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Fatigue Effects in Lower Extremity Biomechanics During Unanticipated Sidestep Cutting in Young Adolescent Lacrosse Athletes

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FATIGUE EFFECTS IN LOWER EXTREMITY BIOMECHANICS DURING UNANTICIPATED SIDESTEP CUTTING IN YOUNG ADOLESCENT LACROSSE ATHLETES

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ABSTRACT

FATIGUE EFFECTS IN LOWER EXTREMITY BIOMECHANICS DURING UNANTICIPATED SIDESTEP CUTTING IN YOUNG ADOLESCENT LACROSSE ATHLETES

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Old Dominion University, 2011
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Over the past decade, youth lacrosse participation has substantially increased across the United States. As well, fatigue has been shown to have a detrimental effect on lower extremity biomechanics, potentially increasing the risk for injury. Yet, the effects of fatigue on lower extremity biomechanics in the young adolescent athletic population have not been addressed. The purpose of this study was to assess the effects of a fatigue protocol [Slow Linear Oxidative Fatigue Protocol (SLO-FP)] on lower extremity biomechanics during a side-step cutting task (SCT) in adolescent male lacrosse athletes. This quasi-experimental design was conducted in a controlled laboratory with 24 male recreational lacrosse players (age=11.6±1.5 years; height=153.9±14.0 cm; mass=44.7± 2.2 kg). Each subject performed five successful trials of an unanticipated SCT before and after the SLO-FP. A VO_{2peak} test was performed prior to the SLO-FP. The SLO-FP consisted of four intervals; each interval included four-minutes of jogging (speed set at 70% max VO_{2peak}) and one minute of running (speed set at 90% max VO_{2peak}) for a total of 20 minutes. Dependent variables included knee flexion (KF) angles, hip flexion (HF) angles, knee abduction moments (KABM), hip abduction angles (HAB), hip abduction moments (HABM) and vertical ground reaction force (VGRF) at initial contact. Repeated measures ANOVAs were conducted to compare statistical differences between pre and post SLO-FP. Alpha level was set *a priori* at 0.05. Fatigue significantly altered some dependent measures which were: decreased VGRF (0.256±0.123 N/mBW to

0.185±0.15 N/mBW, $p = 0.037$), KF (-24.51±7.9° to -20.96±5.39°, $p = 0.018$), adductor moment for KABM (0.851±0.135 Nm/Kgm to 0.016±0.096 Nm/Kgm, $p = 0.016$), HF (56.31±17.48° to 51.88±16.25°, $p = 0.003$), HAB (-14.85±5.08° to -12.33±5.98°, $p = 0.002$); and a shift from an adductor moment to an abductor moment for HABM (0.034±0.22 Nm/Kgm to -1.52±0.21 Nm/Kgm, $p = 0.019$). Post-fatigue, the adolescent athletes adopted a cutting position that has been shown to potentially increase the demands at the knee. These results suggest that fatigue affects lower extremity biomechanics and may put these individuals at increased risk of injury. It is important that injury prevention programs start at early ages, and take into account the effects of fatigue.

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CHAPTER I

INTRODUCTION

It is reported that 80,000 to 100,000 anterior cruciate repairs are performed each year in the United States (Griffin et al., 2000). Incurring an anterior cruciate ligament (ACL) injury is one of the most devastating and debilitating injuries that an athlete can experience. The rehabilitation is extensive and the long-term outcomes include meniscal damage, osteoarthritis and decreased knee function (Lohmander, Ostenberg, Englund, & Roos, 2004). Not only is this injury mentally and physically disabling but is also carries expensive financial burden (Bonsell, 2000). In addition, knee injury rates at multiple skill levels have been studied and risk factors for injury have been purported (Agel, Arendt, & Bershadsky, 2005; DeHaven & Lintner, 1986; Hootman, Dick, & Agel, 2007; Ingram, Fields, Yard, & Comstock, 2008). Specifically the adolescent population is becoming more prone to injury (Adirim & Cheng, 2003; Micheli, Metzl, Di Canzio, & Zurakowski, 1999; Mountcastle, Posner, Kragh, & Taylor, 2007).

In high school athletics', the knee is reported to be the second most frequently injured body part (Ingram, et al., 2008), with an ACL sprain as one of the most common injuries (Adirim & Cheng, 2003; Micheli, et al., 1999; Woo, Abramowitch, Kilger, & Liang, 2006). In regards to skeletal maturity, ACL injuries are more likely to occur in mature females than mature males yet, ACL injuries are observed to occur more in immature males in comparison to immature females (Prince, Laor, & Bean, 2005). This indicates that before puberty, boys are more likely to have an ACL injury than girls particularly if they participate in sports that require quick cutting maneuvers.

The sports that place the highest demand on the ACL are football, basketball and soccer (DeHaven, et al. 1986). Lacrosse is similar to soccer in regards to size of field, high speeds and quick changes of direction, though lacrosse has been studied less frequently (Hinton, Lincoln, Almquist, Douoguih, & Sharma, 2005). Sport participation in men's lacrosse has grown 41% nationwide since 2003 (McCulloch & Bach, 2007). Particularly, youth lacrosse is reported to be the fastest growing segment of lacrosse; with a 9.8% participation growth in 2008 (Lacrosse, 2008). Sports participation in children has shown to occur at earlier ages and thus they are developing sport-specific skill sets early on (Sharma, 2003). These young athletes have increased their competitiveness from previous decades, train more intensely, and participate in sports year round (Sharma, 2003). At the high school level, the higher demands of athletics place increased stress to lower extremity joints, particularly the knee (Ingram, et al. 2008). This increased stress can augment the likelihood of knee injuries, and ACL injuries specifically.

Although overall, females are shown to have a greater ACL injury risk rate compared to males (DeHaven & Lintner, 1986; A. W. Gottschalk & Andrish, 2011; Ingram, et al., 2008; Mountcastle, et al., 2007; Powell & Barber-Foss, 1999) for lacrosse specifically, high school boys are found to have a higher injury rate compared to girls (Hinton, et al., 2005). It was also found that in adolescent male lacrosse players, ligament sprains of the knee were most detrimental in regards to the amount of time of being out from play compared to other injuries (Hinton, et al., 2005). Furthermore, there is evidence that the rate of injury changes between the levels of maturation and often times between genders as well (Ahmad et al., 2006; Hewett, Myer, & Ford, 2004; Hinton, et al., 2005).

Pubescent adolescents are more likely to sustain injury than pre-pubescents, yet pre-pubescents are more likely to sustain fractures due to immature bones and greater tendon strength (Adirim & Cheng, 2003). Pubescent adolescent athletes are at an increased risk of ACL injury at early stages of puberty and through maturation (Hewett, Myer et al., 2004). One contributing factor to this is that children develop increased motor skills the most at ages 10-12, yet during puberty there is a temporary decline of coordination and balance and this places them at a higher risk for injury (Adirim & Cheng, 2003; Harris, 2000). These factors, in addition to others, place the pubescent athletes at even greater risk for knee injuries.

There are intrinsic and extrinsic risk factors identified for ACL injuries. Intrinsic factors are related to individual anatomical structures, hormones, laxity, biomechanical, strength and skill sets of an individual while extrinsic factors are related to the environment (I. Davis, 2007; McClay Davis & Ireland, 2001; Shultz, Schmitz, & Nguyen, 2008; Shultz et al., 2010). Furthermore, there is evidence that demonstrates that there are influences of neuromechanical patterns, which are different in females compared to males when performing athletic tasks (Shultz, et al., 2010). Specifically, females exhibit greater quadriceps contraction during early acceleration, greater valgus moments during early stance phase, decreased hip knee flexion angles, decreased hamstring activation, increased knee abduction angles at initial contact, and decreased internal rotation (Sigward and Powers 2006; Malinzak, Colby et al. 2001; Hewett, Myer et al., 2004; Yu, McClure et al. 2005; McLean et al., 2004). On the contrary, a study conducted by Swartz et al. (2005) examined no sex difference in biomechanics for males or females; rather they found developmental differences between children and adults. Particularly, they reported that children exhibit "stiffer" landings, increased valgus angles, decreased knee flexion and decreased hip flexion angles which may increase their risk for ACL injury (Swartz, Decoster, Russell, & Croce, 2005). These neuromechanical patterns between males and females become more pronounced with the presence of fatigue (McLean & Samorezov, 2009; Shultz, et al., 2010).

Fatigue is commonly defined as an acute impairment of exercise performance that includes the inability to produce force or power output (Hagberg, 1981). This inability to maintain a desired output has been reported to alter landing patterns, potentially placing athletes at higher risk of injury when fatigued (Chappell et al., 2005; McLean et al., 2009; Sanna et al., 2008; Tsai et al., 2009). With fatigue, athletes exhibit altered strategies at the knee, ankle and hip by having increased ground reaction forces and less hip and knee flexion; these strategies have been theorized to increase the likelihood of ACL injury (McLean, Fellin et al. 2007; McLean and Samorezov 2009; Gribble and Hertel 2004; Orishimo et al., 2006).

It has been found that the risk for ACL injuries has increased for male lacrosse athletes in comparison to other sports (Dick, Romani, Agel, Case, & Marshall, 2007; Hinton, et al., 2005; McCulloch & Bach, 2007; Mihata, Beutler, & Boden, 2006). Along with this increase, fatigue has also been linked to as a possible risk of ACL injury as well (Borotikar, Newcomer, Koppes, & McLean, 2008; Chappell et al., 2005; Kernozek, Torry, & Iwasaki, 2008; McLean & Samorezov, 2009; Sanna & O'Connor, 2008; Tsai, Sigward, Pollard, Fletcher, & Powers, 2009). Since there is limited research in adolescent male lacrosse athletes, particularly in fatigued states, this study will provide further insight concerning lower extremity biomechanics of this high injury risk population. This knowledge may contribute to a better understanding of how fatigue, as a risk factor, may be one of the major culprits of ACL injury mechanisms.

Purpose Statement

The purpose of this study was to compare kinetic and kinematic variables during the unanticipated side-step cutting task of young adolescent male lacrosse athletes before and after a slow-linear oxidative fatigue protocol (SLO-FP).

Null Hypothesis

There will be no statistically significant differences in kinetic and kinematic variables of youth adolescent males' during the side-step cutting task following a slow-linear oxidative fatigue protocol (SLO-FP).

Alternative Hypothesis

Initial Contact Hypotheses

1. There will be an increased internal knee adduction moment after a SLO-FP fatigue protocol at initial contact (Chappell, et al., 2005; Tsai, et al., 2009).
2. There will be an increased knee abduction angle after a SLO-FP at initial contact (Chappell, et al., 2005; Kernozek, et al., 2008; McLean et al., 2007; Nyland, Caborn, Shapiro, & Johnson, 1999; Sanna & O'Connor, 2008; Sigward & Powers, 2006; Tsai, et al., 2009; Wikstrom, Powers, & Tillman, 2004).

3. There will be a decreased knee flexion angle after a SLO-FP at initial contact (Borotikar, et al., 2008; Kernozek, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; Sanna & O'Connor, 2008).
4. There will be an increased knee internal rotation angle after a SLO-FP at initial contact (Borotikar, et al., 2008).
5. There will be a decreased hip flexion angle after a SLO-FP at initial contact (Borotikar, et al., 2008; Kernozek, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; Sanna & O'Connor, 2008).
6. There will be a decreased hip abduction angle after a SLO-FP at initial contact (Sanna & O'Connor, 2008).
7. There will be an increased hip internal rotation angle after a SLO-FP at initial contact (Borotikar, et al., 2008).

Peak Stance Hypotheses

8. There will be a decreased knee flexion angle after a SLO-FP during the peak stance (McLean, et al., 2007; Sanna & O'Connor, 2008).
9. There will be a decreased internal knee flexion moment after a SLO-FP during the peak stance (Chappell, et al., 2005; McLean, et al., 2007; McLean & Samorezov, 2009; Sigward & Powers, 2006).
10. There will be an increased knee abduction angle after a SLO-FP during the peak stance (Borotikar, et al., 2008; Chappell, et al., 2005; Ford, Myer, Toms, & Hewett, 2005; McLean, et al., 2007; McLean & Samorezov, 2009; Nyland, et al., 1999; Sanna & O'Connor, 2008).

11. There will be an increased internal knee adduction moment after a SLO-FP during the peak stance (McLean, et al., 2007; McLean & Samorezov, 2009).
12. There will be an increased knee internal rotation angle after a SLO-FP during the peak stance (Borotikar, et al., 2008).
13. There will be a decreased hip flexion moment after a SLO-FP during the peak stance (McLean, et al., 2007; McLean & Samorezov, 2009).
14. There will be a decreased hip flexion angle after a SLO-FP during the peak stance (McLean, et al., 2007; Sanna & O'Connor, 2008).
15. There will be a decreased hip abduction angle after a SLO-FP during the peak stance (Pollard, Davis, & Hamill, 2004; Sanna & O'Connor, 2008).
16. There will be an increased hip internal rotation angle after a SLO-FP during the peak stance (Borotikar, et al., 2008; McLean & Samorezov, 2009).

Vertical Ground Reaction Force Hypotheses

17. There will be an increased peak vertical ground reaction force after a SLO-FP (Hass et al., 2005; Kernozek, et al., 2008; McLean, Lipfert, & Aj, 2004; Wikstrom, et al., 2004).
18. There will be a decreased knee flexion angle after a SLO-FP at peak vertical ground reaction force (Chappell, et al., 2005; Kernozek, et al., 2008).
19. There will be a decreased hip flexion angle after a SLO-FP at peak vertical ground reaction force (McLean, et al., 2007; Sanna & O'Connor, 2008).
20. There will be a decreased hip abduction moment after a SLO-FP at peak vertical ground reaction force (Sanna & O'Connor, 2008).

Posterior Ground Reaction Force Hypotheses

21. There will be an increased peak posterior ground reaction force after a SLO-FP (Hass, et al., 2005; McLean, et al., 2007).

22. There will be a decreased knee flexion angle after a SLO-FP at at peak posterior ground reaction force (Chappell, et al., 2005; Kernozek, et al., 2008).

23. There will be a decreased knee flexion moment after a SLO-FP at peak posterior ground reaction force (Kernozek, et al., 2008).

24. There will be a decreased hip flexion angle after a SLO-FP at peak posterior ground reaction force (McLean, et al., 2007; Sanna & O'Connor, 2008).

25. There will be a decreased hip abduction moment after a SLO-FP at peak posterior ground reaction force (Sanna & O'Connor, 2008).

Independent Variables

Time with two levels:

1) Pre slow-linear oxidative fatigue protocol

2) Post slow-linear oxidative fatigue protocol

Dependent Variables

The kinetic and kinematic variables analyzed during the side-step cutting task included (1) knee abduction/adduction angles (KAB/KAD) and moments (KABM/KADM), (2) knee flexion angles (KF) and moments (KFM), (3) knee internal/external (KIR/KER) angles, (4) hip flexion angles (HF) and moments (HFM), (5) hip abduction/adduction angles (HAB/HAD) and moments (HABM/HADM), (6) hip internal/external rotation (HIR/HER) angles (5) vertical ground reaction force (VGRF), and (6) posterior ground reaction force (PGRF).

These variables were recorded at initial contact, peak vertical ground reaction, peak posterior ground reaction and peak stance.

Operational Definitions

a. *Contact ACL Injury-* ACL injury which occurs as a result of a "direct blow" to the knee (Olsen, Myklebust, Engebretsen, & Bahr, 2004).

b. *Dominant Limb-* The leg by which one kicks a ball with as far as possible (Ford, Myer, & Hewett, 2003).

c. *Fatigue-* An acute impairment of exercise performance, which leads to an inability to produce maximal force output (Hagberg, 1981)

  i. *Central Fatigue-* A reduction in voluntary activation of muscle at the proximal site to the neuromuscular junction (Garner, Hicks, & McComas, 1989)

  ii. *Peripheral Fatigue-* Fatigue produced by changes at or distal to the neuromuscular junction (Garner, et al., 1989)

d. *Initial Contact-* The time instance at which 10 Newtons of force is recorded from the vertical ground reaction force. (Padua et al., 2009)

e. *Non-contact ACL Injury -* ACL injury occurring in absence of player-to-player or body-to-body contact (Olsen, et al., 2004).

f. *Peak Stance-* The phase occurring between 0-50% of stance (McLean & Samorezov, 2009).

g. *Peak Vertical Ground Reaction Force (PVGRF) -* The greatest vertical force recorded by the force plates during the first 50% of the stance phase.

h. *Rate of Perceived Exertion (RPE)* - A scale used to assess exertion perception of subjects during the SLO-FP. The children's OMNI pictorial scale is used for this study and is valid and reliable (Lagally & Robertson, 2006; Robertson et al., 2000; Utter, Robertson, Nieman, & Kang, 2002).

i. *Side-Step Cutting Task-* A running approach where the dominant foot makes contact with a force plate followed by the subject cutting approximately 45°, making a directional change towards the non-dominant side.

j. *Slow Linear Oxidative Fatigue Protocol (SLO-FP)* - The protocol consisted of the participant completing a VO2peak test and then completing a 20-minute jog/run based on speed values calculated from the VO2peak test. The participant jogged for four minutes at 70% of the top speed from the VO2peak test and then ran for one minute at 90% of their top VO2peak speed. They repeated this cycle for up to 20 minutes or until they reached a point which they could not continue (Quammen et al., 2011).

Assumptions

1. All of the participants performed the tests to the best of their ability.
2. The administrators of the tests followed the outlined protocol and did not deviate by any means.
3. The calibration of the Vicon motion analysis system was maintained throughout each test.
4. The Vicon motion analysis system is valid and reliable.

5. The subjects were physiologically fatigued after the fatigue protocol.
6. The $VO2_{peak}$ metabolic cart and heart rate monitor provided accurate readings for each subject.
7. The calibration of the VO2peak was maintained throughout each test.
8. There is a high inter-rater reliability between the testers administering the tests.
9. The attire worn by the subject had no effect on the performance of the individual.

Limitations

1. The population being tested was a sample of convenience and was not a random selection.
2. All testing was performed in an in-door laboratory and therefore may not fully simulate a game-like situation.
3. The peak aerobic capacity test is completed partially based upon the participant's subjectivity to the feeling of being "tired" and varied from person to person.
4. The subjects were allowed to wear their own athletic shoes and therefore there was no consistency between subjects in regards to footwear.

Delimitations

1. This study included 24 youth adolescent males who participate in recreational lacrosse in the Hampton Roads Area of Virginia.
2. The subjects were healthy individuals with no previous history of lower extremity injury within the last six months or knee surgery in the last two years.

