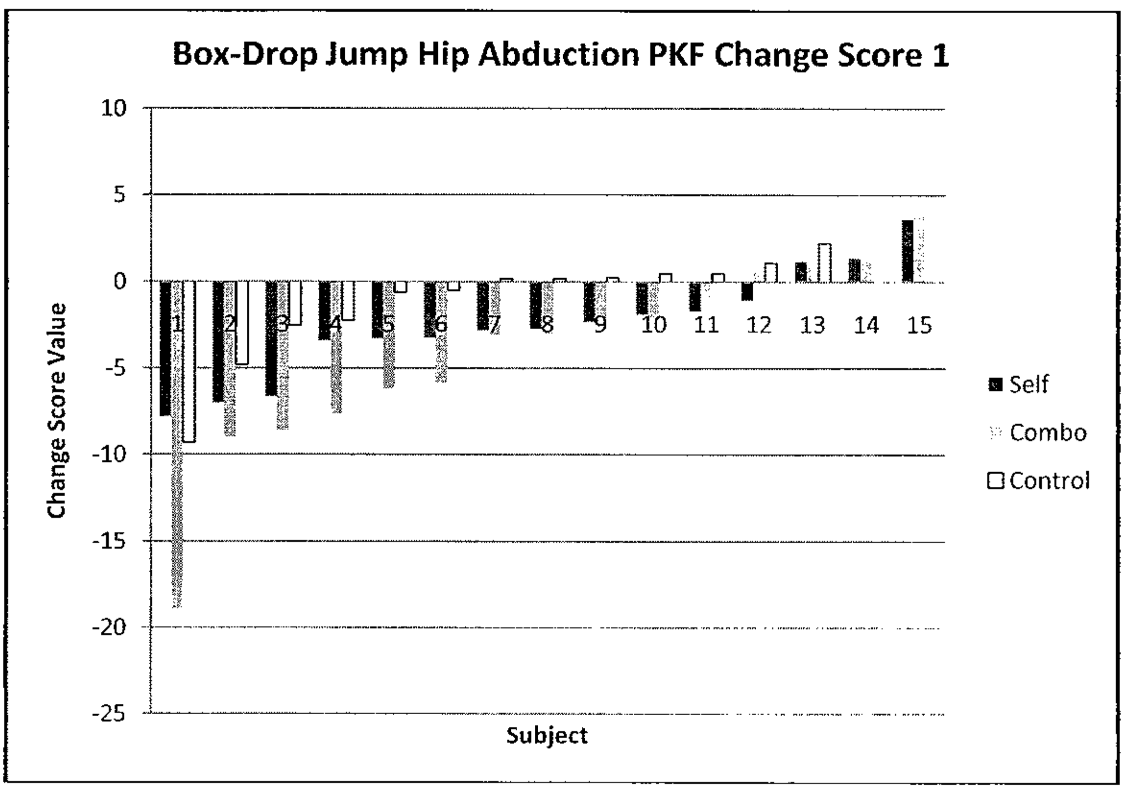
CHange Score Value
30
25
20
15
10
5
0
-5
-10
-15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Subject
Self
Combo
Control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Change Score Value
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-10
-15
-20
-25
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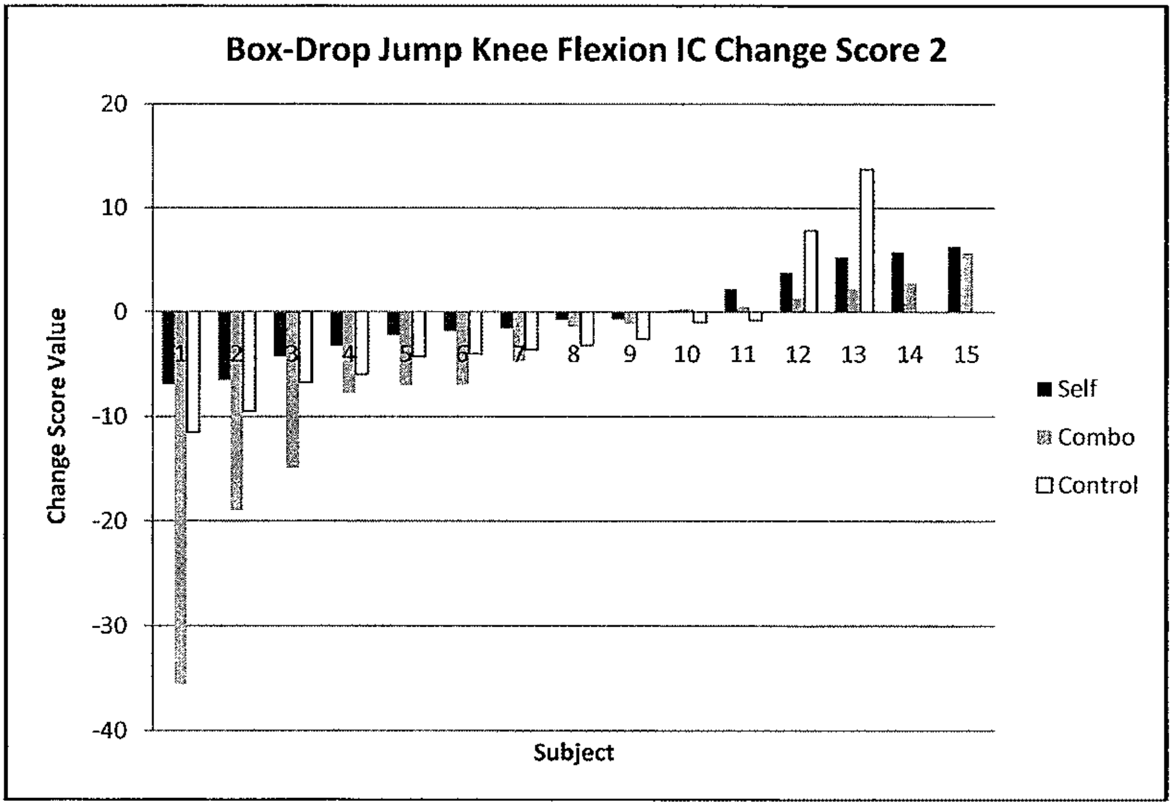
Combo
Control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10
