The Effects of Repeated Bouts of Fatigue on Peak Ground Reaction Forces and Kinematics during Drop Landings in Recreational Athletes

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Authorization to Submit Thesis

This thesis of Danielle Lawson, submitted for the degree of Master of Science with a Major in Movement and Leisure Sciences and titled "The Effects of Repeated Bouts of Fatigue on Peak Ground Reaction Forces and Kinematics during Drop Landings in Recreational Athletes," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

This study examined repeated bouts of fatigue and its influence on biomechanical variables of drop landings known as risk factors for ACL injury.

A repeated measures ANOVA was performed on fatigued conditions and gender as the independent variables. The dependent variables studied included: max ground reaction force, time to peak ground reaction force, sagittal hip, knee, and ankle angles, frontal knee angles, and knee joint moments. A 20-sec wingate anaerobic test was used as the repeated fatigue protocol and 5-drop landings were recorded in each fatigue condition.

Results indicated that no significant differences across fatigue groups for max vertical ground reaction force, time to peak ground reaction force, knee joint moments (sagittal, frontal, transverse planes), hip flexion, knee flexion, ankle flexion, and knee abduction angles. Gender was noted as a significant factor regardless of fatigue condition on max vertical ground reaction force, ankle and knee flexion, and knee abduction angles.

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Dedication

I would like to dedicate this paper to my Mother, who has constantly given me inspiration, hope, and a sense of worthiness.

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Chapter 1: Background

The National Collegiate Athletic Association Injury Surveillance System (NCAA ISS) has been a useful tool in describing the prevalence of different injuries in collegiate athletes across many different sports, highlighting areas where stronger injury prevention initiatives are required (Agel, Arendt, & Bershadsky, 2005; Agel, Palmieri-Smith, Dick, Wojtys, & Marshall, 2007). Among the injuries reported by the NCAA ISS, injury to the anterior cruciate ligament (ACL) has been identified as one of the most common knee injuries (Agel, Arendt, & Bershadsky, 2005; Arendt, Agel, & Dick, 1999).

The ACL works in collaboration with two other ligaments, which together provide three dimensional stability to the knee joint. The ACL accounts for approximately 85 percent of the total restraint in anterior translation of the tibia in relation to the femur, and it also helps resist medial rotation (Hamill & Knutzen, 2003).

Injury to the ACL has occurred under two main mechanisms, either a contact or a non-contact injury manifested in either a partial or complete tear of the ligament. Contact ACL injury is recognized as injury due to contact with an object, such as another player or a ball. Non-contact injury can be due to both external and internal factors. External factor examples include shoe type, playing surface, weather, etc. Internal factors for non-contact injury relate to anatomic, hormonal, and neuromuscular factors. While player contact or contact with other objects is hard to minimize in sporting events, non-contact ACL injuries may be more preventable, due to a common thought that an athlete can be trained in such a way as to improve neuromuscular factors and become more biomechanically sound.

Not only is it thought that non-contact ACL injuries have a greater capacity for being prevented, they are also more prevalent than contact ACL injuries. The NCAA ISS reports that 70 percent of ACL injuries are due to a non-contact injury mechanism. Additionally, ACL injuries have been reported more frequently in females versus male athletes (Agel, Arendt, & Bershadsky, 2005; Arendt, Agel, & Dick, 1999). It has been noted that females are 4-6 fold more likely to acquire a non-contact ACL injury in comparison to their male counterparts (Mihata, Beutler, & Boden , 2006). Numerous studies have aimed to understand and correct this gender disparity, yet the ACL injuries continue to rise for the female athletes in comparison to the male athletes (Agel, Arendt, & Bershadsky, 2005).

For these reasons, ACL injury research has focused on injury prevention surrounding the non-contact injury mechanism. Researchers have found that maneuvers such as lateral pivoting, landing, and other deceleration tasks are potential sources of non-contact ACL injury (Ford, Myer, & Hewett, 2003). Also, according to Agel et al. (2007) non-contact injury stems most frequently from the single-leg landing maneuvers. When not conducted correctly, single-leg landing maneuvers can place the limb in a vulnerable position that increases the risk of ACL injury. This vulnerable position has been described as a combination of knee valgus, slight knee flexion, and external rotation of the tibia with the foot firmly planted on the ground (Lawrence III, Kernozek, Miller, Torry, & Reuteman, 2008). Further, Quatman & Hewett (2009) state that ACL injury occurs as a result of anterior tibial shear or knee valgus collapse, which consists of a combination of knee valgus, hip internal rotation and tibial rotation. Research studies surrounding ACL injuries often have participants perform tasks similar to those that are noted to be potential sources for ACL injury, i.e. landing and pivoting.

Through these landing and pivoting studies and the growing body of research associated with ACL injury prevention, a large group of researchers have begun participating in an ACL Research Retreat every 2 years. This is an ongoing event that focuses on providing information on the most current research surrounding ACL injury risk and prevention. Along with evaluating current research, this retreat also keeps track of what research questions still remain and how best to direct future research. After every retreat, all discussion materials are compiled and published in a consensus statement. The statement is organized by factors associated with ACL injury, they include: neuromuscular, biomechanical, anatomical, structural, and hormonal factors. The most recently published consensus statement states that fatigue alters biomechanical and neuromuscular factors that are associated with increased ACL injury risk (Shultz, et al., 2010). However, much of the research concerning the relationship between fatigue and increased ACL injury risk that is cited in the consensus statement is limited by the fact that only single bouts of fatigue are utilized (Borotikar, Newcomer, Koppes, & McLean, 2008; Kernozek, Torry, & Iwasaki, 2008; Orishimo & Kremenic, 2006).

Currently, Dominguese, Seegmiller, & Krause (2012) is one of a few studies to examine how repeated bouts of fatigue affect landing mechanics. The purpose of their study was to examine the effects of a repeated muscle fatigue protocol, using the wingate anaerobic test, on ground reaction forces (GRF) during drop landings from a height of 60 cm, and to determine if there were differences across gender. The GRF data they analyzed included peak fore-foot and rear-foot force, and anteroposterior and mediolateral forces for both the fore-foot and rear-foot forces. They found statistical significance with greater peak rear-foot force with the landings in fatigue conditions 3, 4, and 5 when compared to the non-fatigued landings. However, no differences were found across gender in any of the GRF data captured and both men and women achieved similar overall percentage power drop during all fatigue protocols. This study has begun to address if fatigue is a part of the variables that contribute to ACL injury and to quantify how much fatigue is required to increase the risk of poor landing mechanics that are associated with ACL injury.

This study leaves several research questions unanswered surrounding how repeated bouts of fatigue affect factors associated with ACL injury during drop landings. While they did find that fatigue increased landing GRFs, without kinematic data, no explanation can be given describing the joint positioning that resulted from increased forces. Additionally, Dominguese (2012) averaged the sampling of landing trials after each fatigue protocol. The first landing had the least amount of time to recover and possibly gives more accurate fatigued landing data versus the second landing when more time has passed and possibly more muscle recovery has taken place. By averaging the trials, it is possible that a recovery effect may not have been accounted for. Therefore, a study that minimizes any recovery effect when sampling landings and one that includes both kinematic and kinetic data is needed to further explain the role fatigue plays in non-contact ACL injury.

Problem Statement

Among the most common lower extremity injuries, the incidence of non-contact ACL injury during landings is well documented. However, the role of fatigue in the etiology of ACL injury is still not well understood.

Purpose Statement

Therefore, the purpose of this study is to examine biomechanical variables during drop landings as risk factors for ACL injury, following repeated bouts fatigue.