CHAPTER II

REVIEW OF LITERATURE

Epidemiology of Anterior Cruciate Ligament Injuries

Injury Surveillance Studies

The higher demands in today's society for sports participation at younger ages have led to the risk of more injuries for youth athletes (Sharma, 2003). In a 1988-2004 NCAA injury surveillance study which examined fifteen sports in all three divisions, there was an 80% increase in female sports participation, an a 20% increase in male sports participation. Men's participation in lacrosse in the U.S. has had an overall growth of 41% since 2003 (McCulloch & Bach, 2007). In another participation survey, it was observed that youth lacrosse, growing since 2001, was one of the fastest-growing segments of sports, growing 9.8% for 2008 (Lacrosse, 2008). With this increase in participation there is also an increase of injuries.

It is estimated that 2000 ACL injuries occurred each academic year (Hootman, et al., 2007). Within the sport of lacrosse specifically, high school injury rates for boys over a three year period was 2.89 per 1000 athletic exposures (AE) in comparison to girls which was 2.54 per 1000 AE (Hinton, et al., 2005). At the collegiate level, a fifteen-year study identified the rate of ACL injury in men's lacrosse (0.17AE) to be higher than men's basketball (0.08AE) and men's soccer (0.12AE) (Mihata, et al., 2006). In collegiate lacrosse, it has been shown that males and females have essentially the same rate of injury (Mihata, et al., 2006).

There is consistency within the literature that conservative treatment for ACL injury in the skeletally immature patients does not have favorable outcomes; instead it results in chronic instability, and increases meniscal and chondral injury (Aichroth, Patel, & Zorrilla, 2002; Millett, Willis, & Warren, 2002; Mizuta et al., 1995). Therefore, surgical reconstruction is recommended as the best treatment, yet it is still controversial (Arbes, Resinger, Vecsei, & Nau, 2007; Barber, 2000; Fuchs et al., 2002). The financial impact of any injury is significant, particularly an injury to the knee. The cost of an anterior cruciate ligament (ACL) reconstruction surgery can range from \$6000- \$9000 (Bonsell, 2000) which doesn't include rehabilitation costs. The cost associated with ACL surgery and rehabilitation is about \$17,000 per patient (Hewett, Lindenfeld, Riccobene, & Noyes, 1999).

There has been widespread research conducted on the prevention, rehabilitation and treatment of ACL injuries. In an injury surveillance study completed in the 2005/2006-2006/2007 school years, the knee was the second most frequently injured body site, and females were twice as likely as males to have a non-contact ACL injury (Ingram, et al., 2008). In the same study, it was reported that the knee was the body part that athletes had surgery on the most compared to any other body part. An earlier study conducted a similar surveillance at the high school level and reported that knee surgeries, compared to other types of injury surgeries, accounted for the majority (60.3%) of the surgeries (Powell & Barber-Foss, 1999). These ongoing surveys show that ACL injuries have not decreased over the past two decades.

Related Anatomy & Physiology

Anterior Cruciate Ligament

The ACL is located in the middle of the tibiofemoral joint and keeps the knee stable (Kurz, Stergiou, Buzzi, & Georgoulis, 2005). It maintains stability by preventing excessive anterior translation of the tibia on the femur, internal rotation, and restrains varus and valgus loads when the knee is in full extension (Markolf et al., 1995; Zantop, Petersen, Sekiya, Musahl, & Fu, 2006). It has been observed that greater strain is placed on the ACL at 0- 30° of flexion (Georgoulis, et al. 2005; Ostermeier et al. 2007). The ACL runs anteriorly, medially, and distally from the inner surface of the femoral condyle to the tibia (Duthon et al., 2006). There are two parts to the ACL, the anteriomedial bundle and posteriolateral bundle (Girgis, Marshall, & Monajem, 1975), and these two bundles change in length throughout knee range of motion. The anteriomedial bundle lengthens during extension and tightens during flexion. The posteriolateral bundle shortens during extension and becomes slack in flexion (Duthon, et al., 2006; Zantop, et al., 2006). One study observed that the anteriomedial bundle increases in length by 12% and the posteriolateral bundle shortens by 32% at 90 degrees of flexion (Hollis, Takai, Adams, Horibe, & Woo, 1991). It was also observed that the anteriomedial bundle provides more restraint for anterior translation than the posteriolateral due to the anatomical positioning. Lastly, internal rotation creates more stress on the ACL compared to external rotation (Amis & Dawkins, 1991).

The knee's mechanoreceptors responsible for proprioception include ruffini receptors, vater-pacini receptors and golgi-like tension receptors. These mechanoreceptors stimulate the afferent nerve fibers in the proximal part of the ACL, referred to as the "ACL Reflex", which affect motor activity in the muscles around the knee (Duthon, et al., 2006). After an ACL rupture, knee joint position sense is disrupted and the quadriceps femoris becomes weak due to the loss of mechanoreceptors (Adachi et al., 2002; Hogervorst & Brand, 1998; Konishi, Fukubayashi, & Takeshita, 2002).

The ACL receives blood supply from the middle genicular artery and this is crucial for the healing process and nutrition. Due to the distribution, the proximal portion of the ACL receives better blood supply compared to the distal portion and therefore this may contribute to poor healing (Duthon, et al., 2006). The ACL is innervated by the posterior articular branches of the tibial nerve (Kennedy, Alexander, & Hayes, 1982).

Intercondylar Notch

The intercondylar notch is the space between the distal femoral condyles in which the cruciate ligaments pass through (Zantop, et al., 2006). There is a statistically significant correlation between anterior intercondylar notch stenosis and ACL injury during cutting and pivoting tasks (LaPrade & Burnett, 1994). The intercondylar notch is measured as a ratio of epicondylar width to notch width, and is referred to as the notch width index (NWI) (Zantop, et al., 2006). This is measured on a radiograph with forty-five degrees of knee flexion for the best view (Shelbourne, Facibene, & Hunt, 1997). Anterior cruciate ligament size increases in proportion to notch width in men but not in women, potentially increasing strain on the ACL more in females (Chandrashekar, Slauterbeck, & Hashemi, 2005). Intercondylar notch stenosis may also cause impingement and adds strain to the ACL (Anderson, Dome, Gautam, Awh, & Rennirt, 2001; LaPrade & Burnett, 1994).

Musculature

The quadriceps muscle group consists of 4 muscles: the vastus lateralis which originates at the lower greater trochanter and upper half of the linea aspera; vastus medialis which originates at the lower half of the intertrochanteric lines and medial portion of linea aspera; vastus intermedius which originates at the promixal two-thirds of the anterolateral surface of the femur; and the rectus femoris which originates at the anterior inferior iliac spine (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). All four quadriceps come together to form the quadriceps tendon at the superior border of the patella and the tibial tuberosity via the patella ligament, known as the patella tendon. The quadriceps muscles also place a great amount of force load on the ACL (Hewett, Myer, & Ford, 2006; Sell et al., 2006; Shimokochi & Shultz, 2008). Particularly, it's been found that the ACL is under significant strain during an isometric contraction when at fifteen and thirty degrees of knee flexion (Beynnon et al., 1995; Durselen, Claes, & Kiefer, 1995; Markolf, O'Neill, Jackson, & McAllister, 2004). One study examined a significant quadriceps loading, with twenty degrees of knee flexion, on cadaver knees that caused a nineteen millimeter anterior displacement of the ACL with slight knee flexion, resulting in injury to the ACL (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004). DeMorat et al. (2004) suggested that aggressive quadriceps loading with slight knee flexion is an intrinsic factor in non-contact ACL injuries.

The hamstring muscle group consists of three muscles: the biceps femoris which inserts at the head of the fibula; the semitendinosus which inserts on the medial surface of the tibia; and the semimembranosus which inserts on the medial tibial condyle. All three hamstrings originate on the ischial tuberosity (Kendall, et al., 2005). The contraction and flexion angles of the quadriceps and hamstring muscles can either provide protection or increase strain to the ACL. It has been found that the ACL protection is provided during knee extension when there is also an antagonist co-contraction of the hamstrings (Markolf, et al., 2004; Ostermeier et al., 2007). This same study (Markolf, et al., 2004) along with another showed there is an increased load to the ACL when at full extension compared to 120°-20° flexion (Durselen, et al., 1995). The hamstrings are shown to be able to have more control of anterior-posterior translation of the tibia compared to the quadriceps, particularly at ninety degrees of knee flexion, which reduce forces placed on the ACL (Markolf, et al., 2004; Ostermeier, et al., 2007). The vastus lateralis is one muscle that can help control for valgus movement at the knee, and it has been observed that in males this muscle was found to activate quicker when performing athletic tasks (Rozzi, Lephart, & Fu, 1999).

The co-contraction of the quadriceps and hamstrings has been researched repeatedly and is understood to be a crucial piece to understanding ACL injury occurrences. With appropriate co-contraction of the quadriceps and hamstrings during knee extension, the tibofemoral joint is stable in the sagittal and transverse planes which decrease anterior tibial translation and rotational movements (Draganich, Jaeger, & Kralj, 1989; Hanson, Padua, Troy Blackburn, Prentice, & Hirth, 2008; MacWilliams, Wilson, DesJardins, Romero, & Chao, 1999; More et al., 1993). One previous study examined an 82% decrease of ACL load during a 200 N force of co-contraction of the hamstrings near full knee extension (Ostermeier, et al., 2007).

The hip abductors and adductors, which may cause out of plane motion, have been shown to influence ACL strain as well (Shultz & Schmitz, 2009). The hip abductors, which also perform hip internal rotation, consist of the gluteus medius, which originates at the external surface of the ilium between the iliac crest and posterior gluteal line dorsally and the anterior gluteal line ventrally ,and gluteal apponeurosis ,which inserts on the oblique ridge of the lateral surface of the greater trochanter of the femur; gluteus minimus, which originates at the external surface of the ilium between the anterior and inferior gluteal lines and margin of the greater sciatic notch and inserts on the anterior border of the greater trochanter; and tensor fascia latae (TFL), which originates at the anterior part of the iliac crest, outer surface of anteriorsuperior iliac spine and deep surface of fascia lata and inserts into the iliotibial tract of the fascia lat at the junction of the proximal and middle third of the thigh (Kendall, et al., 2005). It is theorized that the mechanics at the hip can be directly correlated to ACL injury. It has been found that during weight-bearing exercises, hip adduction and internal rotation may cause knee valgus at the knee, which place an increased load to the ACL (Hanson, et al., 2008). The gluteus medius and minimis along with the TFL are the major hip abductors (F. Gottschalk, Kourosh, & Leveau, 1989). The gluteus medius and minimis stabilize the hip during weight bearing and act as pelvic rotators to rotate the opposite pelvis forward during swing through phase. The TFLs primary role is balancing weight and is activated during the mid-stance phase (F. Gottschalk, et al., 1989).

Mechanism of ACL Injury

The two types of mechanisms for ACL injury are contact and noncontact. The contact mechanism accounts for 30% (McNair, Marshall, & Matheson, 1990) of all ACL injuries and is defined as occurring as a result of a "direct blow" to the knee (Olsen, et al., 2004). The non-contact mechanism accounts for 70% (McNair, et al., 1990) of all ACL injuries and is defined as occurring in the absence of player-to-player or body-to-body contact (Olsen, et al., 2004). For lacrosse, the most common injury mechanisms for boys are cutting and dodging, followed by legal body-to-body contact and falling to the ground with no contact (Hinton, et al., 2005). Many studies describe the mechanism as pivoting, landing, or fast decelerating maneuvers (Boden, Breit, & Sheehan, 2009; Boden, Griffin, & Garrett, 2000; DeMorat, et al., 2004; Hewett, Ford, & Myer, 2006; Krosshaug, Slauterbeck, Engebretsen, & Bahr, 2007; Olsen, et al., 2004; Shimokochi & Shultz, 2008). Another important mechanism identified is rapid unanticipated change of direction like cutting, side stepping or crossing over which are all considered to increase the risk for ACL injury (Boden, et al., 2000; Hewett, Myer, et al., 2006; McNair, et al., 1990).

Risk Factors for ACL Injury

The risk factors for ACL injury are divided into two classifications, intrinsic and extrinsic. The intrinsic factors are within the body, whereas extrinsic factors are outside the body (Dugan, 2005). The intrinsic factors for ACL injuries can be further classified into anatomical and biomechanical. Extrinsic factors are dependent upon sport, skill level, playing surfaces and equipment (Dugan, 2005). Particular ranges of motion, time instances and other factors (e.g. less than 30 degrees of knee flexion, weight bearing, deceleration phase, muscle activation) place the athlete at greater risk for ACL injury (Boden, et al., 2009; Hewett, Myer, et al., 2006; Krosshaug, et al., 2007).

Anatomical intrinsic risk factors include quadriceps angle, pelvic position, excessive quadriceps load near full extension, anterior tibial translation, intercondylar notch width, ACL size, joint laxity and hormonal levels (DeMorat, et al., 2004; Dugan, 2005; Kramer, Denegar, Buckley, & Hertel, 2007; LaPrade & Burnett, 1994; Parkkari, Pasanen, Mattila, Kannus, & Rimpelä, 2008; Shimokochi & Shultz, 2008). Other anatomic risk factors include: increased thigh length (Beynnon et al., 2001), increased quadriceps angle (Hewett, Myer, et al., 2006), decreased notch width (Hewett, Myer, et al., 2006), increased joint laxity (Shultz, Sander, Kirk, & Perrin, 2005), increased muscle flexibility, increased anterior tibial translation (Hewett, Myer, et al., 2006), increased foot pronation and navicular drop (Anderson, et al., 2001), having a BMI greater than 1 SD from the mean (Hewett, Myer, et al., 2006), decreased co-contraction and compression forces and pre-activation of protective muscle groups (Markolf, et al., 2004), decreased proprioception, altered magnitude and timing of muscle activation (Besier, Lloyd, & Ackland, 2003), imbalanced medial-lateral muscle firing patterns (Hanson, et al., 2008), and increased fatigue states (Borotikar, et al., 2008; Chappell, et al., 2005; McLean & Samorezov, 2009; Sanna & O'Connor, 2008; Tsai, et al., 2009)

Biomechanical risk factors are continuously being explored to further the body of knowledge for ACL injury. Boden et al. (2009) proposed that poor ankle kinematics lead to abnormal ground reaction forces (GRF). In the absence of a gastrocnemius contraction, the knee may abduct or internally rotate rather than flex (Boden, et al., 2009). Therefore, landing flat-footed or with the hind foot first leads to inadequate absorption of GRF. Other biomechanical risk factors include multiplane loading, valgus loading, and knee hyperextension (Hewett, Myer, et al., 2006; Hughes & Watkins, 2006; Krosshaug, et al., 2007; Quatman & Hewett, 2009; Senter & Hame, 2006).

It has also been observed that ACL injuries occur on natural grass more than artificial surfaces, 50% occur during game-day, and 95% occur on dry fields (Scranton et al., 1997). In addition, when there is a higher coefficient of friction in shoe-surface conditions risk of ACL injury is high (Dowling, Corazza, Chaudhari, & Andriacchi, 2010). A sport-specific risk factor for lacrosse athletes includes carrying a lacrosse stick in a constrained arm position resulting in increased valgus loading at the knee during cutting maneuvers (Chaudhari, Hearn, & Andriacchi, 2005). In addition, this study found an increase of 60% valgus moment at the knee when compared to baseline measures which had subjects in a non-constraining arm position while performing cutting maneuvers.

Gender in Relation to Cutting Tasks & Fatigue

Difference in Developmental Growth Patterns

At the peak of the growth spurt within puberty, adolescents are likely to have a higher injury risk rate which occurs between the ages of twelve to fourteen (Micheli & Klein, 1991) . In regards to muscle and bone growth during development, boys produce a ten-fold increase in testosterone which produces more muscle mass, and girls' estrogen production during development increases which causes an increase of fat tissue, breast development and makes the hips wider (Buenen, 1988). As for strength development, gains occur for boys 1.2 years after peak height velocity and 0.8 years after peak weight velocity, whereas gains occur for girls after peak height velocity, with more variation than boys (Buenen, 1988). As for anatomical differences during puberty, females develop an increased quadriceps muscle angle, have a narrower femoral notch and have increased joint laxity (Ford, et al., 2005). It has also been found that during maturation the female athlete's neuromuscular control at the knee is deficient (Hewett, et al., 1999). This same study demonstrated that boys have better neuromuscular control at the knee at the end of puberty whereas girls show a decrease in control from the beginning to the end of puberty.

One of the controversial topics within gender difference, in regards to ACL injury, is hormonal levels in females during their menstrual cycles. One study showed that the rise of estrogen levels during the menstrual cycle of females is associated with increased knee laxity (Shultz et al., 2005). Yet, another study found no association between hormonal levels and knee joint laxity (Van Lunen, Roberts, Branch, & Dowling, 2003).

Biomechanical Differences in Performing Athletic Tasks

An abundance of studies have identified kinetic and kinematic differences between males and females during various athletic tasks like cutting, side-stepping and a stop jump (Ford, et al., 2005; Hewett, et al., 2004; McLean, Huang, & van den Bogert, 2005; Sigward & Powers, 2006). Sigward & Powers (2006) examined fifteen male and fifteen female collegiate athletes, and observed differences during side-step cutting. It was found that when compared to males, females exhibited smaller sagittal plane moments and greater frontal plane moments, as well as more quadriceps activation during early acceleration. This study coincided with findings from other studies (Ford, et al., 2005; Hewett, et al., 2004; McLean, et al., 2005) that females have greater valgus moments during the early stance phase.

Malinak and colleagues (2001) examined eleven male and nine female recreation athletes who performed running, side-cutting and cross-cutting tasks. They found that females exhibited decreased knee flexion angles, increased quadriceps muscle activation, and decreased hamstring activation (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Consistent with other findings, there was increased knee valgus in collegiate male athletes, and middle and high school basketball athletes during unanticipated cutting tasks (Ford, et al., 2005; Malinzak, et al., 2001). It was found that adolescent athletes are at an increased risk of ACL injury at early stages of puberty and through maturation (Ford, et al., 2005; Hewett, et al., 2004). The results of Hewett, Myer and Ford (2004) demonstrate that females have an increased knee abduction angle at initial contact compared to males. There was no gender difference for knee flexion at initial contact or at maximum knee flexion (Ford, et al., 2005). It is suggested that "ligament dominance", described as when the ligament takes the brunt of force from the ground reaction force instead of the LE musculature, may occur in those individuals who also demonstrate with a "dynamic valgus" characteristic which would lead to higher risk for ACL injury (Ford, et al., 2005).

There is a discrepancy in which (Sigward & Powers, 2006) found that females had smaller peak flexion moments than males while Ford et al. (2005) showed no gender difference in knee flexion at initial contact or stance phase. There is another discrepancy in regards to a gender difference of knee flexion angles during sidestepping as to whether or not it correlates to ACL injuries (McLean, Lipfert, et al., 2004). One particular study (Pollard, et al., 2004) found no gender differences in knee abduction, internal rotation, and frontal and transverse kinematics. It is suspected that differences are due to the high level of skill and more experienced athletes adapted (Pollard, et al., 2004).