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-10
-20
-30
-40
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9
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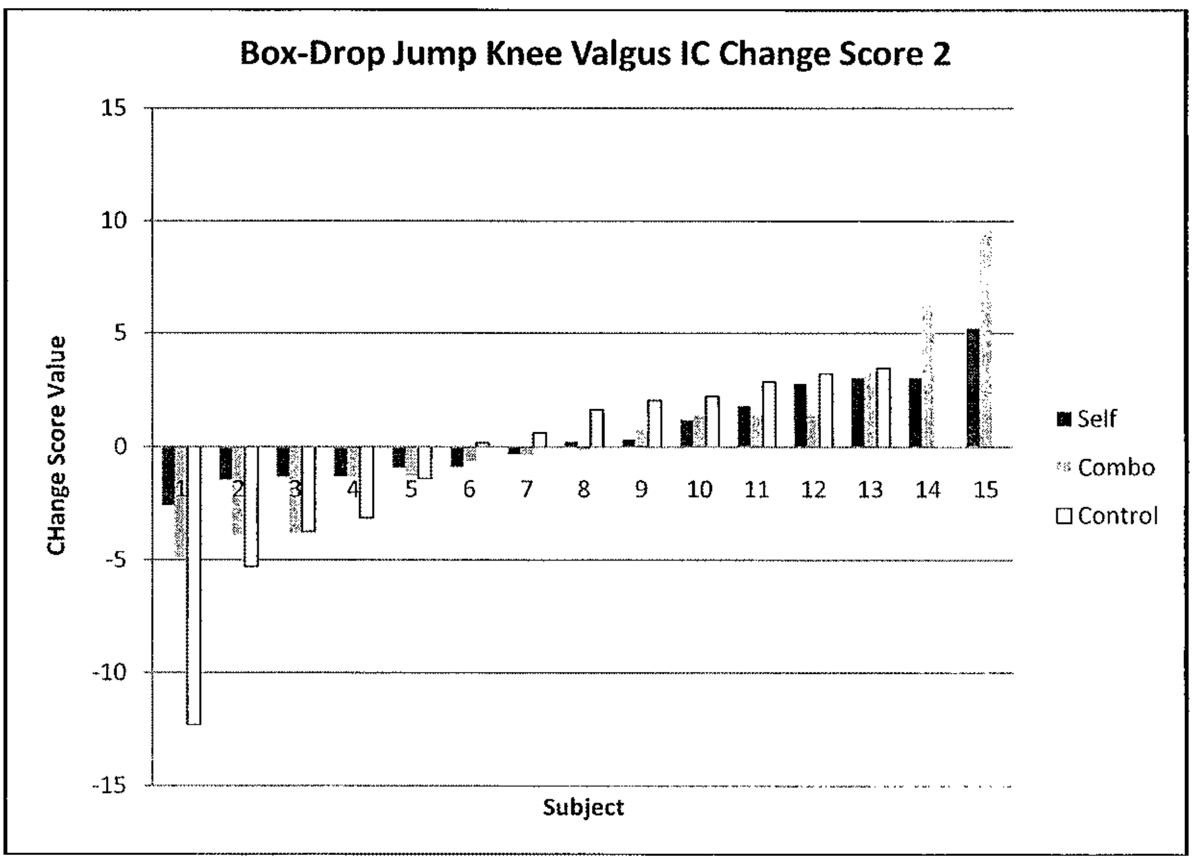
15
Subject
Self
Combo
Control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15
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0
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-10
-15
CHange Score Value