Research Questions

1. To what extent do repeated bouts of maximal-intensity exercise using the 20-second Wingate test affect the kinetics (e.g. ground reaction forces, knee joint moments, and time to peak ground reaction force) of a drop landing? Does an additive affect exist across repeated fatigue bouts? Will there be variation within a sampling of drop landing trials due to fatigue? Will fatigue be dealt with differently across gender?
2. To what extent do repeated bouts of maximal-intensity exercise using the 20-second Wingate test affect ankle, knee, and hip kinematics in the sagittal plane of a drop landing? Does an additive affect exist across repeated fatigue bouts? Will there be variation within a sampling of drop landing trials due to fatigue? Will fatigue be dealt with differently across gender?
3. To what extent do repeated bouts of maximal-intensity exercise using the 20-second Wingate test affect knee kinematics in the frontal plane of a drop landing? Does an additive affect exist across repeated fatigue bouts? Will there be variation within a sampling of drop landing trials due to fatigue? Will fatigue be dealt with differently across gender?

Research Hypotheses

1. In a study comparing individuals who had previously injured their ACLs and those who had no previous history of injury, those with ACL injury history altered their landing mechanics with a 20% percent increase in vertical ground reaction forces, and knee abduction moments will be about 6 times greater in individuals with ACL injury (Hewett, et al., 2005). Additionally, previous research has stated that time to peak

ground reaction force is impacted by fatigue (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010). Therefore we hypothesize:

   a. Landings following multiple bouts of fatigue will exhibit progressive increases in max vertical ground reaction forces, knee abduction moments. Time to peak stabilization will decrease progressively following multiple bouts of fatigue.
   b. The first landing trials following the fatigue conditions will exhibit increased max vertical ground reaction forces, knee abduction moments, and time to peak stabilization in comparison to the second and third trials due to a recovery effect.
   c. Females will overall exhibit greater relative max vertical ground reaction forces, knee abduction angles, times to stabilization than males following fatigue.

2. According to Pappas et al. (2009), following a single bout of fatigue knee flexion angles were found to increase for men and decrease for women. Research has also found hip flexion and ankle flexion to increase due to fatigue (Kernozek, Torry, & Iwasaki, 2008). Therefore we hypothesize:
   a. Following multiple bouts of fatigue, males will exhibit progressive increases in the flexion angles of the hip, knee, and ankle. Females will increase flexion angles of the hip and ankle, but decrease the flexion angles in the knee in comparison to their pre-fatigued landing trials.
   b. The first landing after fatigue will achieve more flexed joint angles than the second and third landings due to muscle recovery.

    c. Females will exhibit stiffer landing mechanics, less flexion in the hips, knees, and ankles, than males following fatigue.

3. In a study comparing individuals who had previously injured their ACLs and those who had no previous history of injury landing mechanics of those with ACL injury tend towards an increase in knee valgus of approximately 7-8 degrees and an increase in knee flexion by about 10 degrees (Hewett, et al., 2005). Frontal knee valgus has been one of the primary predictors of ACL injury. Therefore, we hypothesize:
    a. Landings following multiple bouts of fatigue will progressively increase in the angle of knee valgus.
    b. The first landing trials following the fatigue conditions will exhibit greater knee valgus in comparison to the second and third trials due to a recovery effect.
    c. Females will overall exhibit greater knee valgus angles than males following fatigue.

Null Hypotheses

1. Repeated bouts of maximal-intensity exercise using the 20-second Wingate test will have no effect on kinetics (e.g. ground reaction forces and joint moments) in a series of drop landing trials. There will be no differences across the different fatigue bouts or across gender.
2. Repeated bouts of maximal-intensity exercise using the 20-second Wingate test will have no effect on ankle, knee, and hip kinematics in the sagittal plane in a series of drop landing trials. There will be no differences across the different fatigue bouts or across gender.

3. Repeated bouts of maximal-intensity exercise using the 20-second Wingate test will have no effect on knee kinematics in the frontal plane in a series of drop landing trials. There will be no differences across the different fatigue bouts or across gender.

Independent Variables

1. Condition (Non-Fatigued Condition, Fatigued Condition #1, Fatigued Condition #2, Fatigued Condition #3, Fatigued Condition #4)
2. Gender

Dependent Variables

1. Max Vertical Ground Reaction Forces
2. Sagittal Plane: Ankle, Hip Kinematics
3. Knee Kinematics: Sagittal, Frontal, and Transverse Planes
4. Knee Joint Moments: Sagittal, Frontal, and Transverse

Delimitations

1. Only individuals from the Moscow, ID community will participate.
2. Twelve males and thirteen females with no lower extremity musculoskeletal injuries or surgery for at least six months prior to testing will be included.
3. Participants will perform drop landings from a height of 60-cm, stepping off a box and landing on two force plates while barefoot.
4. When stepping off of the box, participants will step off with their dominant leg first and with arms extended forward, perpendicular to their trunk.

5. A 20-sec Wingate Anaerobic Test will be repeated four times to induce fatigue to the lower extremity muscles for each participant, and drop landings will be recorded after every Wingate Test.
6. All participants will be classified as physically active and healthy from any significant lower extremity injury, cardiovascular, and pulmonary illness as determined by a health questionnaire and orthopedic examination, which will be performed by a Licensed Athletic Trainer (LAT).
7. The experimental protocol will be explained to all participants at least one day prior to data collection. Participants will have the opportunity to practice drop landings as much as they desire to become familiar with the protocol.

Limitations

1. Differences in landing style exist between each participant.
2. The controlled experimental conditions of this study will be different from the participant's actual sport or exercise program.
3. Landings from only one height will be used to make generalizations on how fatigue affects landings from any height.
4. The participants will be volunteers and may not represent a true random sample of the population.

Assumptions

1. Participants accurately answered all medical history questions.
2. Participants accurately answered the physical activity assessment questionnaire.
3. Participants performed the Wingate tests with maximal effort, and accurately reported on the perceived exertion questions.

4. Participants refrained from intense exercise for 1 day prior to testing, and did not consume food within a 2-hr time frame before data collection.

Definition of Terms

1. Drop Landing – A task where participants leave a 60 cm platform and land on a floor containing two force platforms installed flush with the floor.
2. Kinematics – A description of how the body moves.
3. Kinetics – Forces act on the body while in a pose or while moving
4. Max Vertical Ground Reaction Force (MxVGRF) – The forces applied on the body during ground contact in the plane perpendicular to the ground.
5. Muscle Fatigue – A combination of elements that include an increase of perceived effort required to exert a desired force that eventually leads to the inability to produce desired force (Barry & Enoka, 2007).
6. Time to Peak Ground Reaction Force – The time from when force was first applied to the force plate until peak ground reaction forces were achieved.