McLean et al., (2004) studied sidestep cutting of eight females and eight males, and found that females had increased peak knee valgus and increased rearfoot pronation angles, and decreased peak hip flexion, hip abduction, hip internal rotation, knee flexion and knee internal rotation angles. Valgus loading was found to be sensitive to neuromuscular control and that when there is a gender difference even a two degree change in peak valgus, a change of 40 Nm valgus moment can result yielding to valgus buckling (McLean, Lipfert, et al., 2004). It was proposed that one of the risk factors for ACL injuries is increased hip external rotation which leads to knee valgus and foot pronation (McLean, Lipfert, et al., 2004).

Another study had similar results for adolescents which also analyzed lower extremity strength gender differences (Yu et al., 2005). These researchers found that females after the age of twelve had decreased hip and knee flexion angles and also tended to land with their lower extremity more extended compared to males. Another study found gender differences on lower limb frontal plane kinematics during landing (Hughes, Watkins, & Owen, 2008). It was found that females have a significantly greater maximum knee valgus angle and males had greater ankle joint linear motion during the first 40 percent of normal contact time and a minimum net movement. In addition, females had a continuous inward movement of the ankles predisposing them for increased risk of ACL injury (Hughes, et al., 2008).

Young Adolescents

Biomechanical Characteristics in Regards to Growth & Development

More motor skills are developed between pre-pubescence and pubescence than any other developmental stage (Davies & Rose, 2000). Davies & Rose (2000) showed that males were better at strength and speed tasks at the end of puberty and into adult hood than females. A study conducted by Hass et al. (2005) compared pre-adolescent (8-11 years old) girls to post-adolescent (18-25 years old) women and found that pre-adolescent girls land during athletic tasks with more knee flexion which aides as a protective mechanism for the ACL. Yet, it was also found that post-adolescents had decreased ground reaction forces when they landed and thus more load on the ACL (Hass, et al., 2005). Other studies completed found no differences in knee flexion, hip flexion or ground reaction forces between girls and boys (Sigg, 2001; Swartz, et al., 2005).

Swartz et al. (2005) compared children to adults and noticed that children landed with a different strategy. The authors speculated the discrepancy may be due to the lack of physical maturation, skill development and experience in the children (Swartz, et al., 2005). They specifically identified that children compared with adults were landing with less knee flexion (10.25° for children and 12.62° for adults), greater knee valgus angles (12.37° for children and 6.54° for adults), less hip flexion (6.51° for children and 11.1° for adults) and increased vertical ground reaction forces (8.23N/J for children and 4.57N/J for adults) at initial contact and peak vertical ground reaction forces.

Inherent Risk Factors

Previous research indicates that children may have a much higher risk for injury than fully developed adults (Swartz, et al., 2005). This is proclaimed to be due to how children have a larger surface area to mass ratio, they may be too small for protective equipment, growing cartilage may be more vulnerable to stresses, and they have not yet developed the appropriate motor skills needed for particular sports activities (Adirim & Cheng, 2003). One study completed by Shea et al. (2003) found that older children and young adolescents are more likely to incur lower extremity injuries. There is a possibility of the tibial spine avulsion fracture during an ACL injury in children and this is crucial in skeletally immature patients due to complications with physeal healing (Schub & Saluan, 2011; Shea, Apel, & Pfeiffer, 2003). There is a controversial risk for young adolescents, referred to as skeletally immature, because ACL reconstruction surgery requires drilling into the distal femoral and proximal tibial physes which disrupts the growth plates (Fuchs, et al., 2002; Schachter & Rokito, 2007). One study indicated that around the time of growth spurts, adolescents are more vulnerable to injuries because of imbalances in strength and flexibility and also the changes in biomechanical properties of bone (Sharma, 2003). Due to these factors, ACL injuries in children are commonly seen with avulsion of the proximal tibia, keeping the ACL intact (Sharma, 2003).

Unanticipated Cutting Tasks

Description of Tasks

The side-step cutting task has been examined by numerous researchers (Besier, Lloyd, Ackland, & Cochrane, 2001; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Dempsey et al., 2007; Ford, et al., 2005; Hanson, et al., 2008; Houck, Duncan, & De Haven, 2005; McLean, et al., 2005; McLean, Neal, Myers, & Walters, 1999; Pollard, et al., 2004; Sanna & O'Connor, 2008; Sigward & Powers, 2006; Tsai, et al., 2009). One study showed that experienced soccer athletes are at a higher risk of ACL injury during this task (Sigward & Powers, 2006). This was based on the findings of greater knee moments and reduced hamstrings to quadriceps co-contraction seen in experienced soccer players in comparison to novice soccer players when they performed side-step cutting tasks (Sigward & Powers, 2006).

As far as different types of cutting tasks, there are contradictory findings in the literature as to how one task varies from others. For instance, (O'Connor, Monteiro, & Hoelker, 2009) found significant differences in ROM between the unanticipated run and cut (CUT) and close box-land and cut (CLC). For the CLC compared to the CUT, there was a 12° greater knee flexion and a 2.5° greater internal rotation. These findings suggested that the different tasks had a low correlation to each other which contradicts (McLean, et al., 2005) that found high correlations between tasks, particularly with peak abduction angles of planned side-cut and a jump land task.

Depending on the sport, athletes are placed at greater injury risk at different parts in their cutting and landing mechanics. One study examined female basketball players compared to female soccer players in regards to cutting and landing tasks (Cowley, et al., 2006). It was found that during the cut, soccer players exhibited an average increase of 15.6% in peak vertical ground reaction force (GRF) and a 20.5% decrease in stance time. For basketball players during landing they found a 12.5% greater GRF and a 14.6% decrease in stance time. This showed that soccer players have a higher injury risk while cutting and basketball players have higher injury risk while landing.

There have been a few studies which researched the effect of unanticipated movements in relation to ACL injury risk (Besier, et al., 2001; Borotikar, et al., 2008; Sell, et al., 2006). For jumping and landing tasks, it has been noticed that initial contact hip rotation and peak knee abduction angles are more pronounced during unanticipated landing (Borotikar, et al., 2008). Another study identified significant differences in joint angles, ground reaction forces and knee moments which were affected during unanticipated landing tasks (Sell, et al., 2006). Decision making in a little amount of time during unanticipated cutting maneuvers was found to increase the risk of ACL injury due to increased external varus/valgus rotation at the knee (Besier, et al., 2003). Analyzing unanticipated data may provide a better understanding due to the fact that pre-planned movement's do not truly simulate game-like situations where quick decision making and quick change of direction are characteristics of many sports.

Fatigue

Definition

Fatigue is defined as an acute impairment of exercise performance, which leads to an inability to produce maximal force output (Hagberg, 1981). There are two components within fatigue known as central and peripheral. Peripheral fatigue, which can be described as muscular fatigue, is more difficult to pinpoint as opposed to central fatigue. Fatigue that cannot be linked back or explained due to muscles is referred to as central fatigue (J. M. Davis & Bailey, 1997). Central fatigue is defined as a reduction in voluntary activation of muscle at the proximal site to the neuromuscular junction (Garner, et al., 1989). Peripheral fatigue is defined fatigue produced by changes at or distal to the neuromuscular junction (Garner, et al., 1989). Fatigue has also been studied as a conscious sensation rather than a physiological occurrence related to motivation and emotion yet the exact area of the brain or particular time points are still unknown (LeDoux, 1998; St Clair Gibson et al., 2003).

Common Fatigue Protocols

Most recent studies have included fatigue protocols that use plyometric exercises, isokinetic and isometric exercises on machines and examine "volitional exhaustion" from these protocols in efforts to determine the effects fatigue may have on various biomechanical characteristics (Apriantono, Nunome, Ikegami, & Sano, 2006; Borotikar, et al., 2008; Chappell, et al., 2005; Christopher Carcia, 2005; Gribble & Hertel, 2004; McLean, et al., 2007; McLean & Samorezov, 2009; Nyland, et al., 1999; Tsai, et al., 2009). The use of VO2max and a treadmill run have been successful in fatiguing subjects (Moran & Marshall, 2006; Sanna & O'Connor, 2008). One study compared the effects of a functional fatigue protocol to an isokinetic fatigue protocol, in relation to dynamic stability when landing, and reported no significant difference of results between these two protocols (Wikstrom, et al., 2004).

Fatigue Effects on Lower Extremity Kinetics & Kinematics

The idea that fatigue has great impact on lower extremity (LE) kinetics and kinematics leads many researchers to believe there is a direct link of increased injury risk to the ACL from LE fatigue-related changes. The common fatigue effects shown across various studies during different athletic tasks include: increased knee valgus moments for females (Chappell, et al., 2005; Christopher Carcia, 2005), increased peak proximal tibial anterior shear force (Moran & Marshall, 2006), decreased knee flexion angle (Chappell, et al., 2005); increased hip and knee internal rotation angles and moments (McLean & Samorezov, 2009; Nyland, et al., 1999; Sanna & O'Connor, 2008; Tsai, et al., 2009); and increased ground reaction forces (Wikstrom, et al., 2004) . In contrast, one study found greater knee flexion with fatigue during a single leg horizontal hop (Karl F. Orishimo, 2006). This may be due to the specific task involved in comparison to other athletic tasks which do not require as much knee flexion to perform the task. This same study stated that hip extensors are responsible for controlling the vertical position of the center of mass, thus preventing instability of the lower extremity by ways of controlling excessive flexion. Therefore, with greater flexion noticed in this study, the researchers claimed there may be an increased risk for injury of the lower extremity.

There are strategies which are adaptive to various fatigue protocols. One strategy is the knee is positioned in a more extended position from a landing task and results in a decreased knee flexion moment (McLean, et al., 2007; McLean & Samorezov, 2009). Another study noticed similar strategies including postural swaying, to be of benefit for both the hip and knee (Gribble & Hertel, 2004).

Two particular studies discuss fatigue and recovery in relation to athletic tasks (Carcia, 2005; Tsai, et al., 2009) . One study examined altered frontal plane tibial femoral landing after a bilateral hip abduction protocol and documented increased landing angles seen at initial contact from a drop jump during a recovery phase in comparison to immediate post-fatigue (Carcia, 2005). Researchers found similar results including increased max knee flexion, abduction and internal rotation at initial contact with 40-minutes after rest to return to pre-fatigue levels (Tsai, et al., 2009).

There is inconsistency in the literature in regards to knee joint laxity and kinesthetic awareness in relation to fatigue. After a muscular fatigue protocol, knee joint laxity significantly increased when measured by the KT-1000 in one study along with an increased kinesthetic awareness of joint position (Skinner, Wyatt, Stone, Hodgdon, & Barrack, 1986; Wojtys, Wylie, & Huston, 1996). In contrast, another study which measured knee joint laxity after a muscular fatigue protocol reported no significant increase in knee joint laxity and a decrease in knee joint kinesthesia, specifically during knee extension (Rozzi, et al., 1999).

There is a lack of evidence explaining the relationship between fatigue and young adolescent male lacrosse athletes in relation to side-step cutting and the risk for ACL injury. To date, there are no other studies that examine how a SLO-FP affects lower-extremity biomechanics during the side-step cutting task in young adolescent athletes. This information will lead to a better understanding of demands placed on young athletes due to fatigue, thus there will be insight for the creation of injury prevention programs for the youth sports population.

CHAPTER III

METHODOLOGY

Design

This was a quasi experimental design to determine lower extremity biomechanical differences in youth male lacrosse players while performing a side-step cutting task before and after a Slow-Linear Oxidative fatigue protocol (SLO-FP). The independent variable of this study was time (pre and post fatigue). The dependent variables consisted of kinetic and kinematic measurements, measured at initial contact, peak vertical ground reaction, peak posterior ground reaction and peak stance, and included: knee and hip flexion angles and moments, knee and hip rotation angles and moments, knee and hip abduction angles and moments, vertical ground reaction force (VGRF), and posterior ground reaction force (PGRF).

Subject Characteristics

An *a priori* power analysis was conducted to estimate the sample size needed to demonstrate differences in kinetic and kinematic variables before and after an aerobic fatigue protocol (Borotikar, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; Sanna & O'Connor, 2008; Tsai, et al., 2009). To achieve 80% power (d = 0.70) with an alpha level of 0.05, a sample size of approximately thirty subjects was needed. Twenty-four males (age = 11.6 ±1.5 years old, height=153.9 ±14.0cm, mass =44.7 ±12.2kg, body fat percent = 9.9 ±5.5%) from the Hampton Roads Lacrosse League were recruited for participation. Prior to testing, each participant completed a demographical questionnaire and a history of previous injury questionnaire. Height and weight were assessed along with body composition by way of skinfold.

Subjects were included in the study if they were healthy, between 9-14 years old, and a member of the Hampton Roads Lacrosse League. Exclusionary criteria consisted of having any lower-extremity traumatic injury in the past six months, any lower-extremity surgery in the past 2 years, and presence of any cardiac conditions. Approval of the research through Institutional Review Board, and written informed consent and assent for all subjects was obtained prior to testing.

Instrumentation

An eight-camera Vicon motion analysis system (Vicon Motion Systems Ltd., Oxford England) was used to capture kinematic data during the unanticipated side-step cutting task. The cameras were set at a sampling rate of 300Hz. Two Bertec force plates (Bertec Co, Columbus, OH, Model 4010-NC) were used to capture ground reaction force data with a sampling rate of 1200Hz.

Forty retro-reflective markers were placed on specific body landmarks. Thirty were used as tracking markers, whereas the other ten were used for calibration purposes. Calibration markers were placed bilaterally on the following landmarks of the body: greater trochanters, medial and lateral knee joint line, and medial and lateral malleoli. Tracking markers were placed bilaterally on the following landmarks of the body: posterior superior iliac spine and anterior superior iliac spine, a 4-cluster marker on both mid-lateral thigh and shank, and each foot at the heel, lateral calcaneal surface, dorsal surface of first metatarsal head, dorsal surface of fifth metatarsal head and the dorsal surface of the first cuneiforms. The foot reflective markers were placed over top of the shoe and secured down with athletic tape covering the entire shoe, leaving just the reflective markers exposed. The cluster markers were on a rigid-plastic material and securely fastened, over a base of pre-wrap, to the thigh and shank with self-adherent stretch tape. The remaining reflective markers were secured to the skin of the subject using a non-toxic cement, and further taped down to minimize marker movement during testing.

For subject calibration purposes, the subject stood on the force plates with arms across the chest, stood still, and looked straight ahead to capture a static trial (Ford et al., 2003). From this static trial, a reconstructed model was created using Visual 3D (C-Motion Inc, Rockville, MD) to measure the joint angles in relation to the lower extremity. The second subject calibration was a dynamic trial to estimate hip joint centers (Quammen, et al., 2011).The subject stood on the force plates with hands across the chest and made circular motions with the hips to the left for a total of three full circles. Once subjection calibration was complete, the calibration markers were removed.

Two wireless timing systems (Speed Trap II, Brower Timing System, Draper, Utah), consisting of two photoelectric gates each, were used to measure the approach speed during the unanticipated side-step cutting task. The first set of gates were placed one meter away from the front edge of the force plates, while the second set was placed at the front edge of the force plates. The approach velocity of the subject had to be 2.5m/s or faster to meet the trial criteria. For the unanticipated cutting tasks, a projector was used to randomly display which task the subject was to perform. A laptop was utilized to operate the unanticipated custom-made software (Cortes, 2011), which randomly generated the tasks and displayed the cue on the wall in front of the subject via a projector. The tasks were triggered by the photoelectric gate system, with the beam positioned at a height below the hips, placed 2 meters away from the front edge of the force plates. Once the participant passed through the beam, the cue was displayed on the wall in front of them. A directional scenario was selected for the display pictures that flashed on the wall in front of the subject when they passed the horizontal beam from the photoelectric gates which were positioned two meters away from the force plates. For the side-step cutting task the subject saw a blue arrow pointed to the right or left depending on the leg dominance and the subject saw a red stop sign for the stop-jump.

A Vmax Encore (VIASYS Healthcare, Yorba Linda, CA) metabolic cart was used to measure the $VO2_{peak,}$ and was paired with a Quinton Q-Stress Treadmill System (TM 55, Cardiac Science, Hanover, Germany). A flow sensor calibration was completed before each participant was tested. The flow sensor was attached to a facemask, which was securely strapped to the head. The $VO2_{peak}$ was calculated by taking the average of the three highest values in 20-second continuous intervals over a one-minute period. A zero incline was maintained throughout the VO2peak testing and has been used in previous fatigue studies (Flouris, Metsios, & Koutedakis, 2006; Quammen, et al., 2011). A heart rate monitor (T31 Transmitter, Polar Electro Inc., New Hyde Park, New York) was attached to the participant during $VO2_{peak}$ testing to monitor heart rate, which was recorded after every speed increment.

Testing Procedure

Dynamic Tasks

The side-step task consisted of the subject running towards the force plates, landing on the force plates with the dominant leg, and cutting to the non-dominant side at an approximate 45° angle (Dempsey et al., 2007). The subject's leg dominance was determined by the leg used to kick a ball the farthest (Ford, et al., 2003). The subjects began approximately 9 meters from the force plates to be able to reach an acceptable approach speed. A stop-jump was only used as an alternate task, thus making the side-step cutting task unanticipated. The stop-jump consisted of having the subject run towards the force plates, land with both feet on the force plates and immediately jump vertically as high as they could while landing back down onto the force plates.

An accepted trial for the side-step task was based on the following criteria, (a) attaining a minimum running speed of 2.5m/s, (b) performing the correct task according to the cue that was displayed, (c) having the whole foot land on the force plate before cutting, (d) having the foot land in the corresponding force plate (e.g. left leg dominant must land with their left leg on the left force plate), and (e) performing the side step within a 45° angle to the non-dominant side. Each subject had one practice trial for each task and completed five accepted trials.

Slow-Linear Oxidative Fatigue Protocol

For the $VO2_{peak}$ test, the subject was given specific instructions to follow (Appendix- G). The subject began the test at 9.0 kph for five-minutes and then the speed increased every two minutes by 1.0 kph with zero incline (Flouris, et al., 2006). The subject was instructed to grab onto the bars in front of them on the treadmill when they felt they could no longer continue. At this point, the $VO2_{peak}$ test was stopped, and the heart rate and stopping time were recorded. The subject's heart rate and rate of perceived exertion (RPE) was recorded every time the speed increased. The RPE scale used was the OMNI Pictorial Scale and is shown to be valid (Roemmich et al., 2006). The subject had to reach at least two of the following four criteria to be considered to have reached a $VO2_{peak}$: (1) the stopping heart rate reached 90% of aged-calculated max, (2) the respiratory quotient (RQ) was greater than 1.1, (3) a plateau in VO2peak curve occurred, or (4) the subject was unable to continue. There were 5 minutes of rest between completing the $VO2_{peak}$ and the start of the SLO-FP. The parameters collected from the $VO2_{peak}$ test were used to set-up the speeds for the SLO-FP.