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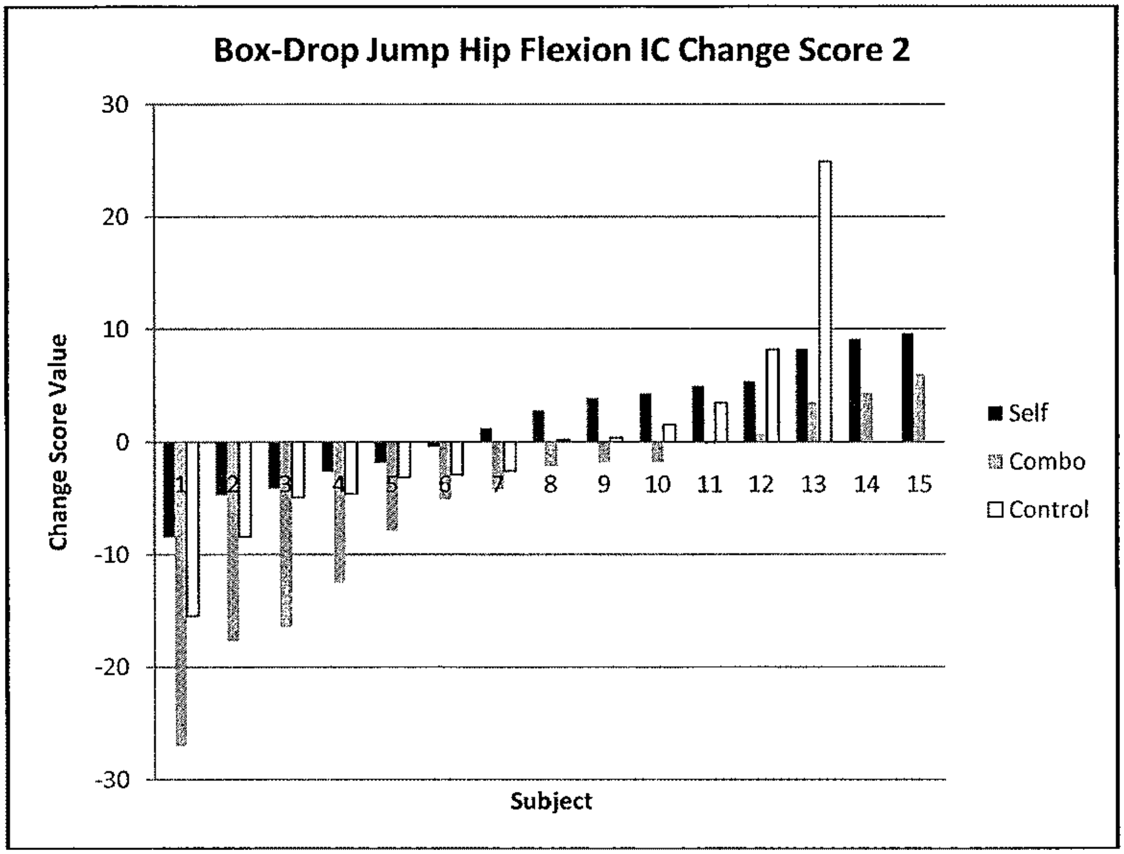
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Change Score Value
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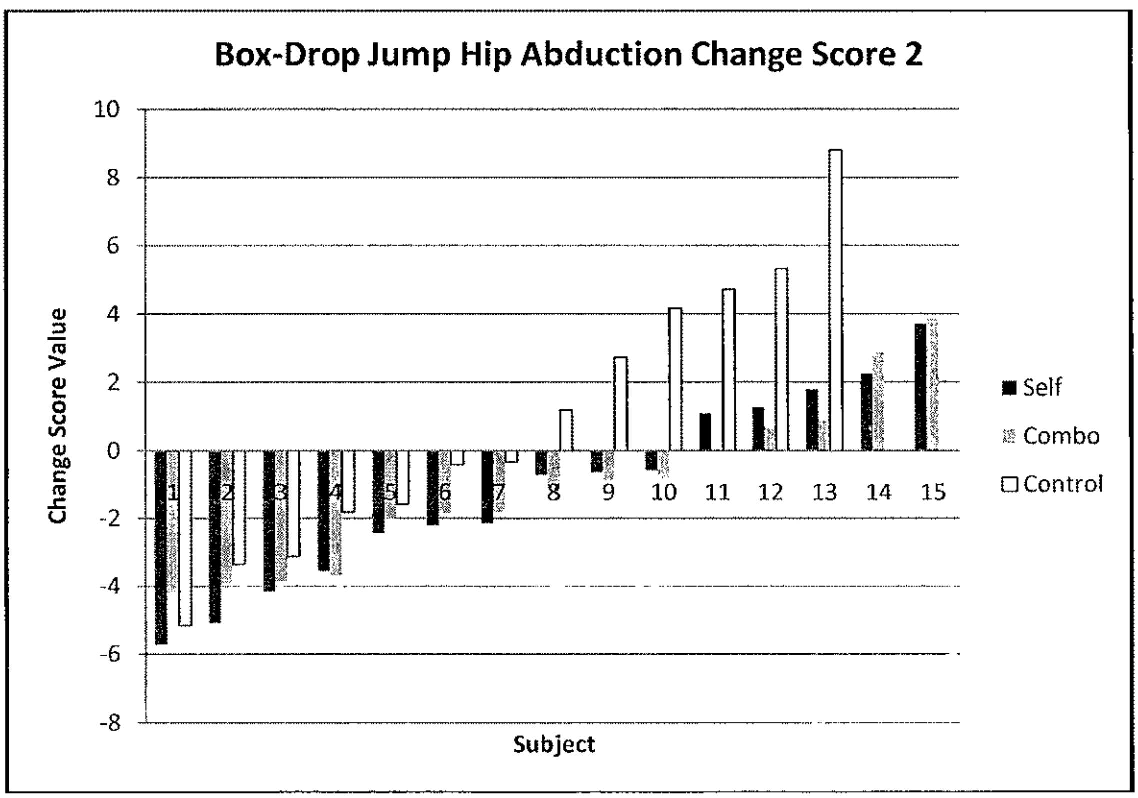
Combo
Control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8
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4
2
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-4
-6
-8
Change Score Value