Chapter 2: Literature Review

Stabilizing the Knee

Many structures work together to form stability of the knee including: skeletal, articular cartilage, meniscal, capsular, ligamentous, and musculature structures. Passive structures include the bones, cartilage meniscus, capsule, and ligaments. The purpose of the passive structures is to maintain the relationship of the bones moving against each other so as to restrict certain movements and to assist in the gliding of the joint structures. In addition to the passive structures, the musculature surrounding the knee is an active structure that works functionally and dynamically to assist in maintaining joint alignment. (Al-Turaiki, 1986; Behnke, 2006)

The ligamentous structures in the knee include the lateral collateral ligament, medial collateral ligament, posterior cruciate ligament, and the anterior cruciate ligament. The lateral collateral ligament resists varus displacement of the knee in flexion between 0 and 30 degrees and secondarily resists posterolateral rotatory displacement with flexion less than 50 degrees. The medial collateral ligament resists valgus displacement of the knee and secondarily works in conjunction with the ACL to provide resistance to axial rotation. The posterior cruciate ligament resists posterolateral rotation of the tibia on the femur and secondarily resists varus angulation and posterior displacement of the tibia in relationship to the femur. The anterior cruciate ligament resists anterolateral displacement of the tibia in relationship to the femur and secondarily resists varus displacement and the knee is fully extended. (Woon & Hughes, 2015; Behnke, 2006)

The primary muscles that are used to stabilize the knee through dynamic movements include the quadriceps, sartorious, gracilis, tensor fasciae late, hamstrings, and gastrocnemius. The quadriceps work to extend the knee and provide stability on the anterior side of the knee. The sartorious and gracilis both work to adduct the knee and provide stability on the medial side of the knee. The tensor fasciae late works to abduct the knee and provide lateral stability. While the hamstrings and gastrocnemius work to flex the knee and provide posterior stability. (Al-Turaiki, 1986; Behnke, 2006)

The Kinetic Chain

The knee is a part of a kinetic chain in the body that includes the trunk, hips, knees, and ankles and one cannot isolate the knee when discussing how to prevent knee injury. All of these joint systems work together to control movements of the lower-extremity (Mediguchia, Ford, Quatman, Alentorn-Geli, & Hewett, 2011). One example of how this kinetic chain is neurologically stabilized includes with organization starting with the trunk and working more distally, also called a hip strategy to maintain postural control (Putnam, 1993). For example, coordination starts in the trunk moving the center of mass forward while the hip, knee, and ankle work together to ensure that a limb is there to support the center of mass in its forward progress. If one of these joint systems does not function correctly it will impact the coordination of the chain of systems. For this reason, Mendiguchia et al. (2011) caution that decreased activation of proximal stabilizing muscles, such as the hip musculature, may increase the load-bearing requirements of the knee and predispose it to ACL injury.

Other theories are used to explain the neuromuscular control of the lower extremity, one of which is called the ankle strategy. (Williams, Chmielewski, Rudolph, Buchana, & Snyder-Mackler, 2001). The ankle strategy restores the body’s center of mass to stability through moving the body surrounding the ankle joints (Nasher, 1977). This strategy is used primarily in situations where perturbations to balance is small.

Both of these different theories are very complex and can be modified and adapted to allow for different circumstances. Additionally more than one strategy can be used at the same time. (Williams, Chmielewski, Rudolph, Buchana, & Snyder-Mackler, 2001).

Injury of the ACL

The neuromuscular system and how it coordinates the body in sport participation is believed to play a role in non-contact ACL injury. Several different neuromuscular strategies have been described to increase risk for ACL injury. Hewett, Ford, Hoogenboom, & Myer (2010) link four different neuromuscular imbalances to non-contact ACL injury. These neuromuscular imbalances include ligament dominance, quadriceps dominance, leg dominance, and trunk dominance. The first imbalance, ligament dominance, is characterized as using bones, cartilage, and ligaments to absorb high amounts of ground reaction forces over a brief period of time because the muscles do not sufficiently absorb enough of the forces. The second imbalance, quadriceps dominance, refers to the tendency to stabilize the knee joint by primarily using the quadriceps muscles. This technique results in posterior translation of the tibia, which causes the ACL to be the primary antagonist resisting the shear force. To eliminate the quadriceps imbalance the hamstrings should be more engaged, as this relieves the stress on the ACL by providing it assistance against the quadriceps. The third imbalance, leg dominance, is the concept that there is a lateral discrepancy between the two limbs. With one leg being more dominant, the force is not evenly spread causing more force to be applied to the ACL on the non-dominant side. The final imbalance, trunk dominance, is defined by the lack of ability to control the trunk in three-dimensional space. Without being able to control the trunk, the center of mass can easily be perturbed outside of the base of support putting more lateral force on the knee. This increase in lateral force encourages the knee to adapt a more valgus position.

Muscle Fatigue

Beyond these different neuromuscular imbalances, fatigue should also be considered when attempting to understand how to stabilize the knee during high risk sporting movements. Bigland-Ritchie and Woods (1984) define muscular fatigue as a decrease in maximal voluntary contraction that can arise due to local changes within the muscle or when the central nervous system doesn’t adequately excite the motor neurons that drive the muscles required for the task. Enoka and Stuart (1992) proposed that sensations of perceived effort should also be included in the previous definition. They define fatigue as, “an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (p.465).

There are many mechanisms involved in muscle fatigue, which has made previous muscle fatigue research challenging to summarize (Barry & Enoka, 2007). In a review of muscle fatigue, several characteristics about fatigue should be noted: fatigue characteristics are task dependent, a relationship exists between muscle force and endurance time, a muscle’s unit discharge rate adjusts to minimize fatigue, and the sense of effort can alter muscle contractions (Barry & Enoka, 2007). A decrease in muscle contraction can have an effect on human performance and can lead to injury in settings where high performance is required such as in many sporting events. This decrease in human performance can lead to ACL injury. It has been reported that fatigue alters lower limb biomechanical and neuromuscular factors that are associated with increased risk for non-contact ACL injury (Shultz, et al., 2012).

Fatigue Characteristics and Protocols

The muscle fatigue principle of task dependency laid out by Barry & Enoka (2007) states that, “there is no single cause of muscle fatigue and that the dominant mechanism depends on the details of the task being performed” (p. 465). Some of the task fatigue variables that are significant include: subject motivation, the pattern of muscle activation, intensity and duration of activity, and continuous or intermittent activity (Barry & Enoka, 2007). Unfortunately, the fatigue and ACL literature has used different fatigue protocols involving different tasks to study the effects of fatigue as a mechanism for ACL injury. In an effort to produce fatigue similar to most jumping and cutting sports, most fatigue protocols in recent studies have used methods that include jumping over obstacles and vertical jumps (Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2009), weighted parallel squats at a percentage of a 1 Repetition Maximum (Kernozek, Torry, & Iwasaki, 2008), agility ladder drills and jumping (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010), and a Wingate Anaerobic Test (Dominguese, Seegmiller, & Krause, 2012). Additionally, research has disagreed on use of double-leg landings and single leg landings when studying ACL injury. Arguments surrounding a single or double leg landing used to study fatigue and ACL injury are due to a lack of being able to identify at what point during the landing the ACL is ruptured and if it predominantly takes place during a asymmetrical or symmetrical landing. In addition to differences in both landing style and fatigue protocols, it has been noted that male and females exhibit different fatigue responses. Barry and Enoka (2007) summarize this explanation by the differences in strength between the genders. Due to the varying characteristics of fatigue and the difficulty this brings in defining the dominant fatigue mechanism across studies, care should be taken when trying to summarize the fatigue and ACL literature. For this reason, the fatigue research described in the next two sections note very specific details to allow the identification of dominant fatigue mechanisms.

Single Bout of Fatigue and Bilateral Landings

Pappas, Hagins, Sheikhzadeh, Nordin, and Rose (2009) designed a study to determine if the peak value of knee angles, vertical ground reaction forces, and muscle activity occur in the initial phase of landing as it has been noted that this is when ACL sprains usually occur. Their study worked to determine the effects of gender and fatigue on knee flexion angles at the occurrence of peak biomechanical variables. The specific peak biomechanical variables that were addressed included: knee valgus angle, MxVGRF, and normalized electromyography amplitude of the quadriceps and hamstring muscles. Pappas et al. (2009) found that neither gender, nor fatigue had a significant effect on knee valgus angle or knee flexion angle at occurrence of peak values of the biomechanical variables within 40 degrees of initial knee flexion. However, they did find that the interaction between gender and fatigue had a significant effect ($P<0.05$) for knee flexion at peak vertical ground reaction force (VGRF). Knee flexion angle at peak VGRF was found to increase by 1 degree in males and decrease by 5.6 degrees in females for the post fatigue condition. The main point of this study discussed how previous research identified the initial landing phase (knee flexion <40) as the time when ACL strain is most likely to happen. Secondarily, Pappas et al. (2009), noted during the post-fatigue condition, females had significantly less knee flexion at peak VGRF than in the pre-fatigue condition.