After the subjects performed a $VO2_{peak}$ they had a five-minute resting period and then moved on to complete the SLO-FP; which consisted of a twenty-minute jog and run on the treadmill. The subject jogged for four minutes at 70% of their max speed from the $VO2_{peak}$ test and ran for one minute at 90% of their max speed from the $VO2_{peak}$ test and then repeated three more cycles for a total of twenty-minutes or until volitional exhaustion (Quammen, et al., 2011).

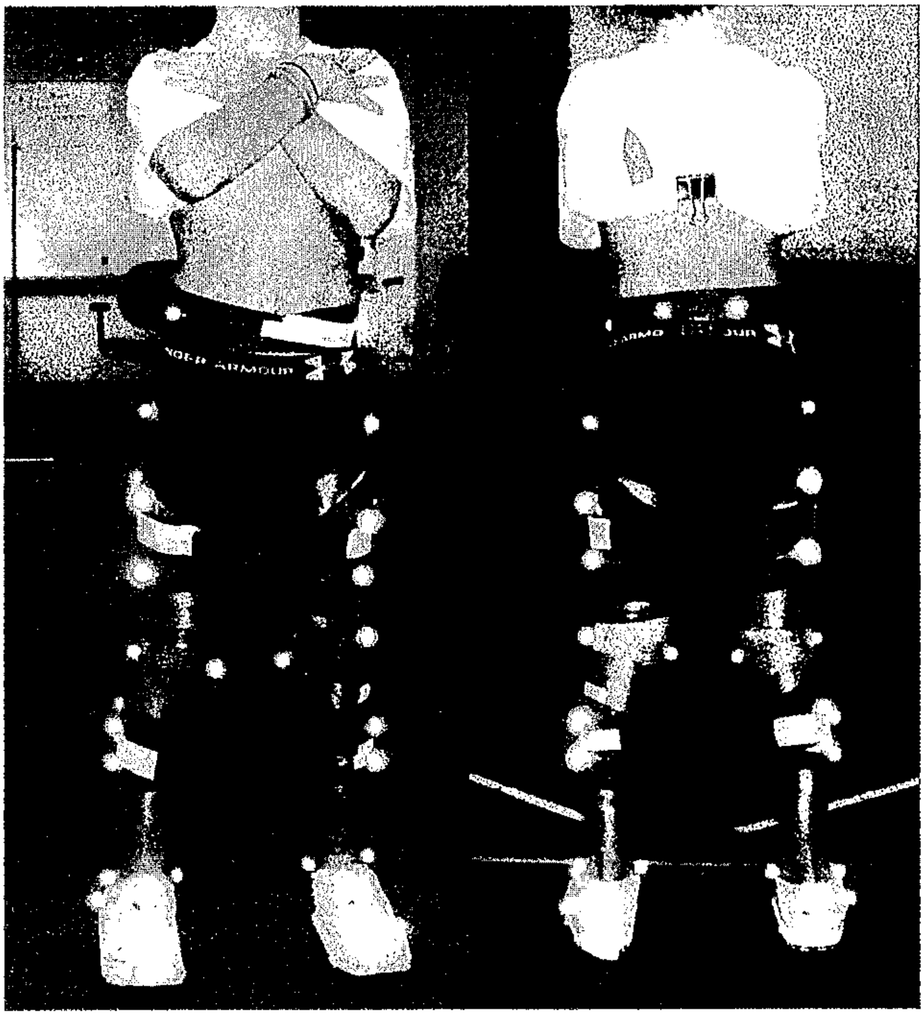
Immediately following the SLO-FP, the subject returned to the Motion Analysis Laboratory where they completed another session of unanticipated movement tasks. During post fatigue cutting trials, the subject performed continuous trials without resting in between trials (in efforts to keep them in a fatigued state) until they achieved five accepted side-step cutting tasks.

Data Analysis

The dependent variables used for this study included: knee abduction/ adduction angles and moments, knee flexion angles and moments, knee internal/ external angles, hip flexion angles and moments, hip abduction/ adduction angles and moments, hip internal/external rotation angles, vertical ground reaction force and posterior ground reaction force. Joint moments were normalized to body height and mass, and ground reaction forces to body weight. The data was processed in Visual 3D and reduced in MATLAB (The MathWorks, Inc., Natick, MA); and was then exported into a Microsoft Excel spreadsheet.

All data trials were imported into SPSS version 18.0 (SPSS Inc., Chicago, IL) from the spreadsheet for statistical analysis. We used repeated measures Analysis of Variance (ANOVA) with an alpha level set at 0.05 to analyze the side-step kinetic and kinematic data. These variables were measured at initial contact, peak vertical ground reaction force, peak posterior ground reaction force and the peak stance before and after the SLO-FP.

Figure 1. Placement of Retro-reflective tracking and calibration markers for three dimensional data capture.



CHAPTER IV

RESULTS

Descriptive Data

In efforts to monitor the progression of the participants during the SLO-FP we observed and measured the average rate of perceived exertion at the end of the SLO-FP and at end of the VO2peak test, the overall average heart rate and the average heart rate at the end of the SLO-FP, and the average $VO2_{peak}$, average 70% speed, and the average 90% speed during the SLO-FP (Table 1). Approximately 42% of the participants completed the 20-minute jog/run during the SLO-FP, the remaining 58% were unable to complete this jog/run due to volitional exhaustion; the average time to completion for this group was ten-minutes and eighteen seconds (10:18).

Initial Contact (IC)

We found statistically significant differences from pre to post fatigue ($p<0.05$) at initial contact (Table 2 and 3) for hip and knee sagittal and frontal kinematics and kinetics. Particularly, we noticed a decrease in knee flexion (-24.6±7.89° to -21.25±5.67°, p= 0.02)(Figure 2), hip flexion (56.25±17.43° to 51.85±16.15°, p= 0.01)(Figure 3) , hip abduction (-14.78±5.1° to -12.47±5.94°, p= 0.01) (Figure 4), knee abduction moment (0.09±0.07Nm/Kgm to .02±0.08Nm/Kgm, p= 0.01) (Figure 5),and an increase in hip flexion moment (0.38±0.22 Nm/Kgm to 0.47±0.24 Nm/Kgm, p= 0.05) (Figure 6) . It was also noticed that at the hip, there was a significant shift from an adduction moment to an abduction moment (0.01±0.15Nm/Kgm to -0.11±.18Nm/Kgm, p= 0.01) (Figure 7).

No statistically significant differences ($p>0.05$) were found for the remainder of the variables at initial contact for the pre and post SLO-FP (Tables 2 and 3): knee abduction angle, knee rotation angle, knee flexion moment, and hip rotation angle.

Peak Vertical Ground Reaction Force (PVGRF)

At the point of peak vertical ground reaction force, we found statistically significant differences, specifically affecting the frontal and sagittal planes for the knee and hip pre and post SLO-FP ($p<0.05$) (Table 4 and 5). A decrease was observed for knee flexion (-35.13±6.9° to -32.37±6.18°, $p= 0.02$) (Figure 8), hip flexion (54.2±16.55° to 51.55±16.18°, $p= 0.01$) (Figure 9), hip abduction (-15.77±6.02° to -13.09±6.52°, $p= 0.01$) (Figure 10), and knee abduction moment (0.11±0.14 Nm/Kgm to 0.02±0.24 Nm/Kgm, $p= 0.04$) (Figure 11). No statistically significant difference were found for the kinetic and kinematic variables at peak vertical ground reaction force for pre and post SLO-FP ($p>0.05$) (Tables 4 and 5): knee abduction angle, knee rotation angle, hip rotation angle, vertical ground reaction force, knee flexion moment, hip flexion moment and hip abduction moment.

Peak Posterior Ground Reaction Force (PPGRF)

We found a statistically significant difference in kinetic and kinematic variables at peak posterior ground reaction force for the pre and post SLO-FP ($p<0.05$) (Table 6 and 7). Similarly to peak vertical ground reaction force, a decreased value pattern was found for knee flexion (-33.82±7.27° to -30.48±6.37°, $p= 0.01$) (Figure 12), hip flexion (54.9±16.95° to 51.8±16.24°, $p= 0.01$) (Figure 13), and hip abduction (-15.77±5.82° to -12.84±6.62°, $p= 0.01$) (Figure 14) . No statistically significant differences were found for the remainder of kinetic and kinematic variables at peak posterior ground reaction force for pre and post SLO-FP ($p>0.05$) (Table 6 and 7). These included knee abduction angle, knee rotation angle, hip rotation, posterior ground reaction force, knee flexion moment, knee abduction moment, hip flexion moment and hip abduction moment.

Peak Stance

We observed a statistically significant difference, specifically decreased values, for kinetic and kinematic variables pre and post a SLO-FP ($p<0.05$) at peak stance (Tables 8 and 9). We found a decrease in hip flexion (58.34±17.19° to 55.14±16.55°, $p=$ 0.03) (Figure 15), knee adduction moment (0.65±0.39Nm/Kgm to 0.52±0.29Nm/Kgm, $p=$ 0.03) (Figure 16), knee abduction moment (-0.17±0.25 Nm/Km to -0.25±0.22 Nm/Kgm, $p=$ 0.01) (Figure 17), and hip abduction (-19.15±5.73° to -16.64±6.36°, $p=$ 0.01) (Figure 18). It is important to note that we observed a statistically significant difference in the occurrence of hip flexion at a later point in time (at 12.13% of stance to at 16.84% of stance, $p=$ 0.03). In contrast to hip flexion, we found hip abduction to occur at an earlier point in time (at 35.91% of stance to at 29.86% of stance, $p=$ 0.05).

No statistically significant differences were found for the remainder of kinetic and kinematic variables for the pre and post SLO-FP ($p>0.05$) (Tables 8 and 9). Particularly, this was observed for knee flexion, knee abduction, knee rotation, hip internal rotation, knee flexion moment, knee abduction moment and hip flexion moment.

Table 1. Descriptive statistics for fatigue characteristics. Measurements used were Heart Rate (bpm), VO2peak (mL/kg/min.), and speed (kph).

	Minimum	**Maximum**	**Mean**	**SD**
End RPE	2	10	8.35	2.27
End HR VO2peak	190	216	203	7.63
End HR SLO-FP	166	209	190	11.46
FP- 70% Speed	3.9	6.1	5.23	6.97
FP- 90% Speed	5	7.8	6.7	0.887

Table 2. Descriptive statistics for kinetic variables pre and post SLO-FP at initial contact. Measurements were taken in N/BW for ground reaction force and Nm/Kgm for moments. **Statistically Significant Difference, p*≤0.05.

	PRE		**POST**					
Initial Contact	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion Moment	0.23	0.14	0.2	0.17	0.17, 0.28	0.13, 0.27	0.18	0.36
Knee Abduction Moment*	0.09	0.07	0.02	0.08	0.06, 0.12	-0.01, 0.06	0.01	0.01
Hip Flexion Moment*	0.38	0.22	0.47	0.24	0.29, 0.46	0.37, 0.57	0.38	0.05
Hip Abduction Moment*	0.01	0.15	-0.11	0.18	-0.06, 0.07	-0.19, -0.04	0.56	0.01

Table 3 Descriptive statistics for kinematic variables pre and post SLO-FP at initial contact. Measurements were taken in degrees. **Statistically Significant Difference, p*≤0.05.

	PRE		POST					
Initial Contact	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion*	-24.6	7.89	-21.25	5.67	-27.93, -21.27	-23.64, -18.86	0.42	0.02
Knee Abduction	-3.74	3.29	-3.97	3.5	-5.13, -2.35	-5.45, -2.5	0.06	0.55
Knee Rotation	4.6	5.66	3.23	5.71	2.21, 6.99	0.82, 5.64	0.24	0.14
Hip Flexion*	56.25	17.43	51.85	16.15	48.9, 63.61	45.03, 58.67	0.25	0.01
Hip Abduction*	-14.78	5.1	-12.47	5.94	-16.93, -12.62	-14.98, -9.96	0.38	0.01
Hip Rotation	7.35	11.19	6.06	9.71	2.63, 12.08	1.96, 10.16	0.12	0.28

Table 4. Descriptive statistics for kinetic variables pre and post SLO-FP at peak vertical ground reaction force. Measurements were taken in N/BW for ground reaction force and Nm/Kgm for moments. **Statistically Significant Difference, p*≤0.05.

PVGRF	PRE Mean	PRE SD	POST Mean	POST SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Vertical Ground Reaction Force	2.67	0.47	2.72	0.39	2.47, 2.86	5.56, 2.89	0.11	0.4
Knee Flexion Moment	0.82	0.35	0.79	0.33	0.67, 0.96	0.65, 0.93	0.09	0.7
Knee Abduction Moment*	0.11	0.14	0.02	0.24	0.05, 0.17	-0.08, 0.12	0.38	0.04
Hip Flexion Moment	-1.39	0.58	-1.29	0.61	--1.64, -1.15	-1.55, -1.03	0.16	0.44
Hip Abduction Moment	-0.01	0.37	-0.12	0.34	--0.17, 0.15	--0.27, 0.19	0.3	0.08

Table 5. Descriptive statistics for kinematic variables pre and post SLO-FP at peak vertical ground reaction force. Measurements were taken in degrees. **Statistically Significant Difference, p*≤0.05.*

	PRE		**POST**					
PVGRF	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion*	-35.13	6.9	-32.37	6.18	-38.04, -32.21	-34.98, -29.76	0.4	0.02
Knee Abduction	-4.33	4.45	-4.06	4.91	--6.21, -2.45	-6.13, -1.99	0.05	0.56
Knee Internal Rotation	8.12	5.42	7.39	5.39	5.83, 10.4	5.11, 9.67	0.13	0.34
Hip Flexion*	54.2	16.55	51.55	16.18	47.21, 61.19	44.72, 58.38	0.16	0.04
Hip Abduction*	-15.77	6.02	-13.09	6.52	-18.31, -13.23	-15.84, -10.33	0.41	0.01
Hip Internal Rotation	5.33	12.14	4.2	9.82	0.2, 10.46	0.06, 8.35	0.09	0.4

Table 6. Descriptive statistics for kinetic variables pre and post SLO-FP at peak posterior ground reaction force. Measurements were taken in N/BW for ground reaction force and Nm/Kgm for moments. **Statistically Significant Difference, p≤0.05.*

	PRE		POST					
PPGRF	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Posterior ground reaction force	0.93	0.26	0.92	0.25	0.82, 1.04	0.82 1.03	0.38	0.92
Knee Flexion Moment*	1.23	0.29	1.16	0.27	1.11, 1.35	1.05, 1.28	0.24	0.01
Knee Abduction Moment	0.25	0.21	0.17	0.23	0.16, 0.34	0.08, 0.27	0.35	0.1
Hip Flexion Moment	0.29	0.72	0.31	0.88	-0.02, -0.59	0.65, 0.68	0.02	0.92
Hip Abduction Moment	0.08	0.26	-0.03	0.25	-0.04, 0.19	0.14, 0.07	0.42	0.13

Table 7. Descriptive statistics for kinematic variables pre and post SLO-FP at peak posterior ground reaction force. Measurements were taken in degrees. **Statistically Significant Difference, $p \leq 0.05$.*

PPGRF	PRE Mean	PRE SD	POST Mean	POST SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion	-33.82	7.27	-30.48	6.37	-36.88,- 30.75	-33.17, -27.79	0.46	0.01
Knee Abduction	-4.11	4.17	-4.0	4.61	-5.88, -2.35	-5.95, -2.06	0.02	0.78
Knee Internal Rotation	7.88	5.31	7.07	5.93	5.64, 10.12	4.57, 9.58	0.14	0.38
Hip Flexion	54.9	16.95	51.8	16.24	47.74, 62.06	44.94, 58.66	0.18	0.01
Hip Abduction	-15.77	5.82	-12.84	6.62	-18.22, -13.31	-15.64, -10.05	0.44	0.01
Hip Internal Rotation	5.67	12.02	4.65	9.69	0.59, 10.74	0.56, 8.74	0.08	0.44

Table 8. Descriptive statistics for kinetic variables pre and post SLO-FP at peak stance (max). Measurements were taken in N/BW for ground reaction force and Nm/Kgm for moments. **Statistically Significant Difference, $p \leq 0.05$.*

	PRE		POST					
Peak Stance (Max)	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion Moment	-0.3	0.2	-0.05	0.18	-0.11, 0.05	-0.13, 0.02	1.25	0.47
Knee Adduction Moment*	0.65	0.39	0.52	0.29	0.48, 0.81	0.4, 0.64	1.03	0.03
Knee Abduction Moment*	-0.17	0.25	-0.25	0.22	-0.27, -0.06	-0.34, -0.15	0.32	0.01
Hip Flexion Moment	1.13	0.55	1.26	0.61	0.9, 1.37	1.01, 1.52	0.21	0.16

Table 9. Descriptive statistics for kinematic variables pre and post SLO-FP at peak stance (max). Measurements were taken in degrees. **Statistically Significant Difference, $p \leq 0.05$.*

	PRE		POST					
Peak Stance (Max)	Mean	SD	Mean	SD	Upper & Lower 95% Confidence Interval (PRE)	Upper & Lower 95% Confidence Interval (POST)	Effect Size	*p*-value
Knee Flexion	-51.1	7.21	-49.86	6.23	-54.97, -52.5	-48.85, -47.24	0.17	0.09
Knee Internal Rotation	13.17	5.78	13.87	5.65	10.73, 15.61	11.49, 16.28	0.07	0.24
Knee Abduction	-7.34	5.49	-7.62	5.67	-9.66, -5.02	-10.01, -5.22	0.05	0.47
Hip Flexion*	58.34	17.19	55.14	16.55	51.08, 65.6	48.15, 62.12	0.19	0.03
Hip Abduction*	-19.15	5.73	-16.64	6.36	-21.57, -16.73	-19.33, -13.96	0.39	0.01
Hip Internal Rotation	7.81	10.71	7.05	9.57	3.29, 12.34	3.01, 11.09	0.07	0.51

Figure 2. Knee flexion at initial contact decreased pre and post fatigue (-24.6±7.89° to -21.25±5.67°, $p = 0.02$). Measured in degrees.