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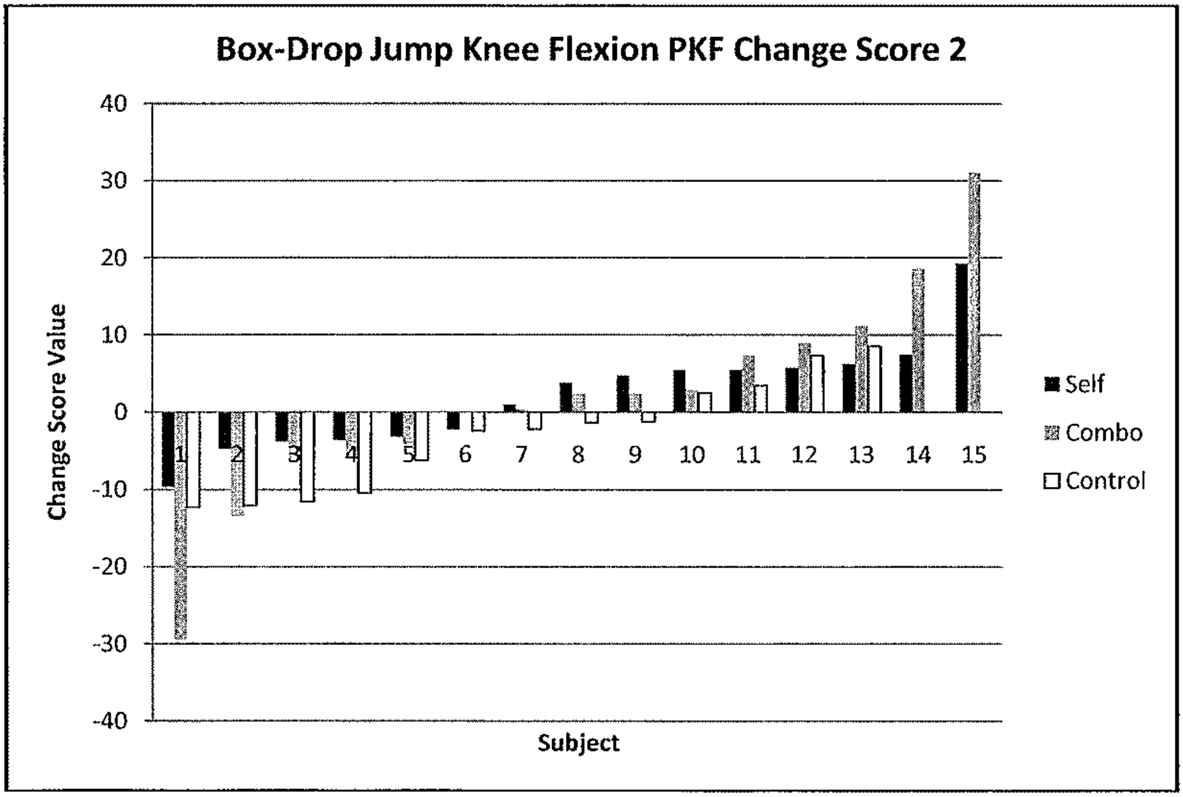
Subject
Self
Combo
Control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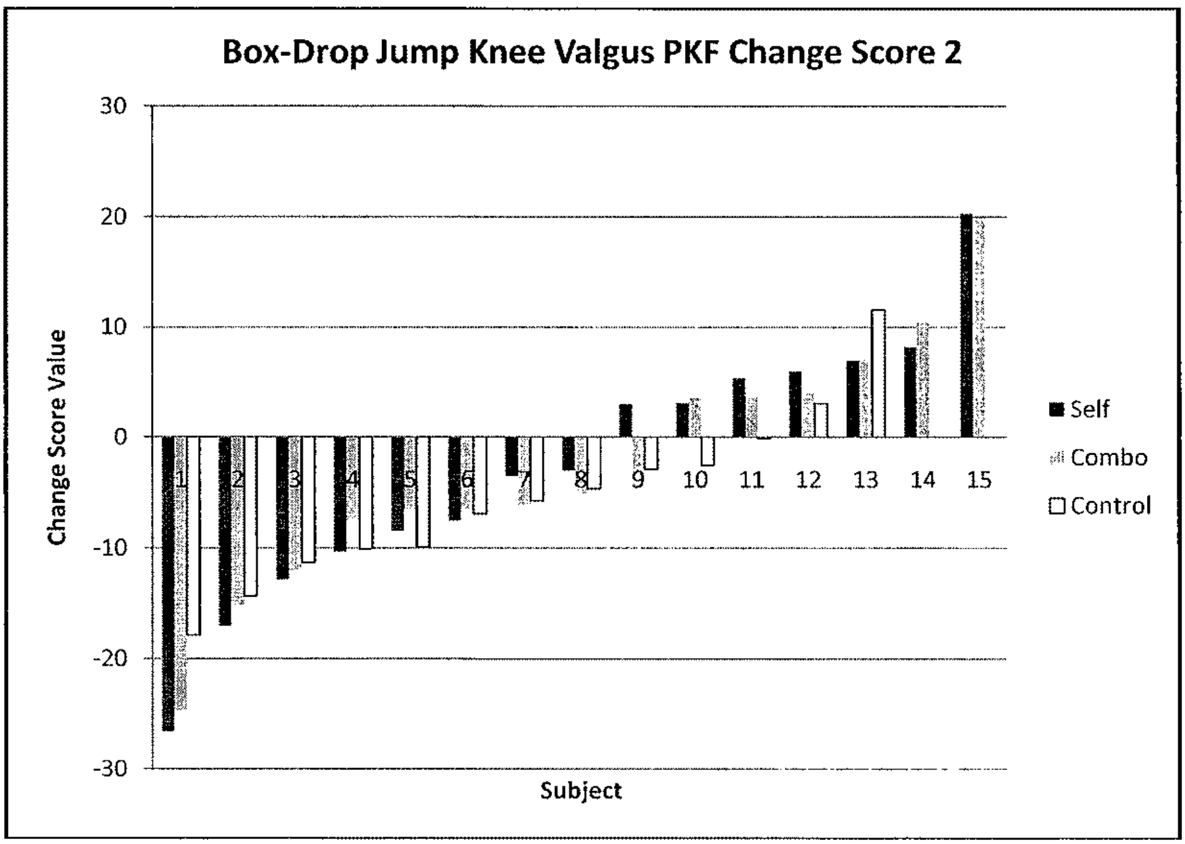
Combo
Control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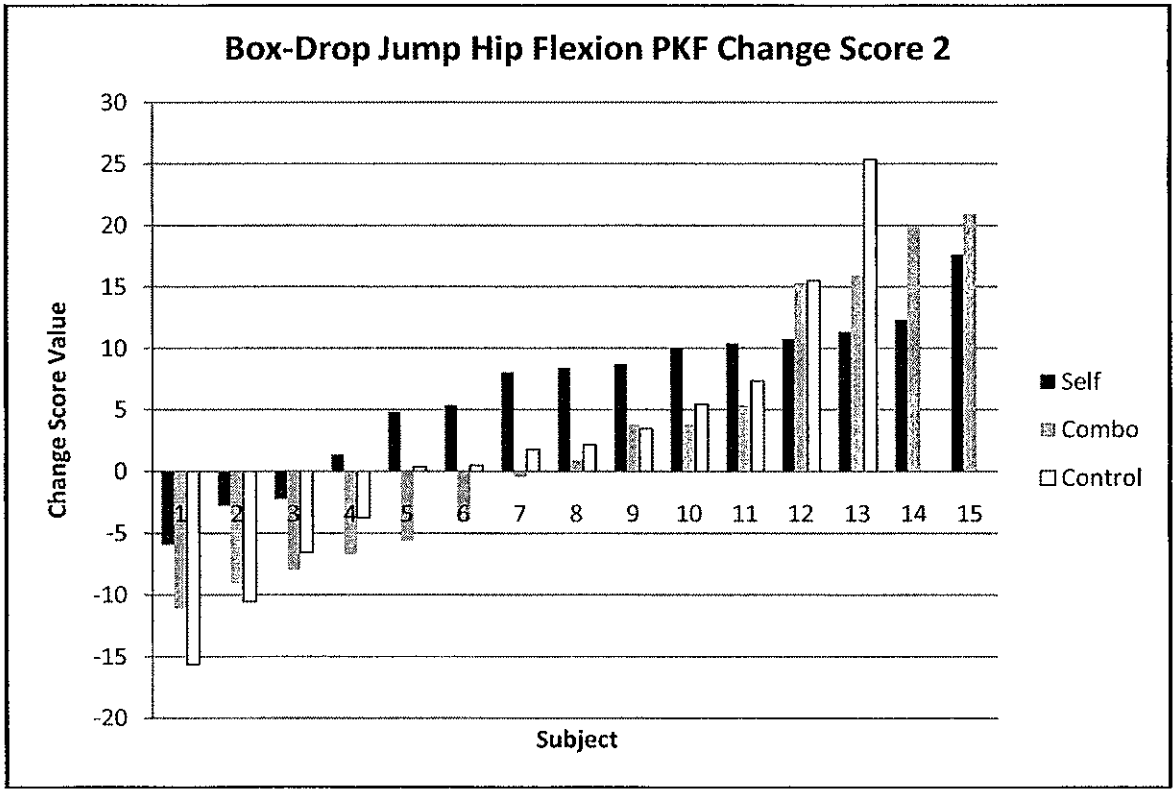
Combo
Control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30
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-5
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-15