The methodology used by Pappas et al. (2009) involved performing two practice drop landings from a height of 40 cm, and then performing three successful bilateral drop landing while arms crossed over the chest. The drop landings were followed by a fatigue protocol. The fatigue protocol used included: jumping over five consecutive 5-7 cm obstacles repeating 20 times and then jumping vertically 50 times as high as possible. Drop landing procedure was completed within six minutes after finishing the fatigue protocol.

While neither gender nor fatigue had a significant effect on the occurrence of the peak biomechanical variables, it is likely that the 6 minutes between the end of the fatigue protocol and the drop landing procedure allowed for the muscles to recover enough to prevent any significant findings. Being able to confirm the presence of fatigue in a study is valuable and will provide further evidence as to the role of fatigue in ACL injury. Pappas et al. (2009) suggested that knee angles at initial contact may be more of a predictor of ACL injury than peak knee angles across the entire landing.

Single bout of Fatigue and Single-leg Landings

Kernozek, Torry, and Iwasaki (2008) studied the kinematic and kinetic differences between genders during single-leg drop landings before and after muscular fatigue. They found that woman had a significantly greater normalized VGRF (P=0.002) when compared to their male counterparts for both pre-fatigue and post-fatigue conditions. They also found that in the sagittal plane, fatigue caused both men and women to increase hip flexion during their drop landings when compared with pre-fatigue trials (P=0.012). There was no gender * fatigue interaction in the frontal plane, however, they found that women showed greater maximum hip flexion angles across all trials compared to men (P=0.001). There were no significant differences between sexes in the frontal plane, however there were differences in hip abduction pre and post fatigue (P=0.0271), with women having decreased their hip abduction angles by 40% and men having increased hip abduction angles. Looking at the knee in the sagittal plane, woman had less maximum knee flexion angles compared to men in the pre-fatigue trials. However, there was a fatigue * gender interaction post fatigue with men increasing their maximum knee flexion angles and women not altering their maximum knee flexion angles from what was recorded for pre-fatigue trials. Men had greater varus angles both pre and post fatigue, and women had greater valgus angles both pre and post fatigue. However, for both genders there were no significant differences due to fatigue. For joint reaction forces, each gender was able decrease hip compression by about 12.5%, and even though not significant, anterior hip shear force was also decreased. At the knee, fatigue caused each gender to lower peak compression force (P=0.000). And although both genders were able to reduce peak anterior knee shear force, men were able to reduce this by 38% compared to women only be able to decrease this force by 20%. This is mostly due to the men having a greater increase in their knee flexion angle during the fatigued state. (Kernozek, Torry, & Iwasaki, 2008)

The fatigue protocol consisted of the participants using 60% of their 1-repetition maximum as their testing weight and repeating as many parallel squat repetitions as possible on a Smith machine. The exercise was controlled by a metronome, which paced each of the participants on the ascent and descent of their squats. A stop was used to make sure each participant was going down to an accurate parallel position. A minimum of 4 sets were performed with 90 seconds of rest allowed between each set. The participants were considered to be fatigued if they had completed at least 4 sets and could perform no more repetitions. (Kernozek, Torry, & Iwasaki, 2008)

The landing protocol consisted of having each subject perform 6 single-leg drop landings by dropping for a hanging bar onto their dominant leg. The height of the bar was adjusted for each individual so that each subject dropped from a height of 50 cm measuring from the force plate to the bottom of the subject's feet. Drop landings were recorded before and immediately after the fatigue protocol. (Kernozek, Torry, & Iwasaki, 2008)

Kernozek, Torry, & Iwasaki (2008) concluded that before fatigue, the kinematic and kinetic differences in and men and women appear mostly in the frontal plane and not in the sagittal plane. Post-fatigue however, women were not able to reduce anterior knee shear force as efficiently as men, who managed this force by increasing knee flexion angles. They also mentioned that fatigue caused an increase in the maximal ankle dorsiflexion angles and that this could also be a part of the process in minimizing knee loads under fatigued conditions. This study goes against Pappas et al (2010) because differences were noted between the genders both pre- and post-fatigue, however, it should be noted the differences in landings used between the studies. Pappas et al (2010) used bilateral landings and Kernozek, Torry, & Iwasaki (2008) used single-leg landings in their study. It may be that it is easier to note differences in gender during both pre- and post-fatigued conditions because a single-leg landing is a more difficult skill.

Brazen, Todd, Ambegaonkar, Wunderlich, and Peterson (2010) also studied the effect a fatigue protocol has on single-leg drop landings. Dependent variables included kinematic data of the landings, VGRF, and TTS. They found that there was no significant differences between genders. In comparing the pre and post fatigue landing trials they found participants had more knee flexion ($P < 0.000$) and ankle plantar flexion ($P=0.012$) after the fatigue protocol. There were no significant differences in the frontal knee angles between the pre and post fatigue protocol or between sexes. They also found that the participants landed with greater peak VGRFs post the fatigue protocol ($P=0.002$), but again there were no significant differences between the genders. And lastly they found that both the anterior-posterior ($P=0.021$) and vertical ($p=0.002$) TTS increased in both sexes after fatigue, but no differences were found between the sexes. Along with capturing the kinematic data of the landings, VGRF and time to stabilization (TTS) was also captured. They found that there was no significant differences between genders and during the fatigue protocol both sexes were working near maximal levels. In comparing the pre and post fatigue landing trials they found participants had more knee flexion ($P < 0.000$) and ankle plantar flexion ($P=0.012$) after the fatigue protocol. There were no significant differences in the frontal knee angles between the pre and post fatigue protocol or between sexes. They also found that the participants landed with greater peak VGRFs post the fatigue protocol ($P=0.002$), but again there were no significant differences between the genders. And lastly they found that both the anterior-posterior ($P=0.021$) and vertical ($p=0.002$) TTS increased in both sexes after fatigue, but no differences were found between the sexes. (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010)

The design of their study included performing 3 single-leg drop landings from a height of 0.36 m onto a force plate before and after a fatigue protocol. After initial landings were recorded all participants engaged in a warmup, to be followed by 6 times through the fatigue course. A brief description of the fatigue course includes: 4 different variations of agility ladder drills (5 times), 30 lateral (side-to-side) jumps, 30 jumps onto a BOSU apparatus, and 5 maximal vertical jumps. After the 1st pass through the course and a 30 second rest, participants were timed to encourage maximal voluntary effort through the remaining 5 passes without allowing any more rest opportunities. Within 30 seconds of the last fatigue course, participants completed 3 more single-leg drop landings. (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010)

Brazen et al. (2010) concluded from their study that it was clear that fatigue affected the single-leg landings. After their participants completed the fatigue protocol they found the participants had more knee and ankle flexion, had greater peak VGRFs, and required more time to stabilize after the landing. (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010)