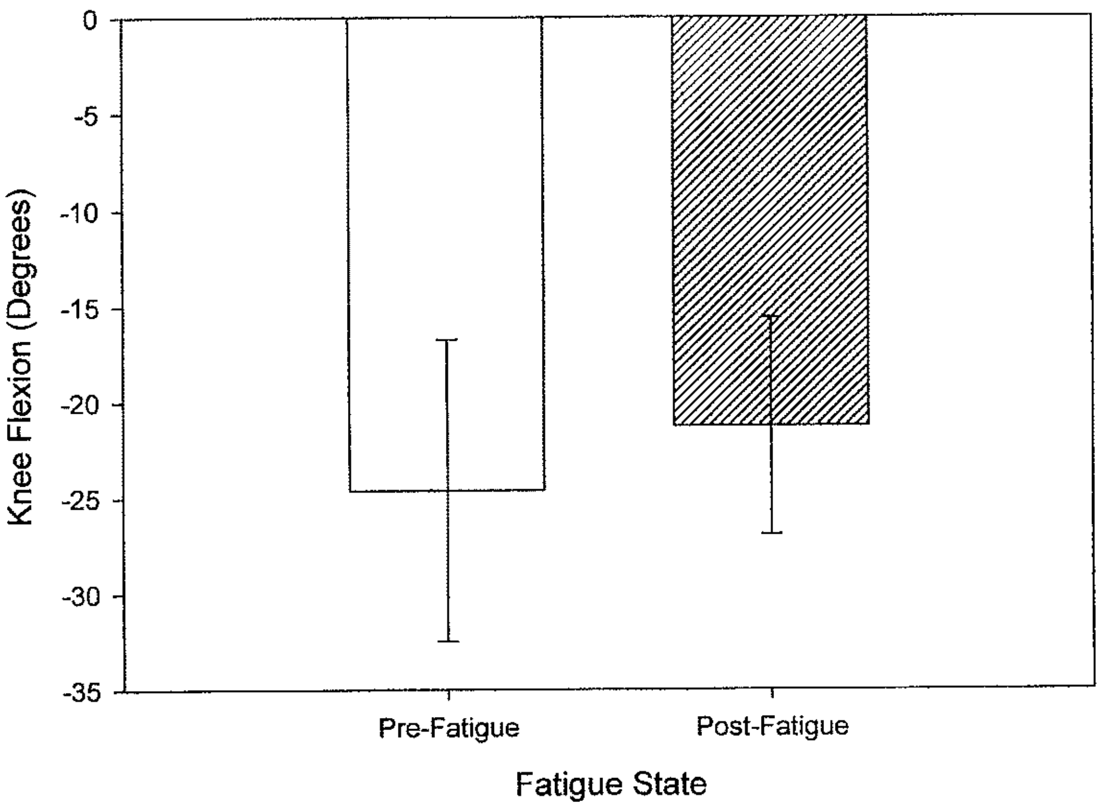


Figure 3. Hip flexion at initial contact decreased pre and post fatigue (56.25±17.43° to 51.85±16.15°, $p = 0.01$). Measured in degrees.

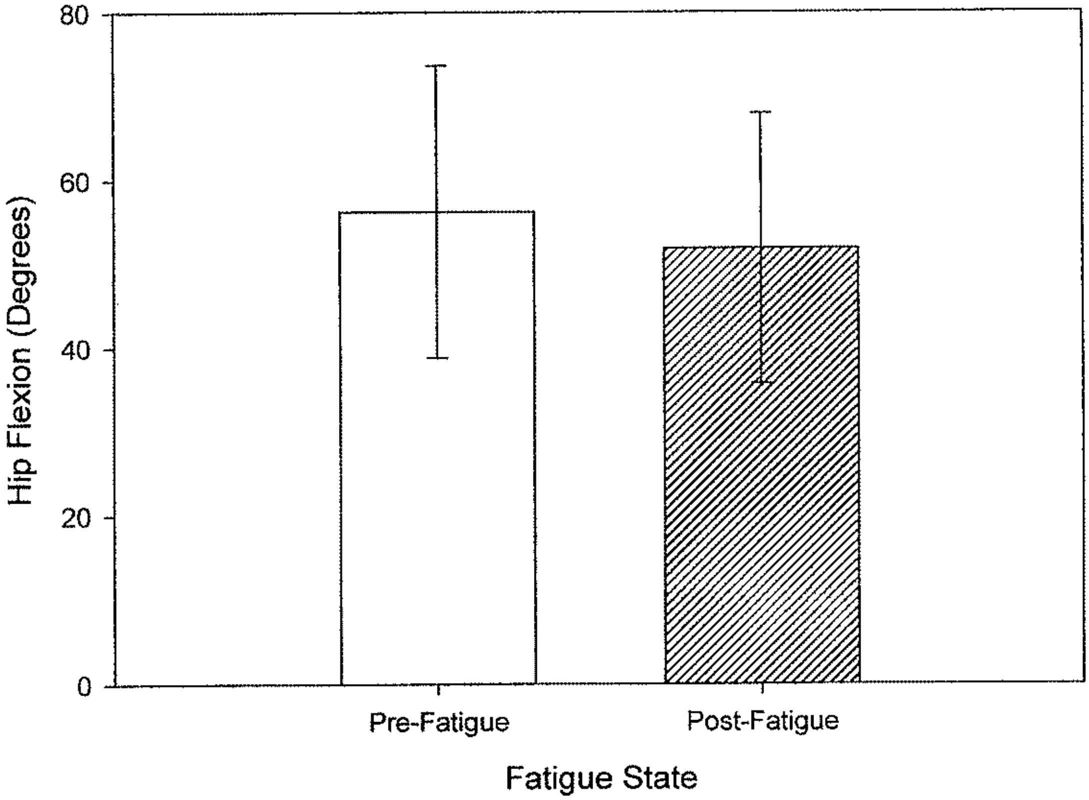


Figure 4. Hip abduction at initial contact decreased pre and post fatigue (-14.78±5.1° to -12.47±5.94°, p= 0.01). Measured in degrees.

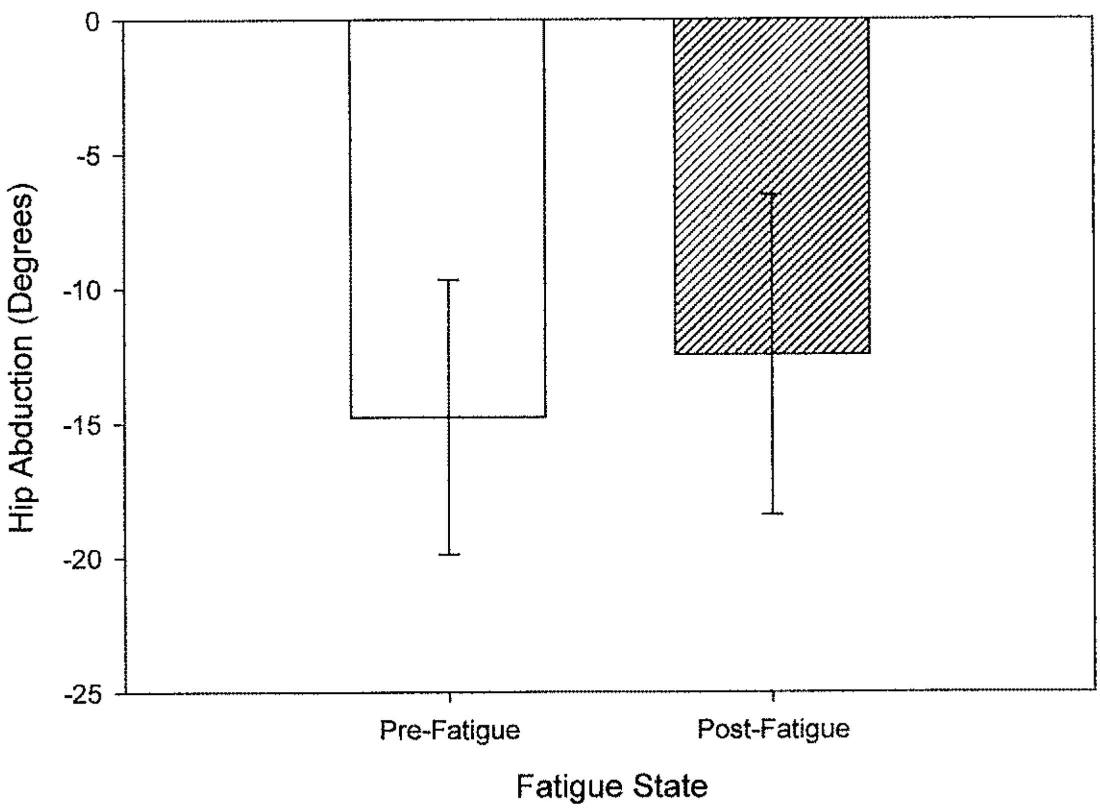


Figure 5. Knee abduction moment at initial contact decreased pre and post fatigue (0.09±0.07Nm/Kgm to 0.02±0.08Nm/Kgm, p= 0.01). Measured in Nm/Kgm.

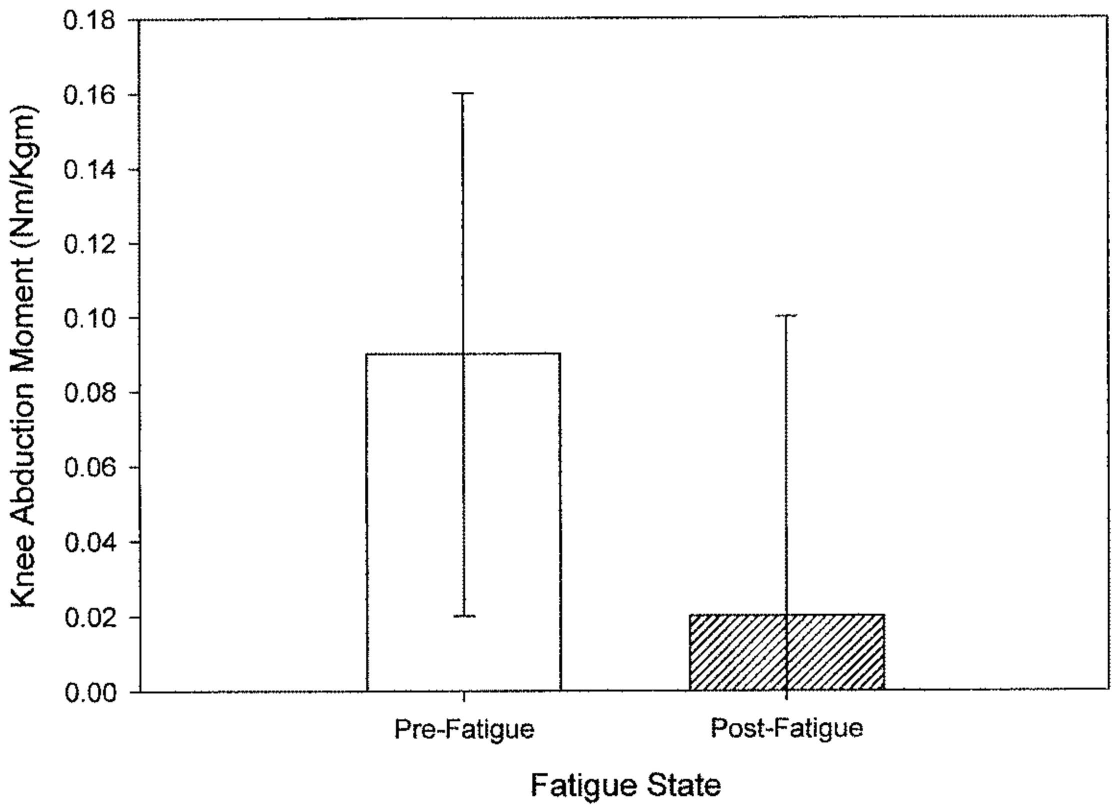


Figure 6. Hip flexion moment at initial contact increased pre and post fatigue (0.38±0.22 Nm/Kgm to 0.47±0.24 Nm/Kgm, p= 0.05). Measured in Nm/Kgm.

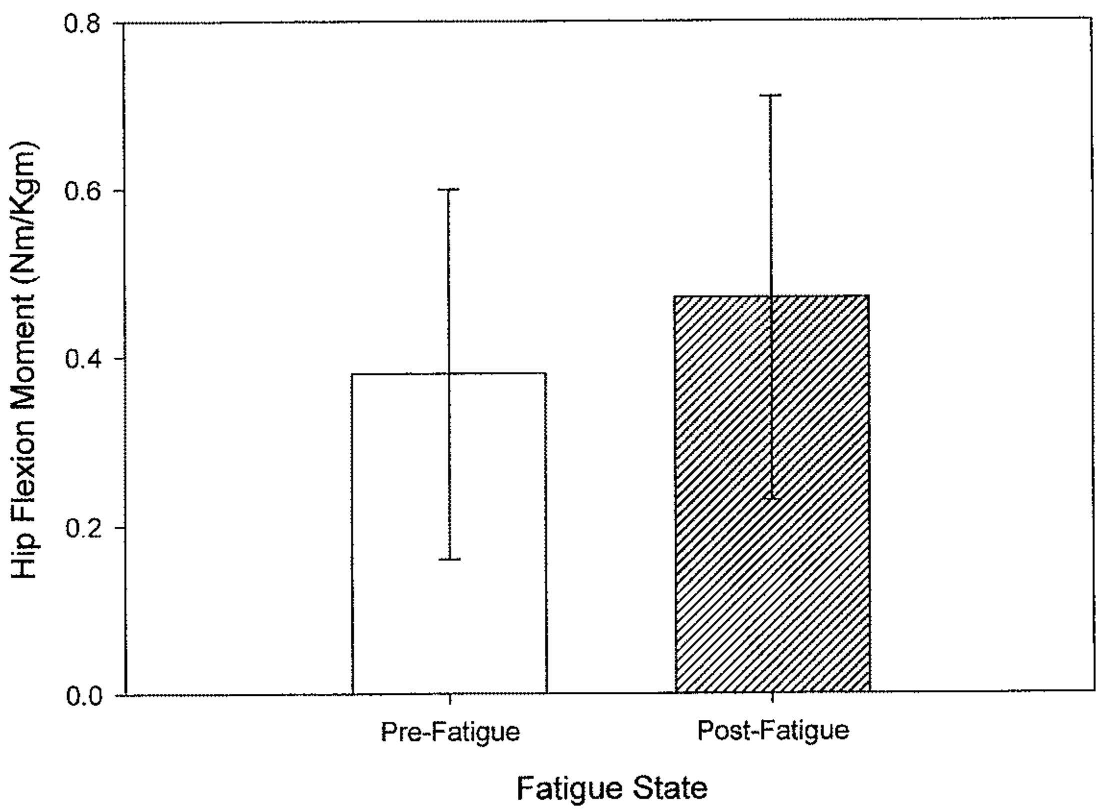


Figure 7. Hip adduction moment shifted to an abduction moment at initial contact pre and post fatigue (0.01±0.15Nm/Kgm to -0.11±.18Nm/Kgm, p= 0.01). Measured in Nm/Kgm.

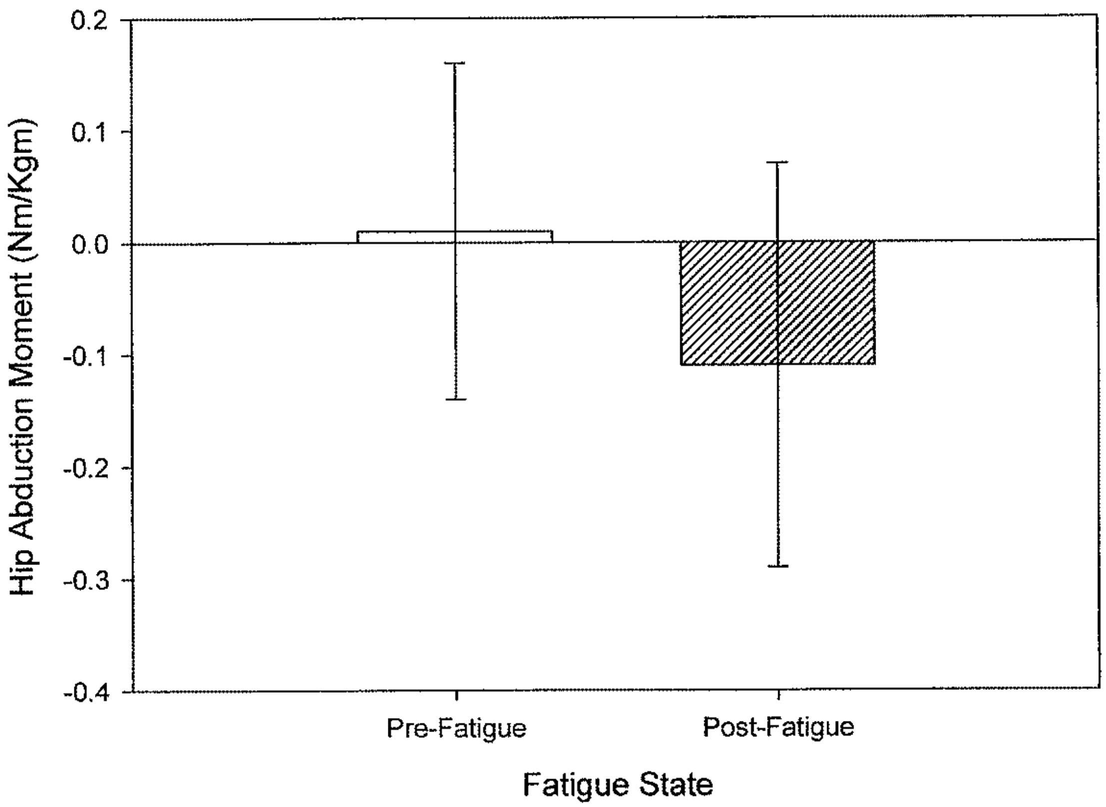


Figure 8. Knee flexion at peak vertical ground reaction force decreased pre and post fatigue (-35.13±6.9° to -32.37±6.18°, p= 0.02). Measured in degrees.