-20
Change Score Value
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5
6
7
8
9
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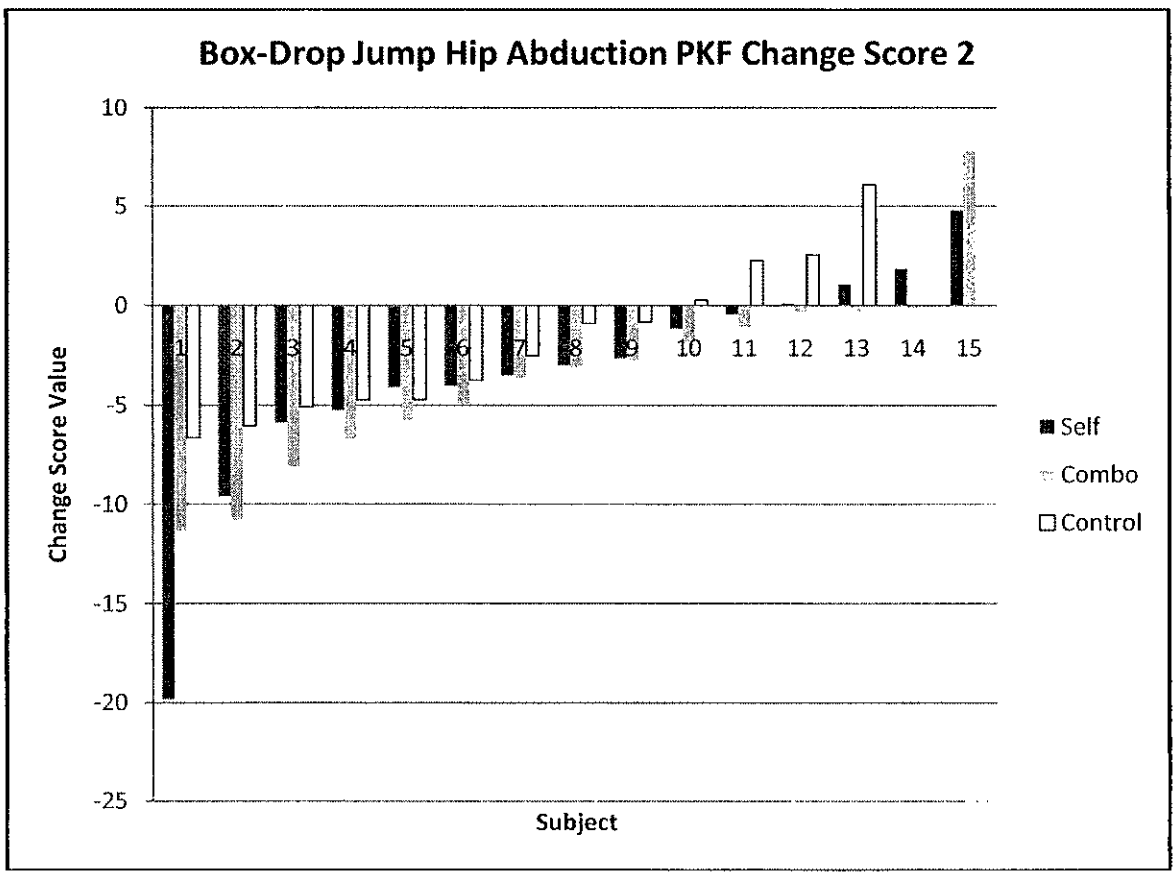
Combo
Control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10
5
0
-5
-10
-15
-20
-25
Change Score Value
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Subject
Self
Combo
Control

VITA

Jena Lynne Etnoyer

Department of Study

Old Dominion University
Department of ESPR
Student Recreation Center
Norfolk, VA 23529

Education

May 2009 Master of Science in Education
Athletic Training
Old Dominion University
Norfolk, Virginia

May 2007 Bachelor of Science
Kinesiology – Athletic Training
The Pennsylvania State University
State College, PA

Professional Experience

01/09 – 05/09 Old Dominion University; Norfolk, VA
Co-Instructor: Advanced First Aid & Emergency Care (HE 224, 3 credits)

- Created syllabus, lesson plans, presentations, lab activities, exam, and practical exams
- Responsibilities included daily administrative and teaching duties

08/07 – 05/09 Old Dominion University; Norfolk, VA
Graduate Assistant Athletic Trainer

- Clinical sport assignments included Men's Varsity Soccer, Women's Varsity Basketball, and Varsity Football
- Responsible for practice and game day preparation, treatment and rehabilitation of injuries, documentation, and some administrative duties