Wingate Fatigue Protocol

The Wingate Anaerobic Test (WAT) was developed in the 1970s by the Department of Research and Sport Medicine of the Wingate Institute for Physical Education and Sport, Israel. The WAT is a 30 second supra-maximal cycling test with a resistance set to each individual's relative body weight. This allows researchers to assess an individual's anaerobic performance, quantified through three measurements: peak power, mean power, and rate of fatigue (Bar-Or, 1987). When using the Wingate Anaerobic Test, Fernandez-del-Olmo et al. (2011) reports, "An important feature of this test is that the participants must perform at their maximal effort from the beginning to the end of the test. This test allows us to investigate the impact of this regime exercise over the capacity of the central nervous system to generate volitional force. This may also provide an insight regarding the mechanisms of the regulation of neural drive during exhaustive locomotor exercise" (p. 2). Also, because participants are supposed to perform at maximal effort, the length of the test could interfere with the participant's voluntary effort to work maximally. In an effort to encourage maximal effort in the WAT, researchers have tried to decrease the required test time for the WAT. Laurent, Meyers, Robinson, and Green (2007) did a cross-validation study looking at the 20 second Wingate Anaerobic Test compared to the 30 second Wingate Anaerobic Test. While using a non-linear regression equation, the last 10 seconds of the 20-second test could be predicted with less than a 10 percent error in comparison to the 30-second test. There was also no significant difference found between the mean power and fatigue index values of the 20-second and 30-second Wingate Anaerobic Tests. (Laurent, Meyers, Robinson, & Green, 2007)

Currently, the only study to utilize the Wingate anaerobic test in the study of fatigue and ACL injury was done by Dominguese, Seegmiller, and Krause (2012). They used the Wingate to study how repeated bouts of fatigue affect drop landings. The study design included 20 recreational athletes (10 male, 10 female) performing drop landings from a height of 60 cm under 5 different conditions. The conditions included a non-fatigued state and then 4 different fatigued conditions. The fatigue protocol used was a 20-second WAT, which was repeated 4 times, with drop landings recorded in between each of the tests and five minutes of active rest allotted between the WATs. The results of the study revealed that there were significant differences between all the fatigued conditions ($P<0.05$), except the first bout, when compared with the baseline measurements. However, no differences were found between GRF and gender. This study showed how fatigue significantly changes drop-landing kinetics. However, without kinematic data there is no way of describing how fatigue changes kinematic landing strategies. Future research should include kinematic data analysis. (Dominguese, Seegmiller, & Krause, 2012)

Chapter 3: Methods

Power Analysis

A previous study performed in the University of Idaho's Biomechanics Lab looked at a similar population and similar independent and dependent variables as this current study (Dominguese, Seegmiller, & Krause, 2012). Using the max vertical ground reaction force data, a power analysis on this study provided an effect size of 0.634. A statistical power of 0.956 was accomplished with a total sample size of 22 (Faul, Erdfelder, Lang, & Buchner, 2007). This calculation was based on the alpha error of probability set at .05, 1-β of .95, and with 2 groups and 4 measurements using a between factors, repeated measures ANOVA.

Participants

Considering the above power calculation, a total of 25 (12 males and 13 females) healthy, recreationally active adults were recruited for this study. However, 5 participants (2 male, 3 female) were excluded due to errors with data collection. A recreationally active adult was defined as a participant who regularly participated in physical activity and who had previous involvement in an organized sport or training program that included jumping activities such as basketball, volleyball, or track (Dominguese, Seegmiller, & Krause, 2012). However, no intercollegiate athletes were included in this study. Additionally, recommendations from ASCM on quantity and duration of aerobic activity was used to define a participant who is regularly physically active, i.e. 30 minutes of moderate intensity activity ~5 days a week. To be eligible to participate in this study participants were required to be between the age of 18 and 39 years old, free from any contraindications for maximal intensity exercise, have no history of back injury, and have no history of lower extremity musculoskeletal injury or surgery six months prior to the testing.

All participants signed an informed consent form that details the study requirements and potential risks. Additionally, participants were required to complete a Physical Activity Readiness Questionnaire (PAR-Q), medical history questionnaire, and a physical activity assessment questionnaire (Baecke, Burema, & Frijters, 1980). All forms are presented in Appendix A. All rules and guidelines laid out by the National Institutes of Health and the American College of Sports Medicine involving human research were followed throughout this study.

Participants were excluded from the study if they did not fall into the age range defined above, if they weren't recreationally active, if they had any history of back injury, or if they had lower extremity injury or surgery 6 months prior to data collection. All participants were screened by a Licensed Athletic Trainer (LAT) and were excluded if they had any lumbar spine or lower extremity pain or dysfunction.

Procedures

First & Second Session

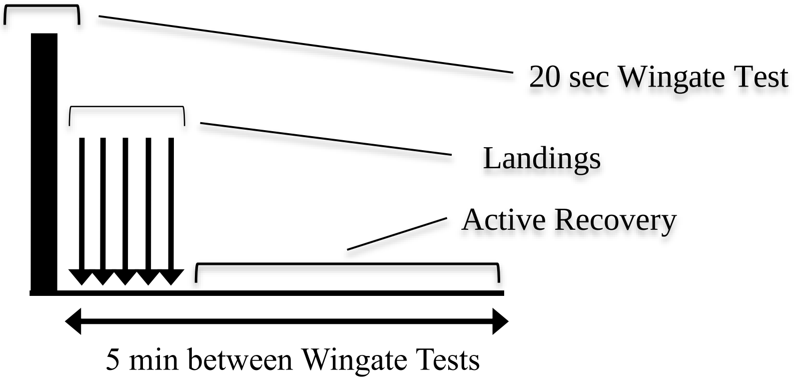
The study purpose and procedures were described to participants. Following this explanation, participants were then asked if they had any additional questions and then asked to sign their informed consent form. Next, participants filled out a PAR-Q, the Baecke physical activity questionnaire (Baecke, Burema, & Frijters, 1980), brief medical questionnaire, and receive a physical examination by a Certified Athletic Trainer to use the Functional Movement Screen for contraindications. On the second visit, participants were instructed on how to perform drop landings and were given an opportunity to practice and familiarize themselves with the testing procedures. The landing procedure started by having participants step atop a 60cm box and then place their toes at the edge from which they would step off. Before stepping off the box they were asked to extend their arms in front of their torso. Once participants stepped off the box they were allowed to move their arms freely. Once their arms were extended, participants were asked to extend their dominant leg before stepping off the 60cm box and landing. The dominant leg was determined by asking the participant which foot they would use to kick a ball. Participants were told to try and land as normal as possible, with one foot landing on each force platform. A successful landing was counted if participants stepped straight of the box without lowering ones self and landing one foot on both left and right force platforms without losing balancing and taking a second step or sitting backwards on to the box.

Participants were then given an opportunity to familiarize themselves with the Wingate test protocol and to practice cycling as maximally as possible for the 20-second duration of the test.

Finally, participants were given instructions regarding what items would be needed for the third visit such as a water bottle and spandex shorts/bra.

Third Session

Upon arrival to the lab, participants were prepped for data collection, which included taking anthropometric measurements and placing reflective markers, both of which were required for kinematic analysis. A static picture was then captured for kinematic analysis. Participants then performed 5 non-fatigued bilateral drop landings from a 60 cm box with each foot landing on a separate force platform. After pre-fatigued conditions were recorded, participants performed a 5-minute warm-up on the cycle ergometer alternating between 30 seconds exercise and 30 seconds of rest so their heart rate reached approximately 150bpm (Inbar, bar-Or, Skinner, 1996). Immediately following the warm-up, the fatigue protocol began. The fatigue protocol consisted of a 20 sec Wingate test immediately followed by 5 drop landings. Participants were given a total of 5 minutes of active rest between Wingate tests. The active rest activity included the 5 landings after the Wingate at the start of this time period, after which participants cycled lightly on the bike until the start of the next Wingate test. The time between participants finishing the Wingate test and the time till their first drop landing was recorded to ensure that the first landing was recorded within 30 seconds of completing the Wingate test. This 30 sec time frame was maintained to minimize the effect that muscle recovery might have on the landing data. The fatigue protocol was completed four times; please refer to Figure 1 for a pictorial representation of one bout of the protocol.