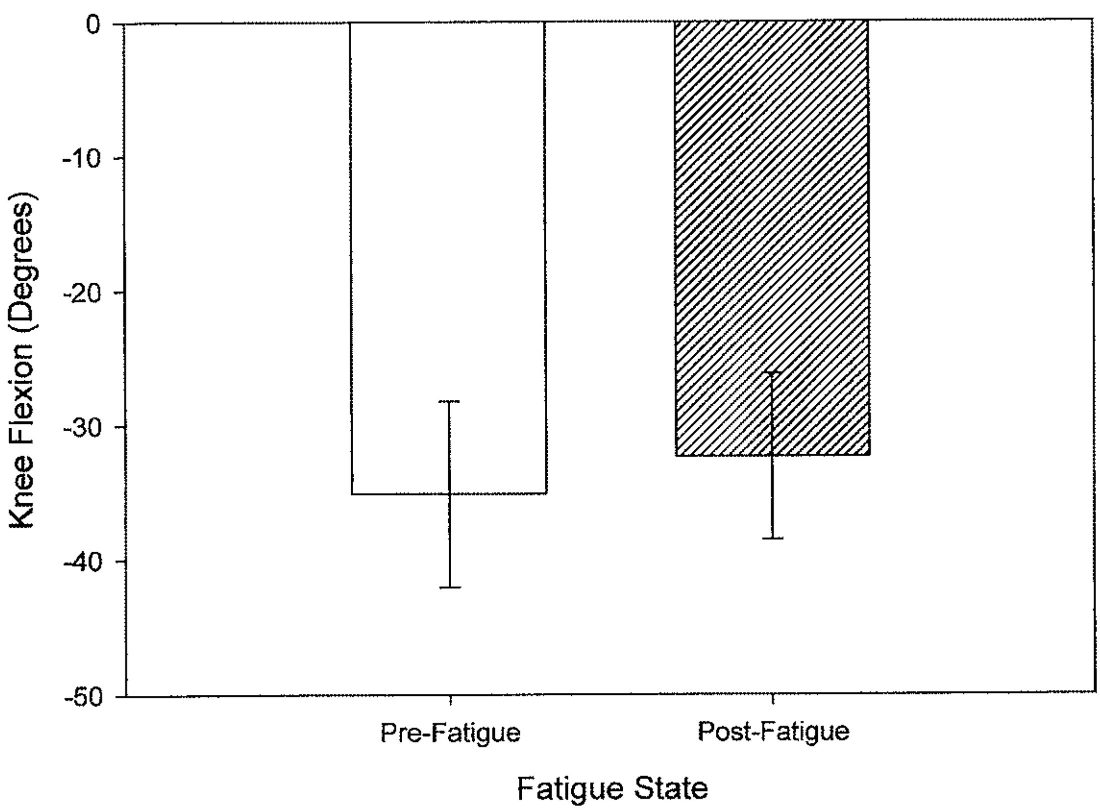


Figure 9. Hip flexion at peak vertical ground reaction force decreased pre and post fatigue (54.2±16.55° to 51.55±16.18°, p= 0.01). Measured in degrees.

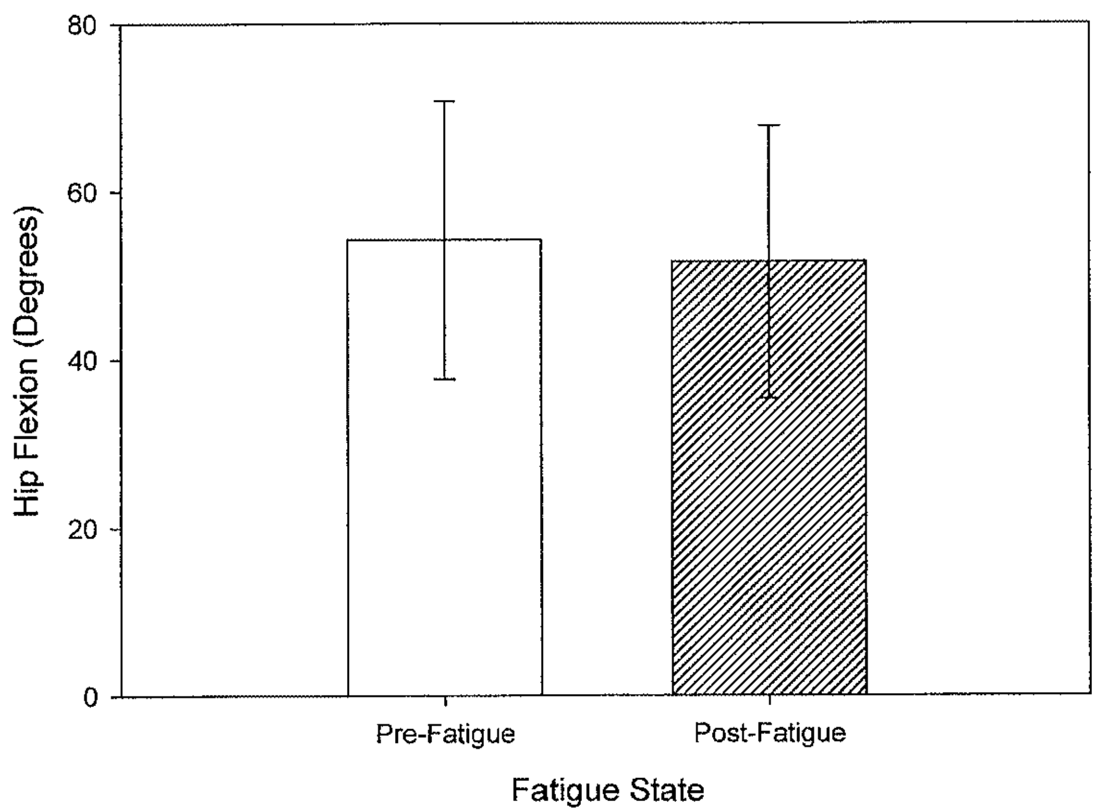


Figure 10. Hip abduction at peak vertical ground reaction force decreased pre and post fatigue (-15.77±6.02° to -13.09±6.52°, $p = 0.01$). Measured in degrees.

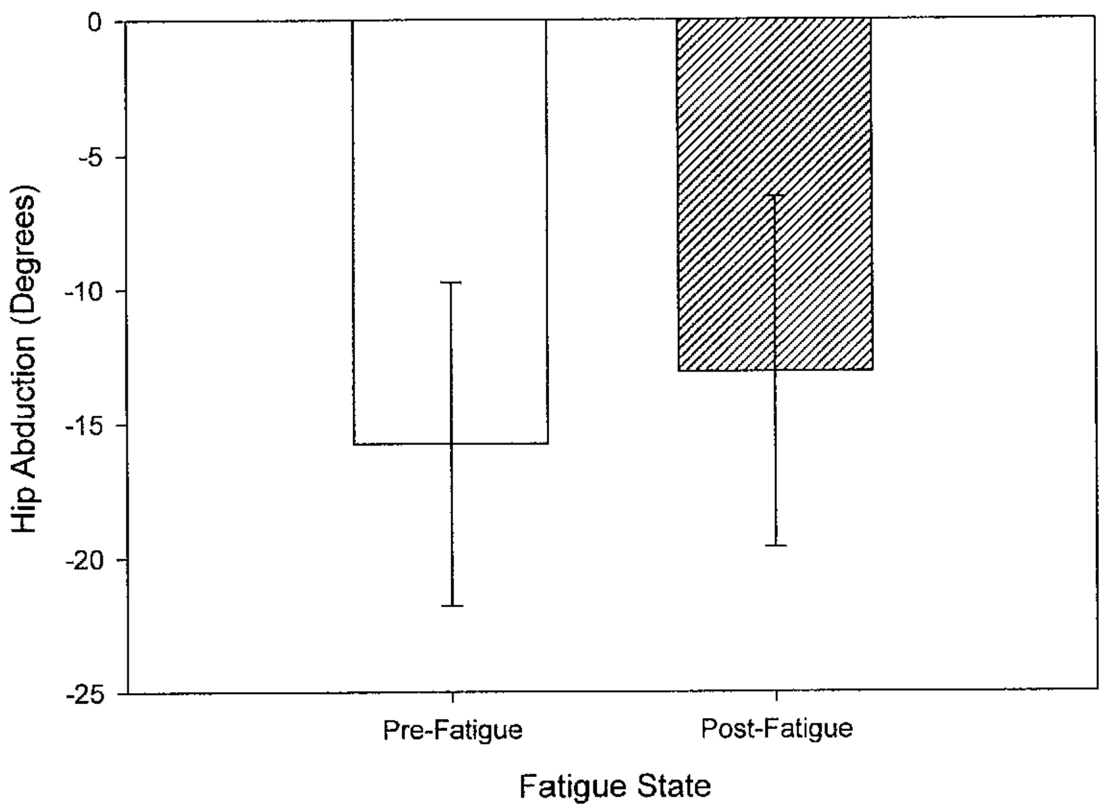


Figure 11. Knee abduction moment at peak vertical ground reaction force decreased pre and post fatigue (0.11±0.14 Nm/Kgm to 0.02±0.24 Nm/Kgm, p= 0.04) . Measured in Nm/Kgm.

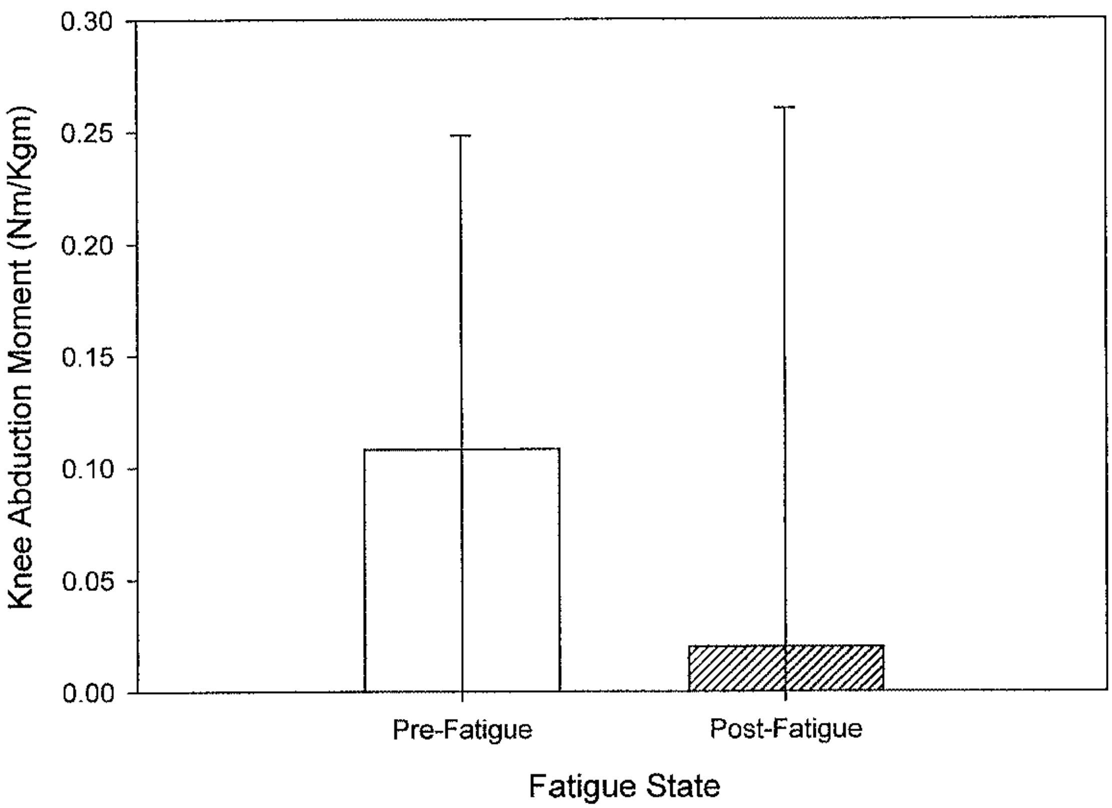


Figure 12. Knee flexion at peak posterior ground reaction force decreased pre and post fatigue (33.82±7.27° to -30.48±6.37°, p= 0.01). Measured in degrees.

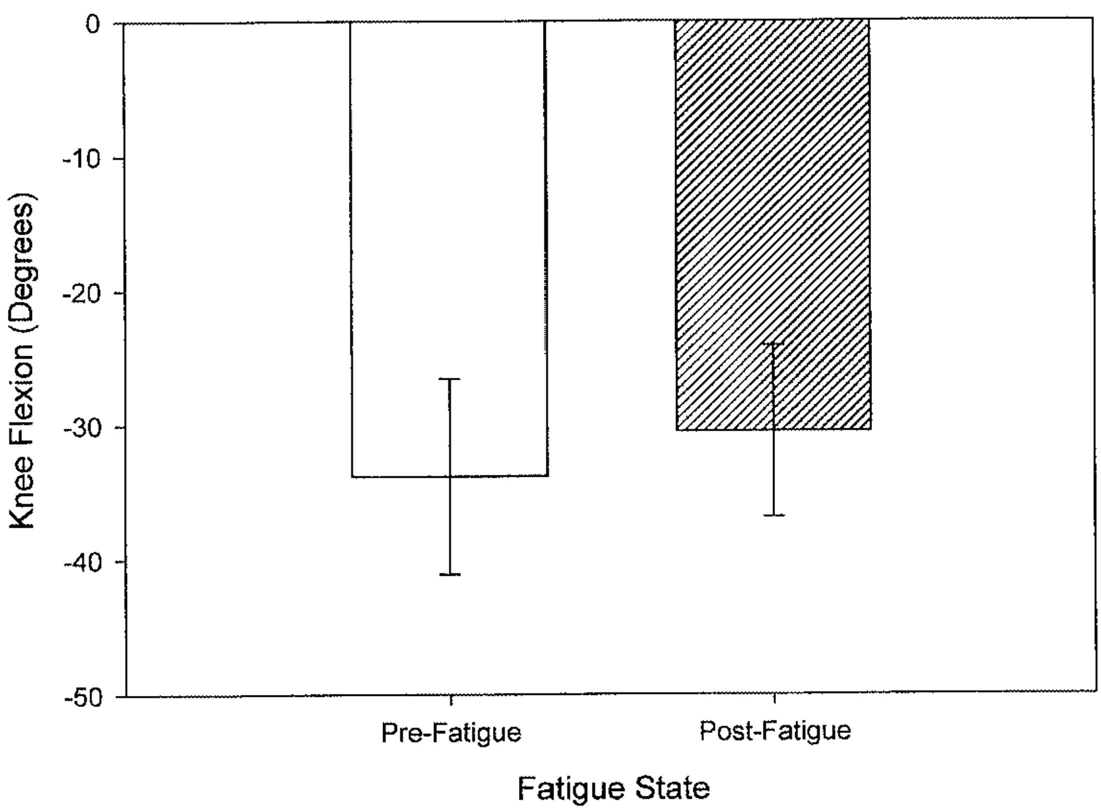


Figure 13. Hip flexion at peak posterior ground reaction force decreased pre and post fatigue (54.9±16.95° to 51.8±16.24°, p= 0.01). Measured in degrees.

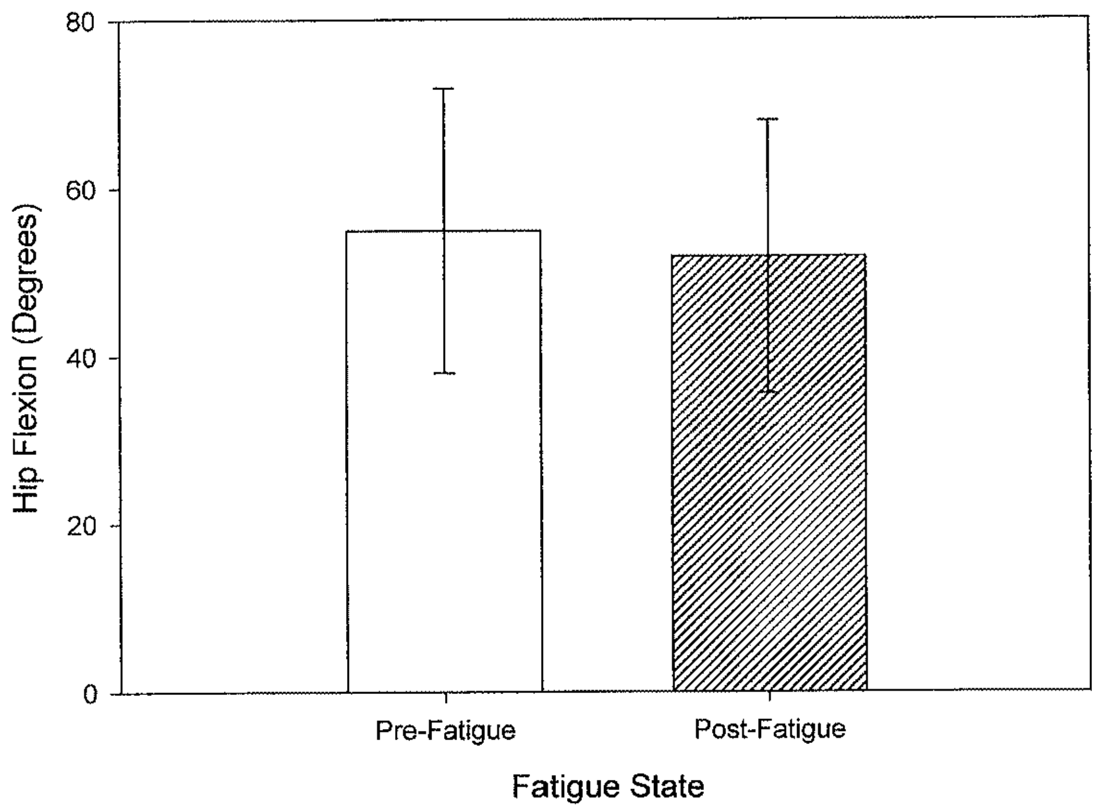


Figure 14. Hip abduction at peak posterior ground reaction force decreased pre and post fatigue (-15.77±5.82° to -12.84±6.62°, p= 0.01). Measured in degrees.

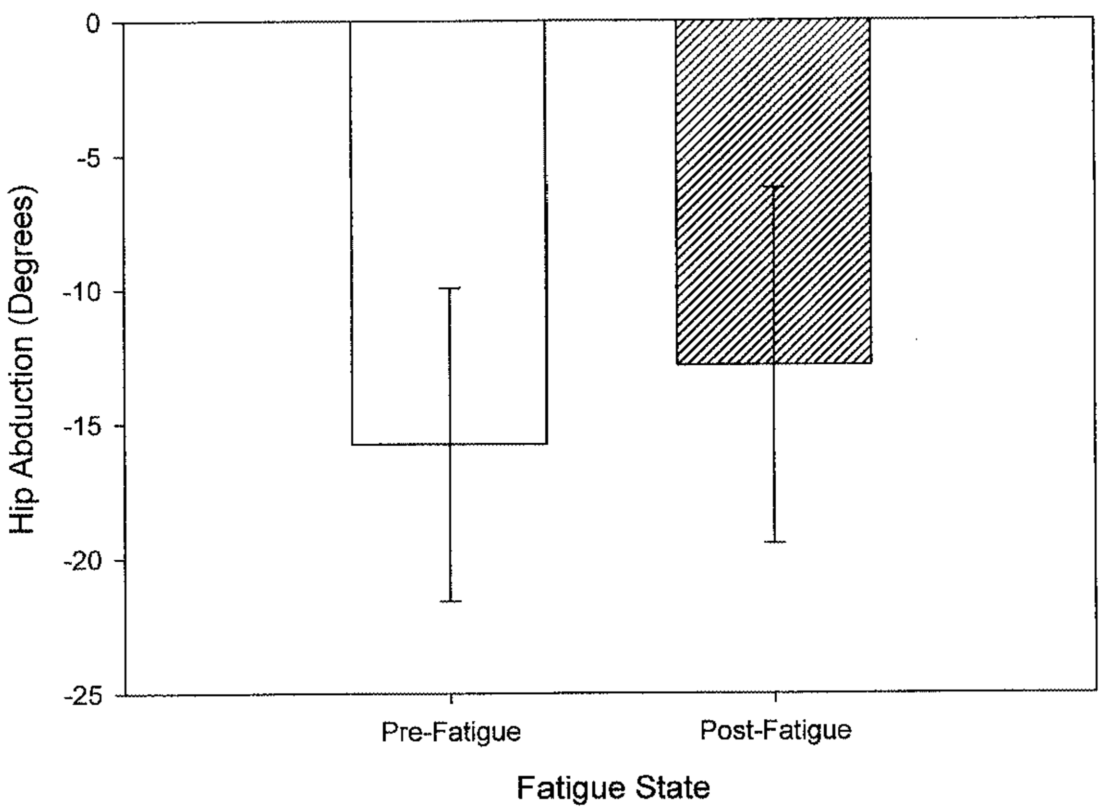


Figure 15. Peak hip flexion decreased pre and post fatigue (58.34±17.19° to 55.14±16.55°, p= 0.03). Measured in degrees.