The Wingate tests included 20 seconds of stationary biking at maximal effort with the resistance set at 7.5% of subject’s body mass. Immediately following each 20 sec Wingate test, the subject’s heart rate was recorded using a polar heart rate monitor. Participants wore the heart rate monitor throughout the testing procedures. While the subject was exiting the bike, following the Wingate test, the participant reported a Borg Rating of Perceived

Figure 1. Pictorial Representation of One Bout of the Fatigue Protocol

Exertion (RPE) from a scale of 6 to 20 for the perceived exertion during the Wingate test. The 20-second Wingate test was chosen over the traditional 30-second test due the number of times that the participant was required to complete the fatigue protocol. This decision was also based on a study that concluded that the 20-second protocol induced fatigue similar to the traditional 30 second Wingate test (Laurent, Meyers, Robinson, & Green, 2007).

Participants performed both the fatigue and landing protocol barefoot in attempt to lessen the effect of shoes during landings. The fatigue protocol was performed barefoot in order to eliminate extra recovery time that would be available between the Wingate test and the first landing if the shoes had to be removed between the fatigue and landings. Additionally, participants wore tight fitting athletic clothes to decrease the chance of interference with reflective markers.

Data Collection

Anthropometric Data

Height and weight were recorded using a Health-O-Meter (Continental Scale Corp, Chicago, IL) scale. The anthropometric data needed for the kinematic analysis was collected using a tape measure and an Anthropometer (Model 01291, Lafayette Instrument Company, Lafayette, Indiana).

Kinematic Data

The drop landings were analyzed using an eight-camera Vicon MX motion analysis system (Vicon, Oxford Metrics Ltd., UK) sampling at a frequency of 250 Hz. The system uses infrared sensitive solid-state cameras for locating and tracking reflective markers through space. The 35 markers used were 13 mm spheres covered with retro-reflective tape that were affixed with double-sided tape to specific landmarks bilaterally across the lower and upper extremity. Markers were placed in a modified Helen Hays configuration as described by Kadaba et al. (1990). The lower extremity marker configuration included markers on the left and right anterior and superior iliac spines, lateral mid-thigh, lateral femoral epicondyle, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus. The upper body marker configuration included markers on the left and right temple and back of head, C7, T10, Jugular notch, xiphoid process, right back, left and right acromio-clavicular joint, upper arm, lateral epicondyle of the elbow, forearm, medial and lateral wrist, and the 2nd metacarpal head. Height, weight, leg length, and widths of ankles and knees were measured for appropriate anthropometric scaling. Marker trajectory data was filtered using a Woltring filtering routine with a predicted mean square error value of 4 mm^2.

Kinetic Data

The three orthogonal components of the GRF data were captured at 1000 Hz from the AMTI (OR6-6) force plates in synchrony with the motion capture data. Force plate data were low-pass filtered at 30 Hz using a second-order Butterworth filter before being down sampled and combined with the motion capture data. Max vertical ground reaction force data were analyzed using data from each participant’s dominant kicking leg.

Fatigue Data

The Wingate Anaerobic Tests were performed using a Monark Ergometer (Ergomedic 874 E, Monark Exercise, Sweden). A magnetic switch was configured to digitally record the time per wheel revolutions during the Wingate tests. Through the use of the digital recording device, more accuracy was given to calculate the participant’s wingate scores.

Regression equations were applied to all wingate data to predict the last 10 seconds of our 20-second wingate. The regression equations allowed for the computation of the power outputs and fatigue index to be able to compare against other similar demographic 30 second wingate results. Two separate equations were used, one for the males, and one for the females (Laurent, Meyers, Robinson, & Green, 2007; Stickley, Hetzler, & Kimura, 2008). After applying appropriate regression equations for males and females, the max, min, and mean power outputs and percent power drop were calculated with the following equations. Each equation worked with a different definition of peak power. For the males, the peak power definition was defined as the power output over the first 5 seconds of the test. For the females, the peak power definition was defined as the highest power output over a 5 second interval, which was not always be the first 5 second interval. This study maintained these separate definitions of peak power for both genders.

Power output per wheel revolution was calculated as follows:

$$P = Fr\omega$$

$$\omega = 2\pi/t,$$

Where P = mechanical power output (W), F = the weight applied to the flywheel (N), r = flywheel radius and t = time per revolution (s). For the males, peak power output was calculated with only first 5 seconds of the test and for the woman peak power was calculated as the highest power output over a 5 second interval. Mean power output was calculated with the mean power output averaged across 30 seconds of data. Minimum Power output was predicted through the regression equations and the power output was over a 10 second interval. Percent power drop for each Wingate was calculated by the following equation:

Power Drop (%) = [Highest P (W) – Lowest P (W) / Highest P (W)] * 100,

Where P = mechanical power output (W).

For comparison across groups all wingate scores were divided by the participant's body weight to determine relative scores.

Statistical Analysis

All statistical analyses were performed using SPSS version 22 (SPSS, Inc, Chicago, IL). The independent variables analyzed were gender and the fatigued conditions. The fatigued conditions included: pre-fatigue, fatigue #1, #2, #3, and #4. The dependent variables included kinetic variables (i.e. MxGRF and knee joint moments), kinematic variables (i.e. hip, knee, ankle joint flexion/extension and knee varus/valgus). Descriptive statistics were computed for all variables including participant anthropometrics and dependent variables. All data were plotted prior to data analysis to ensure normality of the population. Data were analyzed using a mixed factorial repeated measures analysis of variance (ANOVA) with alpha set to 0.05. A Tukey *Post hoc* test was utilized to find pairwise comparisons while maintaining the experiment-wise error rate at the pre-established alpha level when the group sizes are equal.

The independent variables for this study included condition (Non-Fatigue, Fatigue 1, Fatigue 2, Fatigue 3, & Fatigue 4) and gender. The dependent variables included: time to peak vertical ground reaction force (TTPGRF), max vertical ground reaction force (MxVGRF), sagittal ankle angle, sagittal knee angle, sagittal hip angle, valgus knee angle, sagittal knee joint moment, frontal knee joint moment, and transverse knee joint moment. In each analysis only one dependent variable was included. Additionally, only participants who had no missing values were used, consequently altering the number of participants used for each statistical analysis.

The results of this study are limited in scope due to experiencing a lack of essential data points during the data cleaning process. Reasons behind the incomplete data set surround the issue of maintaining view of anatomical markers used during data collection to record correct joint positioning and angles. Future research should work to develop inverse dynamic modeling computer programs designed specifically for landing research, as the computer modeling program used for this study was designed for gait analysis and is suspected to be the cause for incomplete data. Additionally, it was discovered, post data collection, that one of the 8 motion capture cameras was defective and it is unclear whether the camera was defective during the data collection of this study and also attributed to a lack of complete data.

Chapter 4: Results

The purpose of this study was to examine biomechanical variables during drop landings as risk factors for ACL injury, following repeated bouts of exercise that may cause fatigue using a 20-second Wingate anaerobic test. Additionally, both male and female recreational athletes were used in this study to examine potential differences in biomechanical variables between genders. Our kinetic analysis included max vertical ground reaction forces, knee joint moments in all three planes, and time to peak ground reaction forces. The kinematic analysis included sagittal angles of the hip, knee, and ankle, and frontal plane knee angles.

The participants used for this study consisted of nine males (26.5 ± 3.09 years) and eleven female (24.2 ± 4.69 years) recreationally active athletes who were free from any contraindications for maximal intensity exercise, history of back injury, and lower extremity musculoskeletal injury or surgery six months prior to the testing. In the Table 1, a summary of the participant anthropometrics is shown.