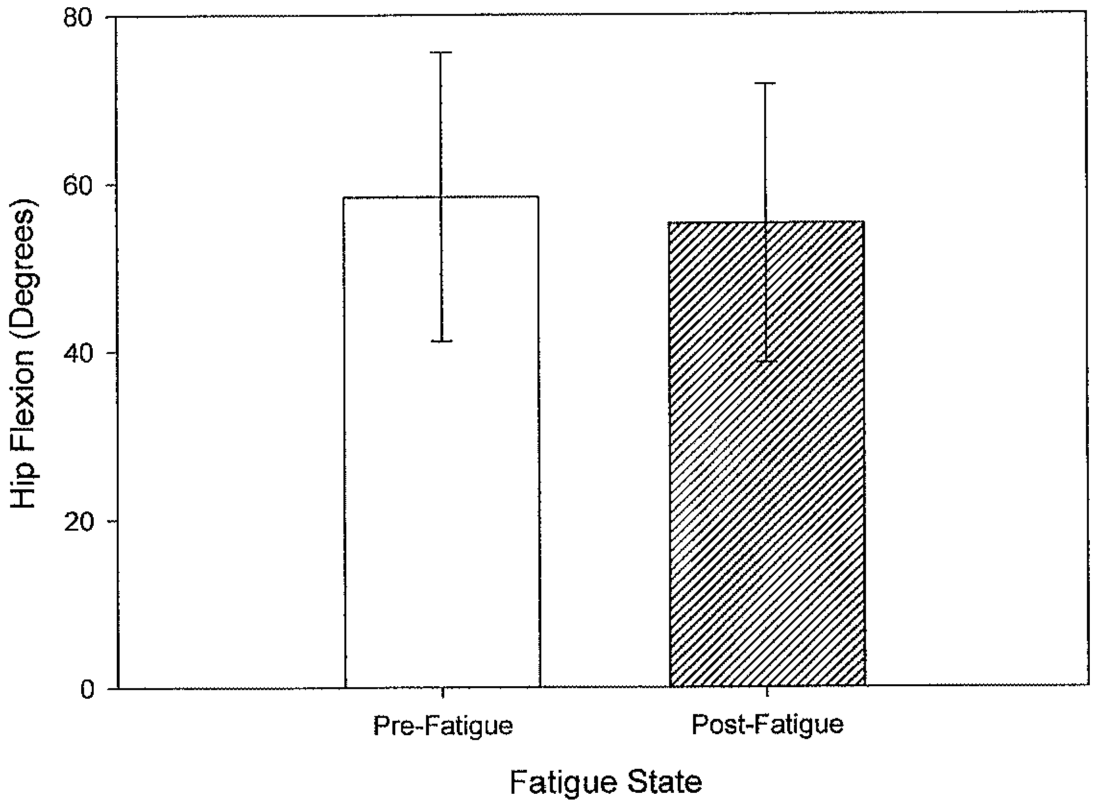


Figure 16. Peak knee adduction moment decreased pre and post fatigue (0.65±0.39Nm/Kgm to 0.52±0.29Nm/Kgm, p= 0.03). Measured in Nm/Kgm.

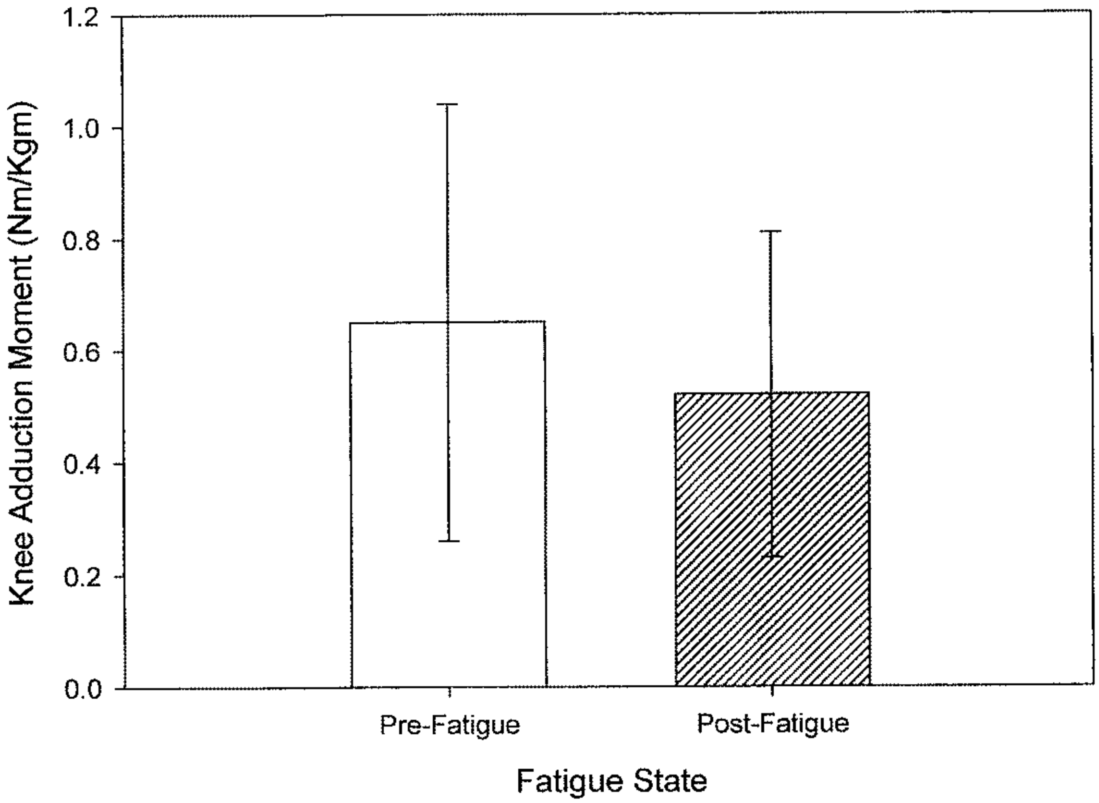


Figure 17. Peak knee abduction moment increased pre and post fatigue (-0.17±0.25 Nm/Km to -0.25±0.22 Nm/Kgm, p= 0.01). Measured in Nm/Kgm.

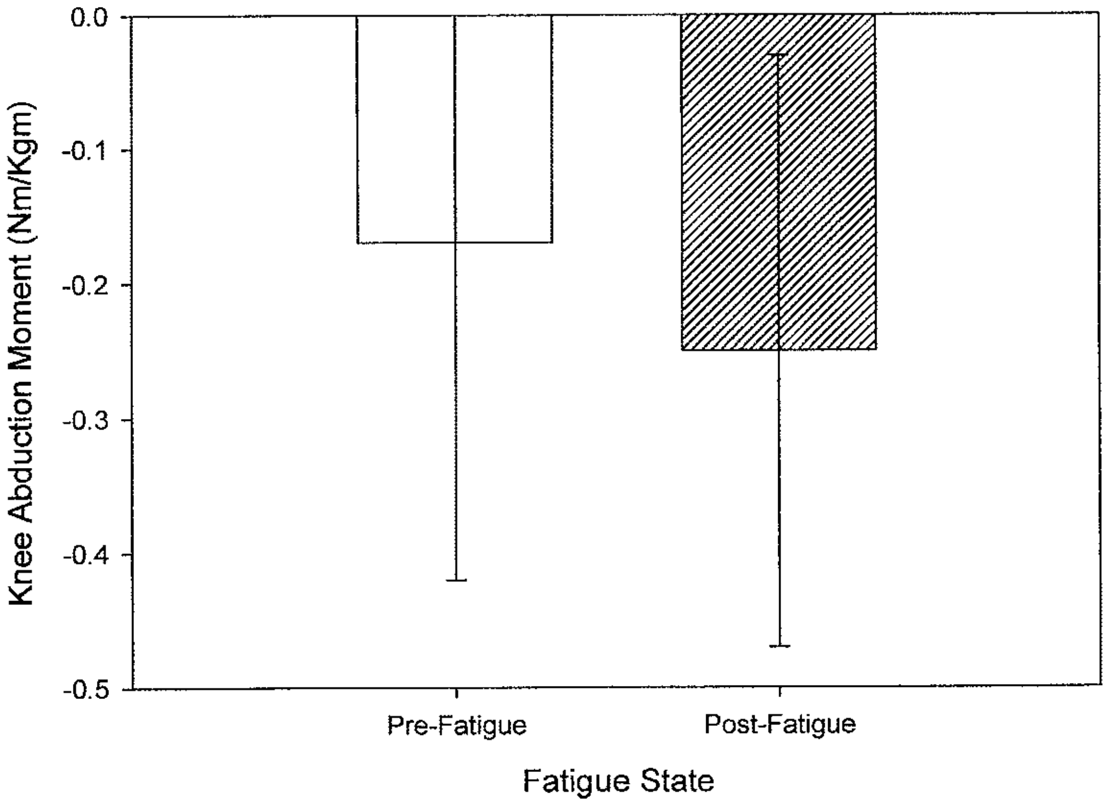
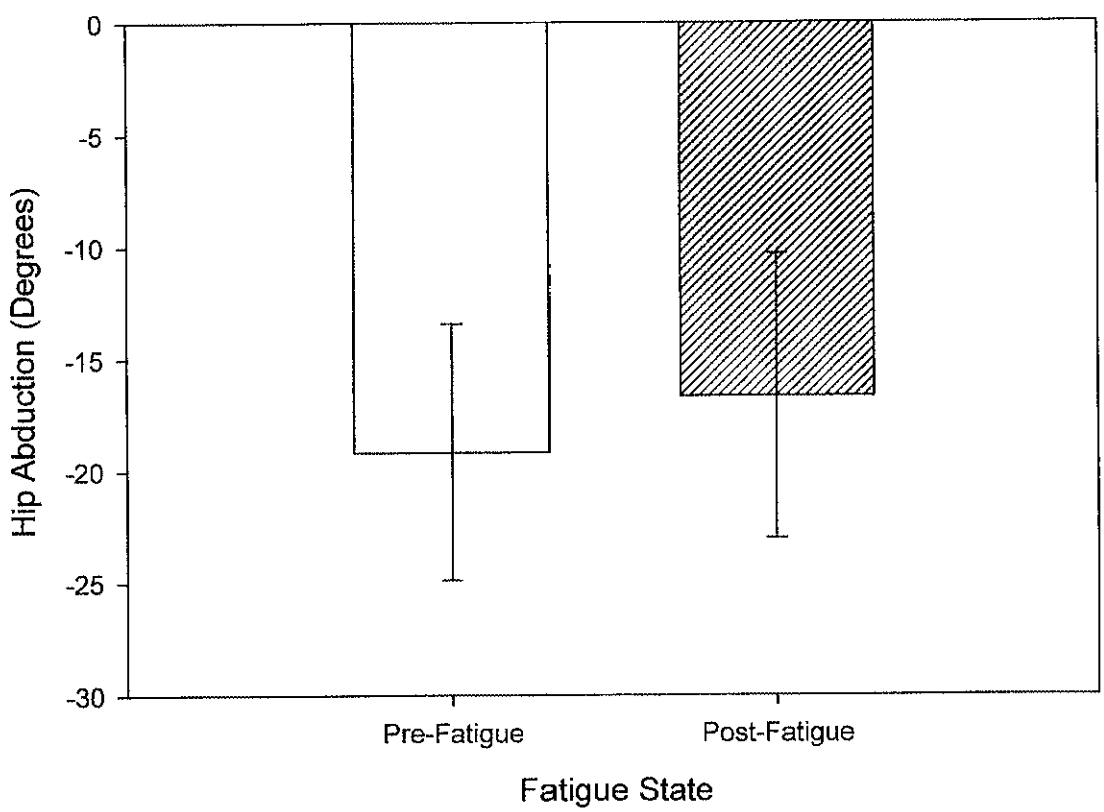


Figure 18. Peak hip abduction decreased pre and post fatigue (-19.15±5.73° to -16.64±6.36°, p= 0.01). Measured in degrees.



CHAPTER V

DISCUSSION & CONCLUSIONS

Discussion

We examined the effects of fatigue on lower extremity biomechanics in young adolescent male lacrosse athletes. It was hypothesized that fatigue would negatively alter lower extremity kinetics and kinematics during an unanticipated side-step cutting task. The primary finding of this study is that youth lacrosse athletes exhibited significant kinematic changes in the sagittal plane of the knee and hip after completing a fatigue protocol. We also found kinetic and kinematic changes in the frontal plane; however no observable change was noted for the transverse plane and ground reaction forces. These findings have been previously supported by other studies who found an increased load on the knee in the frontal and sagittal planes, which may influence the load on the ACL and thus increase the likelihood of ACL injury (Chappell, et al., 2005; Hughes & Watkins, 2006; McLean, et al., 2007). This suggests that lower extremity biomechanical changes due to fatigue may increase the risk for ACL injury for youth lacrosse athletes.

Within the sagittal plane, we found that these athletes demonstrated a decrease in hip and knee flexion at initial contact, peak vertical and posterior ground reaction forces, and at peak stance after a fatigue protocol. It has repeatedly been reported that decreased hip and knee flexion creates a more extended lower extremity posture when performing cutting, jumping and landing athletic tasks (Borotikar, et al., 2008; Chappell, et al., 2005; Hughes & Watkins, 2006; Kernozek, et al., 2008; McLean & Samorezov, 2009) . The extended posture causes greater quadriceps pull at the knee increasing the anterior translational pull on the tibia and not allowing for proper co-contraction of the hamstring muscle group (DeMorat, et al., 2004; Hanson, et al., 2008; Markolf, et al., 2004; Ostermeier, et al., 2007; Padua et al., 2006). This increase in anterior translation augments the stress loads placed on the ACL, which can increase the risk for injury (Chappell, et al., 2005; McLean & Samorezov, 2009; Rozzi, et al., 1999). The sagittal plane kinematics and its relation to ACL mechanism of injury is not definitively agreed upon within current literature. Some found no significant changes in the sagittal plane kinematics after a fatigue protocol during athletic-related tasks (McLean, et al., 2007; McLean, Lipfert, et al., 2004; Sanna & O'Connor, 2008; Tsai, et al., 2009). These studies who did not find sagittal plane changes found changes occurring the frontal and sagittal planes and believe that those changes are more of the "culprits" for ACL risk biomechanical risk factors. It is purported by another study the reason for fatigue-related changes is that exercising at full exhaustion increases knee joint laxity thus this may compromise ligament mechanoreceptor feedback and therefore compromise muscle contributions to joint stability (McLean et al., 2007). The conflicting results from each study may be explained by differing fatigue protocols, analyzing various athletic tasks, or having various skill levels of the subjects. Furthermore, one study claims that the ACL cannot solely be injured by an isolated sagittal plane mechanism (McLean, Huang, Su, & Van Den Bogert, 2004). However, the sagittal plane may still indirectly contribute to ACL injury risk due to the ability of limiting out-of-plane motions (McLean, Lipfert, et al., 2004). This idea of out-of-plane motions includes frontal and transverse plane motions. The dominant sagittal muscle activations, quadriceps and hamstrings, have shown the ability to stabilize the knee joint from varus-valgus loads as well as internal and external rotational loads (Besier, et al., 2001; Hanson, et al., 2008; Lloyd &

Buchanan, 2001). The increased posture on the sagittal plane may be associated with an increased ACL strain following a fatigue protocol. This strain is explained by the decreased knee flexion (less than 30°), which has been previously shown to potentially increase anterior shear force (Durselen, et al., 1995). This finding, in comparison to the current evidence, lends support to the idea that fatigue may negatively alter sagittal plane biomechanics for young male athletes when performing cutting tasks.

As a secondary finding, changes were found for the frontal plane kinetic variables as well as a few kinematic variables. These findings partially supported our hypotheses. We hypothesized there would be a decrease in hip abduction and our data supported this prediction. Unexpectedly, we found a decrease in knee adduction moment but no difference was found for knee abduction, contradicting previous research (Borotikar, et al., 2008; Chappell, et al., 2005; Kernozek, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; Sigward & Powers, 2006; Tsai, et al., 2009; Yu, et al., 2005). It is important to note that this finding is inconsistent within the literature. There are studies that found an increase in knee abduction and knee valgus yet the inconsistency lies within gender, some report significant increases for both men and women after a fatigue protocol while others report an increase just for women (Chappell, et al., 2005; Kernozek, et al., 2008; McLean, et al., 2007). This may support the notion that our subjects, in regards to knee abduction, do not exhibit angles due to fatigue that have previously been shown to increase the risk for ACL injury. Even though our subject's demonstrated with decreased knee flexion, the lack of increased knee abduction could be explained potentially by the subjects' proper co-contraction of the hamstrings and quadriceps muscle activation. This has been shown to control varus-valgus movement at the knee and serves as a protective mechanism for loads acting upon the knee, hence reducing the risk for ACL injury (Lloyd & Buchanan, 2001). A significant decrease in hip abduction angles at initial contact and during peak stance is consistent with the findings of previous research (Pollard, et al., 2004; Sanna & O'Connor, 2008). It is plausible that poor mechanics developed at the hip affect the kinetic chain downward to the knee, and possibly the ankle (McLean, et al., 2007). Additionally, decreased hip abduction angles may be indicative of weak hip abductors and thus reduce joint stability at the hip and inherently the knee. We examined young adolescent males who have not fully developed physically while other studies examined adult females (Tsai et al., 2009). In order to better understand frontal plane biomechanics, more studies are needed to explore how changes occur over time within younger populations, specifically from childhood to puberty and in combination with gender comparisons. Despite these inconsistencies, there is a consensus that increased frontal plane motion places an increased load to the ACL. This was found within this study and supported by previous research (Quatman & Hewett, 2009; Shultz, et al., 2010). Our subjects may be at an increased risk for ACL injury when fatigued due to combined frontal plane changes at the hip.

In addition, we found a lack of change for kinetic and kinematic variables in the transverse plane, which rejects our hypotheses and contradicts previous research (Borotikar, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; Sanna & O'Connor, 2008; Tsai, et al., 2009). It may be plausible that young adolescent males have sufficient hip external rotator strength at this stage of development, this control of the hip possibly prevents the femur from getting into an internally rotated position which has been shown to increase the risk for ACL injury (Besier, et al., 2003; Lloyd &

Buchanan, 2001; McLean, et al., 2005). This lack of transverse plane change at the hip may explain the lack of difference for the knee abduction previously mentioned. It is reported that a hip internal rotation may be directly correlated with an increase abduction moment seen at the knee. With a lack of hip internal rotator strength an abduction load at the knee occur during an athletic task and place the knee in a more vulnerable positon; particularly in combination with fatigue and decision making (Borotikar, et al., 2008). Also, it may be plausible that our methods did not allow for these subjects to reach a high enough level of fatigue to experience transverse plane biomechanical changes. Sanna & O'Connor (2008) incorporated a longer fatigue protocol and found increased knee internal rotation after a sixty-minute fatigue protocol and reported that transverse plane changes may take place later in a game when athletes may be fully fatigued. Further evaluation of young athletes in the fatigued state is needed to better explain the lack of changes noticed. Even though changes were not observed for the transverse plane, evaluation and assessment of transverse biomechanics is an integral part of identifying ACL injury risk patterns. If a different approach was taken there could have been a more observable difference. Particularly, it may be that the level of fatigue or exertional physical activity may need to be observed versus the length of fatigue. This seems logical since our study had less than half the subjects complete a twenty-minute fatigue protocol. Therefore, future studies should continue to explore the injury risk patterns associated with the transverse plane biomechanics utilizing various fatigue and or exertional protocols.

For the remaining kinetic variables, no significant difference was attained for peak vertical ground reaction force (PVGRF) or peak posterior ground reaction force

(PPGRF). This conflicts with the hypotheses proposed, as well as other current research that display increased VGRF and PPGRF after fatigue (Wikstrom, et al., 2004). Another study compared children to adults (boys to men) and found that children have increased PVGRF. In addition, the time to PVGRF was observed to occur earlier than adults (Swartz, et al., 2005). The higher PVGRF indicated children have a "stiffer" landing as compared to the adults. This has been found to increase the risk for ACL injury. One reason for our lack of increase in GRF may be that our subjects performed the side-step cutting task while Swartz et al. (2005) examined the vertical jump, which produces more GRF by nature of the task. Our finding demonstrate that young male lacrosse athletes do not exhibit with significant ground reaction force high risk values that are typically seen in association with ACL risk factors. In this case, foot and body position in relation to an individual's base of support may be more important to observe when analyzing ground reaction force. It is reported that magnitude and direction is important when comparing ground reaction forces to the knee joint center; indicating that poor foot position at ground contact increases the risk for ACL injury (Pflum, Shelburne, Torry, Decker, & Pandy, 2004). Specifically, poor foot positions include increased pronation and external rotation a have been shown to increase the risk for ACL injury (Hewett et al., 2006). Additionally, one study claimed that knee ligament loading is determined by the balance of muscle forces, ground reaction forces and joint contact forces applied to the lower leg (Pflum et al. 2004). Overall, an increase in ground reaction forces in combination with other factors may place the ACL at risk for injury.

It should be noted there were limitations of this study. The subject population is not a random sample; it was a sample of convenience. Since our sample population included youth adolescents it should be noted that each subject demonstrated with varied attention spans. This means some of the subjects demonstrated with focus and followed our testing instructions respectfully while others may have not. This may explain our large standard deviations we reported. Also, it was difficult to determine the level of fatigue, and if subjects maintained a fatigued state during the post-fatigue trials. The inability for every subject to complete the 20-minute SLO-FP may have made for inconsistent fatigue testing. Also, the SLO-FP is not an exact replication of how the athlete may become fatigued in a lacrosse game and therefore these results may not completely represent the mechanism of injury due to fatigue in a game-like scenario for this population. Another limitation was that if the subject was keeping track of the number of accepted or rejected trials, they could have potentially known which task to perform. This could have made the task more of an anticipated cutting task rather than a true unanticipated task. Furthermore, we did not ask them to refrain from any outside activity. This could have meant that the subjects were already in a fatigued-state upon arriving to testing and therefore may not have impacted their pre and post fatigue biomechanical changes.

Conclusion

The results of this study demonstrate that fatigue alters lower extremity biomechanics in young adolescent male lacrosse athletes when performing a side-step cutting maneuver. It is supported that changes in the sagittal and frontal plane kinetic and kinematic variables after a fatigue protocol place greater strain to the knee joint and increase the risk for ACL injury. These findings indicate that young male lacrosse players already exhibit with some poor mechanics and then after a fatigue protocol the poor lower-extremity side-step cutting mechanics worsen after a fatigue protocol. This could place them at greater risk for ACL injury. With knowing that knee injury rates increase as athletes go to high school and then increase again at the collegiate level, it is imperative to pursue preventative measures for the young athletic population. We suggest that proper cutting techniques while in a fatigued state should be reinforced for youth adolescent male lacrosse athletes in a neuromuscular training program. This initiative will potentially reduce the risk for ACL injury for not only the young adolescent athletic population but to also prevent injury that may occur later on in their athletic career.

Future studies should examine the comparison between young male and young female lower-extremity biomechanics, various experience levels, pubertal levels and the effects of fatigue. Also, incorporating sport-specific factors will simulate a closer real-life scenario, for example have the subject hold their lacrosse stick while they dodge and perform "stick-checking". The recording of additional anthropometric measurements would also lend further information for alignment risk factors within this specific population. Also, other fatigue protocols should be explored on how to combat fatigue-related lower-extremity biomechanics in efforts to reduce the risk of ACL injuries within the young adolescent sports population. In addition, a better understanding of the causes of fatigue, specifically the exercise physiology type of fatigue, is needed in order to identify ways to overcome them. Lastly, intervention programs which include proper mechanics should be experimented with young male lacrosse athletes. This could gauge if changes occurred from the training that improve lower-extremity biomechanics in efforts to reduce the risk of ACL or knee injury.

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APPENDIX- A

INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: Effects of a 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes

INTRODUCTION

The purpose of this form is to give you information that may affect your decision whether to say YES or NO to your child's participation in this research, and to record the consent of those who say YES. The name of the research project is "Effects of 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes". The data collection will take place in the Motion Analysis Lab, Room 1007, in the Student Recreation Center on the Old Dominion University campus.

RESEARCHERS

Dr. Bonnie Van Lunen, Ph.D., Associate Professor, Responsible Project Investigator

Crystal Sullivan, B.S., Graduate Student, Human Movement Sciences Department

Julie Bamberg, B.S., Graduate Student, Human Movement Sciences Department

Ashley Brawford, B.S., Graduate Student, Human Movement Sciences Department

Eric Greska, M.S., Doctoral Student, Human Movement Sciences Department

DESCRIPTION OF RESEARCH STUDY

There have been numerous studies that have analyzed the high occurrence of anterior cruciate ligament (ACL) tears in non-contact sports. Research has shown that females are at approximately 4-6 times more likely to sustain an ACL injury when compared to males participating in the same activities. Most studies have looked at the knee joint and how it contributes to this type of injury. There is still a lack of knowledge on how these injuries occur in relation to the knee joint. More recently, research has demonstrated that lower limb mechanics begin to decline at about the onset of puberty. Other studies have suggested that various forms of feedback of athletic tasks can improve mechanics on athletic tasks. The purpose of this study is to determine the effects of various forms of feedback on lower limb mechanics during various athletic tasks in adolescent lacrosse and soccer players.

If your child decides to participate, then your child will join a study involving research of different landing techniques that are related to hip, knee and ankle motion patterns and forces during the stop-jump phase. The study data will be collected in a single session. Your child will be asked to repeat the testing sequence after an 8-week period as desired to evaluate the effects of your child's personal exercise program on physical performance. Your child will report to the Motion Analysis Laboratory, wearing spandex shorts and running shoes, as well as a sports bra for females. You and your child will fill out a questionnaire with questions about your child's history of injury and athletics experience. The testing will take approximately two hours to complete.

- Your child will have a 10-minute warm-up period that will consist of cycling and/or self-directed stretching. After the warm-up period and stretching, measurements will be taken to assess your child's body composition, postural control, strength, and functional movement.

Dynamic Sport Specific Tasks

- Sixteen (16) reflective markers will be placed on specific body landmarks and there will be a short period of time to familiarize your child with the athletic tasks. The three athletic tasks that will be performed consist of a drop-jump task, running stop-jump task, and a running side-step cutting task. All athletic tasks will be randomly performed 5 times each. Following the completion of the three tasks, your child will then perform an aerobic capacity assessment test.

Aerobic Capacity Assessment Testing

- Aerobic fatigue capacity: During the maximum aerobic capacity test your child will be fitted with a chest strap heart rate monitor, a facemask and a head support for the collection of the exhaled. Your child will then run on a treadmill that increases in speed and grade every two minutes. Safe guards are in place on the treadmill with a red STOP button and testers will be within arm's reach of your child. Your child will be instructed to continue to run until he/she voluntarily stops. During the treadmill test, your childs heart rate, breathing, distance traveled, and oxygen consumption will be measured. Your child will rest for five minutes followed by 20 minutes of interval jogging and running.
- After completing the 20-minute run, your child will return to the Motion Analysis Laboratory and repeat the drop-jump task, running stop-jump task, and running side-step cutting task.

- Your child will be asked to return 8-weeks later to retest the entire protocol.

The drop-jump task will be videotaped, this will allow the investigator to insure the landing techniques and athletic tasks are performed correctly. If you and your child do not consent to be videotaped, your child will be excluded from the test. If you and your child say YES, then your child's participation will last for approximately 2.5 hours at the Motion Analysis Lab. Subjects will consist of 60 females and 60 males.

EXCLUSIONARY CRITERIA

Your child will be excluded from the study in the case that you and your child do not consent to be videotaped/photographed.

Your child will be excluded from the study if he/she does not meet specific age requirements described in the questionnaire.

Your child will be excluded if he/she has suffered a traumatic lower extremity injury within the past 12 months.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of ankle sprain, knee injury, muscle pain, and muscle soreness. Ankle sprains can be compared as stepping off the curb, muscle pain and muscle soreness can be compared as the same sensation you might have after workout. The researcher tried to reduce these risks by provided clear directions on how to perform each athletic task and landing technique. You could also experience muscle injury, inappropriate changes in blood pressure or heart rhythm, a heart attack, stroke or death during the maximal fatigue exercise tests. The risk of these events is very low in individuals who are physically active and apparently healthy, such as yourself. The risk is likely no greater than what you experience during your normal training. An automated external defibrillator will be in the laboratory during testing, and available for use if needed. Phone access to EMS is available in the testing room. Finally, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: The main benefit to you for participating in this study is that you will learn your aerobic capacity, your body fat percentage and other indicators of your fitness. The results of the study may be useful in determining more appropriate training strategies for you and other physically active individuals.

COSTS AND PAYMENTS

The researchers want your decision about participating in this study to be absolutely voluntary. Yet they recognize that your participation may pose some inconvenience with travel time to and from the testing site. Unfortunately at this time, 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 unless disclosure is required by law. The researchers will take reasonable steps to insure confidentiality is upheld. The researchers will store all questionnaires, videotapes, and laboratory findings in a locked file cabinet prior to and after processing. 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 and/or injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. Bonnie Van Lunen, at 757-683-3516, Eric Greska, at 757-683-5676, Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460, 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: Eric Greska at 757-683-5676.

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.

Parent/Legal Guardian of Subjects' Printed Name & Signature	**Date**

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**

APPENDIX- B

ASSENT FORM

Effects of a 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes

My name is ______________________. I work at Old Dominion University.

I am asking you to take part in a research study because I am trying to learn more about movement patterns of youth lacrosse and soccer players. I want to see how movement patterns change as you become tired.

If you agree, you will be asked to complete some physical tasks. You will be tested for height, weight, muscle strength, and movement control. You will also be asked to run and make movements as though you were chasing a rolling ball. You will be asked to run on a treadmill for as long as you can, and then run for another 20-minutes. After completing the run, you will be asked to make the movements as though you were chasing a rolling ball again. These tasks will take about 2 hours to complete.

You do not have to be in this study. No one will be mad at you if you decide not to do this study. Even if you start, you can stop later if you want. You may ask questions about the study.

If you decide to be in the study I will not tell anyone else what you say or do in the study. Even if your parents or teachers ask, I will not tell them about what you say or do in the study.

Signing here means that you have read this form or have had it read to you and that you are willing to be in this study.

Signature of subject____________________________________

Subject's printed name ____________________________________

Signature of investigator____________________________________

Date______________________

APPENDIX- C

Demographics & History Questionnaire

Age:__________Gender: Male Female | Weight:__________kg Height:________cm |

Ethnicity: Hispanic or Latino Not Hispanic or Latino Unknown

Race: American Indian/Alaska Native Asian Native Hawaiian/Other Pacific Islander

Black or African American White More than one race Unknown

Dominant Leg: Left Right

This is the leg in which you would kick a soccer ball as far as possible with

How many years have you been playing soccer?__________

Injuries:

Have you had any ankle sprains? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Have you had an ACL injury? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Have you had any surguries (ankle and/or knee)? Yes No

If yes, which leg? Right Left Both

If yes, when?_________________________ (month/year)

Do you presently have any physical impairment that would limit you from performing a jump-landing task?

Yes No

Have you been exercising at least 30 minutes per day, 3 times per week, for the past 6-months?

Yes No

APPENDIX- D

Photo Release Document

FOR USE OF PHOTO/VIDEO MATERIALS

STUDY TITLE: Effects of an 8-week Augmented Feedback Intervention on Lower Extremity Kinematics and Kinetics during Athletic Tasks in Pubescent Athletes.

DESCRIPTION:

The researchers would also like to take photographs or videotapes of you performing a variety of athletic tasks in order to illustrate the research in teaching, presentations, and/or or publications.

CONFIDENTIALITY:

The tapes used during the study will be stored in a locked file cabinet in the Motion Analysis Laboratory (Room 1007, Student Recreation Center). You would not be identified by name in any use of the photographs or videotapes. Even if you agree to be in the study, no photographs or videotapes will be taken of you unless you specifically agree to this.

VOLUNTARY CONSENT

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

If you have any questions later on, then the researchers should be able to answer them: Eric Greska at 757-683-5676. 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.

Parent/Legal Guardian of Subjects' Printed Name & Signature	**Date**
Subject's Printed Name & Signature	**Date**
Investigator's Printed Name & Signature	**Date**

APPENDIX- E

Data Collection Form

SLO-FP Protocol

Resting HR________________ Max HR (age calculated):_____________

Height (m):______________ Mass (kg):________________ Age:_____________

Body Composition M: Chest ______/_______ Abd _______/_______ Thigh _______/_______

F: Tri ______/_______ Abd ______/_______ Thigh _______/_______

Bodpod Mass (kg):_____________________ BF%:______________________

VO_2Max:

Minutes	Km/h	MPH	HR
0-4:59	9	5.6	
5-6:59	10	6.2	
7-8:59	11	6.8	
9-10:59	12	7.5	
11-12:59	13	8.1	
13-14:59	14	8.7	
15-16:59	15	9.3	
17-18:59	16	10	
19-20:59	17	10.6	
21-22:59	18	11.2	
23-24:59	19	11.8	

Time Stopped:___________________________ Speed Stopped:_____________________

Met which criteria (circle two):

HR reached 90% of age-calculated max

Respiratory quotient greater than 1.1

Plateau in VO_2Max curve

Subject was unable to continue

20-minute Run:

Jog Speed(70%):____________________ Sprint Speed(90%):________________________

Did they complete the entire run: Yes No (Time Stopped:__________________)

Jog Speed @ 70%			**Sprint Speed @ 90%**		
Minutes	**MPH**	**HR**	**Minutes**	**MPH**	**HR**
0-3:59			4-4:59		
5-8:59			9-9:59		
10-13:59			14-14:59		
15-18:59			19-20		

APPENDIX- F

Patient Instructions

$VO2_{peak}$

"This test will be assessing your maximal exertion. This means that during this test you will be running for as long and as hard as possible. You will also be wearing a facemask during the test. We will start you out at a slower speed for 5 minutes to warm up then every 2 minutes we will increase the speed. Please don't talk during the test, we will ask you questions periodically and just signal with thumbs up for 'yes' and a thumbs down for 'no'. When you can't go any longer, place your hands on the rails beside you and we will immediately stop the test and take you to a walking speed. Do you have any questions? During the testing, we will be asking periodically if the patient is doing alright. We will also tell the patient that we will be increasing the speed every time we increase it. When the RQ gets to a level where we think they might quit, we will remind them to put their hands on the rails if they need to stop."

Unanticipated Tasks Pre-Fatigue

"You will be performing 5 stop-jump and 5 side-step tasks. The projector in front of you will tell you which task to perform when you get within 2 meters of the force plates. The projector will show a rolling soccer ball at the beginning of each trial. Once the system is tripped it with show an arrow to your non-dominant side for the side-step and a picture of a stop sign will show up for the stop-jump task."

Unanticipated Tasks Post-Fatigue

"Just like before, you will be performing 5 stop-jump and 5 side-step tasks. The projector in front of you will tell you which task to perform when you get within 2 meters of the force plates. The projector will be blank at the beginning of each trial. Once the system is tripped it with show a ball rolling to your non-dominant side for the side-step and a picture of a soccer girl with show up for the stop-jump task. You will not be resting in between trials so as soon as you get back to your starting position you may begin the next trial."

VITA

Julie A. Bamberg, ATC, VLAT

Department of Study

Old Dominion University
Human Movement Sciences Department
Student Recreation Center
Norfolk, VA 23529

Education

May 2011 Master of Science in Education
Post-Professional Athletic Training Education Program
Old Dominion University
Norfolk, VA

May 2009 Bachelor of Science
Athletic Training
Minor: Political Science
University of South Florida

Professional Experience

08/10-12/10 Old Dominion University; Norfolk, VA
Co-Instructor: Advanced First Aid and CPR (HE224, 3 credits)

- Created and implemented course syllabus, lesson plans, lectures, exams, quizzes, assignments and organized laboratory sessions following the curriculum of the American Red Cross.

08/09- 5/11 Old Dominion University; Norfolk, VA
Graduate Assistant Athletic Trainer

- Certified athletic trainer with varsity athletes during Athletic Training Facility coverage; rotations with Women's Soccer, Men's Basketball, Football, Women's Lacrosse, Men's & Women's Tennis, Women's Field Hockey and Women's Rowing.
- Performed initial evaluations and on-field assessment of athletic injuries, created and implemented treatment and rehabilitative protocols for athletes, assisted in the creation of various administrative policies and procedures.