Table 1. Means (M) and Standard Deviations (SD) of Age (years), Height (m), and Weight (kg) of All Participants

	Male^a		Female^b		Overall^c	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	26.6	3.17	24.7	4.92	25.6	4.22
Height	1.78	0.04	1.65	0.03	1.71	0.07
Weight	78.3	7.41	60.9	5.51	68.7	10.9

Note: ^{a} n =9, ^{b} n = 11, ^{c} N = 20.

Fatigue

Descriptive data were collected on all the Wingate anaerobic tests to monitor the level of fatigue the participants acquired throughout the different fatigue protocols. In Table 2, a summary of means and standard deviations for each Wingate test is provided. No significant main effects were found across: Relative Peak Power ($F(2, 232) = 0.262$, $p = 0.786$), Relative Mean Power ($F(0.4, 141) = .046$, $p = 0.958$), or Relative Minimum Power ($F(3, 54) = .091$, $p = .965$). However, a significant main effect was found for Power Drop ($F(3, 54) = 3.58$, $p = 0.020$). A Tukey post hoc analysis revealed that the Power Drop for both WAT 1 ($M = 40.8$) and WAT 2 ($M = 43.6$) were statistically different from WAT 4 ($M = 53.2$). An increase in power drop across WAT shows an increase in fatigue. The between-subject effects for gender was also statistically significant ($F(1, 18) = 9.72$, $p = 0.006$).

Table 2. Means (M) and Standard Deviations (SD) of Relative Peak Power (PP), Relative Mean Power (MP), Relative Minimum Power (Min P), and Power Drop for each Wingate Anaerobic Test (WAT) Performed

		Male[a]		Female[b]		Overall[c]	
Variable	Wingate	*M*	*SD*	*M*	*SD*	*M*	*SD*
Relative PP (W/kg)	1	6.18	3.64	5.54	2.98	5.83	3.22
	2	7.94	1.40	4.41	3.66	6.00	3.33
	3	6.77	2.89	5.86	3.04	6.27	2.93
	4	6.87	1.15	5.94	3.03	6.36	2.37
Relative MP (W/kg)	1	4.17	2.54	4.50	2.50	4.35	2.46
	2	5.62	1.41	3.40	2.87	4.40	2.54
	3	4.81	2.18	4.17	2.27	4.46	2.20
	4	4.60	1.14	4.27	2.22	4.42	1.78
Relative Min P (W/kg)	1	2.11	1.45	3.35	1.98	2.79	1.83
	2	2.94	1.17	2.54	2.29	2.72	1.84
	3	2.46	1.43	2.97	1.91	2.74	1.69
	4	2.08	0.99	3.07	1.80	2.62	1.54
Power Drop (%)	1	51.7	30.5	31.9	19.3	**40.8**	26.3
	2	64.0	9.3	27.0	24.1	**43.6**	26.4
	3	57.2	23.7	40.4	24.1	48.0	24.8
	4	70.3	11.7	39.3	22.6	**53.2**	24.0

Note. *a* = 9, *b* = 11, *c* = 20.
Bold Emphasis $p \leq .005$ in comparison to Wingate 4.

Additionally, all the reported Rate of Perceived Exertion (RPE) data were collected after each WAT and the means and standard deviations are shown in Table 3. RPE was significantly different across WATs ($F(1, 40) = 26.1$, $p = 0.000$). Mauchy's sphericity assumption did not hold and the Greenhouse-Geisser test reported, $\varepsilon = 0.683$.

Table 3. Means (M) and Standard Deviations (SD) of the Reported Rate of Perceived Exertion (RPE) for each Wingate Anaerobic Test (WAT) Performed

	Male[a]		Female[b]		Total[c]	
WAT	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	16.7	2.11	16.0	1.49	16.4*	1.86
2	17.5	1.51	17.0	1.41	17.3*	1.45
3	17.8	1.97	17.4	0.70	17.6*	1.54
4	18.8	1.35	18.4	0.97	18.6*	1.19

Note. [a] $n = 13$. [b] $n = 10$. [c] $N = 23$.
* $p < 0.001$ across condition

Time to Peak Ground Reaction Force

The complete ANOVA table for time to peak ground reaction force (TTPGRF) can be found in Appendix A and means and standard deviations are reported in Table 4. No significant main effects were observed across trial (F(3,201) = 1.05, $p = 0.373$) or condition (F(4, 65) = 0.992, $p = 0.418$). However, a between-subject effect was found across gender (F(1, 65) = 7.69, $p = 0.007$) for TTPGRF, $p > 0.05$. Mauchy's test was conducted to test the assumption of sphericity ($p > 0.05$). Sphericity assumption did not hold and the Greenhouse-Geisser correction was reported, $\varepsilon = 0.774$.

Table 4. Means (M) and Standard Deviations (SD) of Time (ms) to Peak Ground Reaction Forces for All Participants

		Male			Female			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	7	1.07	0.29	10	1.77	2.33	17	1.48	1.80
	2	7	1.27	0.44	10	0.93	0.36	17	1.07	0.42
	3	7	1.10	0.13	10	0.99	0.32	17	1.04	0.26
	4	7	1.09	0.20	10	1.01	0.17	17	1.04	0.18
	5	7	1.29	0.47	10	1.06	0.16	17	1.15	0.33
Condition 1	1	6	2.17	2.30	6	1.33	0.28	12	1.75	1.62
	2	6	1.22	0.25	6	1.15	0.30	12	1.18	0.27
	3	6	2.03	2.09	6	1.12	0.30	12	1.58	1.50
	4	6	2.12	2.10	6	1.13	0.15	12	1.63	1.51
	5	6	0.77	0.49	6	1.10	0.30	12	0.93	0.43
Condition 2	1	7	1.24	0.29	10	1.03	0.18	17	1.12	0.25
	2	7	1.20	0.36	10	1.05	0.25	17	1.11	0.30
	3	7	1.17	0.36	10	1.06	0.25	17	1.11	0.29
	4	7	1.06	0.27	10	1.03	0.28	17	1.04	0.27
	5	7	1.17	0.34	10	0.98	0.21	17	1.06	0.28
Condition 3	1	6	1.15	0.19	9	1.00	0.18	15	1.06	0.19
	2	6	1.32	0.39	9	0.98	0.11	15	1.11	0.30
	3	6	2.15	2.83	9	1.00	0.17	15	1.46	1.79
	4	6	1.28	0.41	9	0.98	0.12	15	1.10	0.30
	5	6	2.43	2.61	9	0.86	0.36	15	1.49	1.77
Condition 4	1	6	2.10	2.17	8	1.50	1.42	14	1.76	1.73
	2	6	1.43	0.42	8	1.08	0.21	14	1.23	0.36
	3	6	1.40	0.30	8	1.01	0.22	14	1.18	0.31
	4	6	2.13	2.07	8	1.06	0.27	14	1.52	1.41
	5	6	2.27	2.39	8	0.94	0.23	14	1.51	1.64

Note. $p > 0.05$ for all comparisons.

Max Vertical Ground Reaction Force.

The complete ANOVA table for max vertical ground reaction force (MxVGRF) is presented in Appendix A and the means and standard deviations are presented in Table 5. No significant main effect was observed between trial (F(4, 360) = 2.18, $p = 0.071$), or by condition (F(4, 90) = 1.39 , $p = 0.243$). However, a significant between-subject was observed between genders (F(1, 90) = 29.6, $p = 0.000$). A Mauchy's test was conducted to test the assumption of sphericity ($p > 0.05$) and the assumption was met.

Table 5. Means (M) and Standard Deviations (SD) Max Vertical Ground Reaction Forces (in Body Weights) for All Participants

		Male[a*]		Female[b*]		Total[c]	
Condition	Trial	M	SD	M	SD	M	SD
Baseline	1	3.09	2.36	3.55	1.65	3.37	1.92
	2	2.27	0.81	3.30	1.39	2.89	1.28
	3	3.06	0.72	3.52	1.24	3.33	1.06
	4	2.60	1.44	3.76	1.23	3.29	1.41
	5	2.58	0.97	3.45	1.79	3.10	1.55
Condition 1	1	1.60	0.30	1.73	1.23	1.68	0.96
	2	1.74	1.04	3.07	2.12	2.54	1.86
	3	1.97	1.07	3.01	2.12	2.60	1.81
	4	2.51	1.12	3.49	1.30	3.10	1.30
	5	1.57	1.30	3.43	1.84	2.68	1.86
Condition 2	1	2.15	0.55	3.00	1.48	2.66	1.25
	2	2.13	1.19	3.79	1.80	3.13	1.76
	3	2.70	1.07	3.72	0.95	3.31	1.10
	4	2.80	1.00	3.39	1.52	3.16	1.34
	5	2.16	0.59	3.72	0.95	3.09	1.13
Condition 3	1	1.94	0.41	3.49	1.10	2.87	1.17
	2	2.42	0.93	4.03	1.09	3.38	1.29
	3	3.02	1.18	3.63	0.93	3.38	1.05
	4	2.17	1.65	3.55	1.56	3.00	1.70
	5	2.14	1.44	3.22	1.95	2.79	1.80
Condition 4	1	2.08	0.88	3.44	0.98	2.89	1.14
	2	2.12	1.26	3.87	1.58	3.17	1.67
	3	2.21	0.69	3.57	1.78	3.03	1.57
	4	2.29	1.34	2.71	1.87	2.54	1.66
	5	2.05	1.04	3.65	1.52	3.01	1.54

Note. [a] $n = 8$. [b] $n = 12$. [c] $n = 20$.
* $p < 0.05$ for group totals.

Knee Joint Moments

Means and standard deviations for knee joint moment for all 3 planes (sagittal, frontal, transverse) are presented in Tables 6, 7, 8, and additional statistics are provided in Appendix B. The results of the repeated measures ANOVA found no significant main effects for the joint moments in all three planes. For knee joint moments in the Flexion/Extension main effects were: trial (F(4, 216) = 0.275, *p* =0.894), condition (F(4, 54) = 0.511, *p* = 0.728), and gender (F(1, 54) = 0.939 , *p* = 0.337). For knee joint moments in Varus/Valgus main effects were: trial (F(4, 216) = 1.93, *p* = 0.107), condition (F(4, 54) = 0.406 , *p* = 0.804), and gender (F(1, 54) = 1.80 , *p* = 0.185). And knee joint moments in Internal/External rotation were: trial (F(4, 216) = 1.63 , *p* = 0.168), condition (F(4, 54) = 0.360 , *p* = 0.836), and gender (F(1, 54) = 0.712 , *p* = 0.403). In all joint moment statistics the spherical assumption was met.

Table 6. Means (M) and Standard Deviations (SD) Knee Joint Moments (Nmm/kg) in Flexion/Extension for Participants

		Male			Female			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	6	2367	2025	8	2278	1499	14	2316	1670
	2	6	1492	1370	8	2262	1335	14	1932	1356
	3	6	1523	1343	8	2672	970	14	2180	1245
	4	6	1912	1322	8	1806	785	14	1852	1004
	5	6	2164	909	8	2313	1183	14	2249	1038
Condition 1	1	4	1470	1315	6	1797	781	10	1666	971
	2	4	1569	935	6	2314	971	10	2016	981
	3	4	1787	1013	6	1462	1075	10	1592	1006
	4	4	1201	1676	6	2833	1225	10	2180	1575
	5	4	1482	1769	6	2395	1010	10	2030	1353
Condition 2	1	6	1287	1062	9	1652	1275	15	1506	1169
	2	6	1258	1328	9	1984	1138	15	1693	1227
	3	6	1789	1005	9	1652	1112	15	1707	1035
	4	6	1655	1585	9	1605	1066	15	1625	1244
	5	6	1466	898	9	1783	1357	15	1656	1169
Condition 3	1	5	1604	416	8	1486	1272	13	1531	1002
	2	5	1622	618	8	2125	815	13	1931	762
	3	5	2012	891	8	2258	1204	13	2163	1061
	4	5	2183	769	8	1270	1020	13	1621	1009
	5	5	2036	440	8	1594	1383	13	1764	1109
Condition 4	1	6	1741	437	6	1831	1044	12	1786	764
	2	6	1550	447	6	1773	1117	12	1662	819
	3	6	1551	502	6	2060	1269	12	1806	958
	4	6	1890	629	6	1370	1502	12	1630	1131
	5	6	1675	387	6	1436	1269	12	1556	903

Note. $p > 0.05$ for all comparisons.

Table 7. Means (M) and Standard Deviations (SD) Knee Joint Moments (Nmm/kg) in Internal/External Rotation for All Participants

		Male			Female			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	6	211	588	8	67.9	538	14	129	543
	2	6	312	597	8	-24.8	425	14	120	514
	3	6	391	483	8	-252	587	14	23.4	620
	4	6	142	672	8	-136	663	14	-17.1	656
	5	6	106	609	8	-117	638	14	-21.3	613
Condition 1	1	4	490	1063	6	233	506	10	336	733
	2	4	264	438	6	359	674	10	321	564
	3	4	541	879	6	78.0	460	10	263	657
	4	4	-311	791	6	113	646	10	-57.0	699
	5	4	-113	559	6	374	594	10	179	603
Condition 2	1	6	114	588	9	-167	509	15	-54.7	540
	2	6	29.8	865	9	76.5	579	15	57.8	678
	3	6	25.8	552	9	10.6	357	15	16.7	426
	4	6	-122	646	9	-73.4	560	15	-92.7	573
	5	6	294	449	9	-337	492	15	-84.7	559
Condition 3	1	5	120	449	8	13.4	466	13	54.6	443
	2	5	285	438	8	110	825	13	177	684
	3	5	37.7	286	8	116	928	13	85.9	729
	4	5	109	490	8	49.8	607	13	72.5	544
	5	5	362	666	8	80.5	922	13	189	815
Condition 4	1	6	277	759	6	-216	384	12	30.7	629
	2	6	41.4	406	6	-91.2	369	12	-24.9	376
	3	6	30.5	287	6	-247	619	12	-108	482
	4	6	121	491	6	-204	824	12	-41.3	669
	5	6	248	1176	6	-329	229	12	-40.3	862

Note. $p > 0.05$ for all comparisons

Table 8. Means (M) and Standard Deviations (SD) Knee Joint Moments (Nmm/kg) in Varus/Valgus for Participants

Condition	Trial	Male			Female			Total		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	6	164	127	8	59.5	75.1	14	104	110
	2	6	219	257	8	72.8	65.1	14	135	182
	3	6	138	135	8	76.3	102	14	103	117
	4	6	150	146	8	75.2	77.3	14	107	113
	5	6	52.2	127	8	70.6	65.8	14	62.7	93.1
Condition 1	1	4	74.2	295	6	96.1	43.6	10	87.4	174
	2	4	108	116	6	124	59.5	10	117	80.9
	3	4	149	147	6	98.6	51.2	10	119	96.6
	4	4	125	86.1	6	87.6	42.6	10	102	62.0
	5	4	85.1	104	6	87.5	72.9	10	86.5	80.8
Condition 2	1	6	93.5	169	9	32.7	68.6	15	57.0	118
	2	6	79.3	164	9	79.9	51.9	15	79.6	106
	3	6	88.5	115	9	52.5	66.2	15	66.9	87.1
	4	6	91.1	137	9	112	103	15	104	114
	5	6	129	164	9	65.7	78.2	15	91.2	119
Condition 3	1	5	26.5	105	8	56.9	79.4	13	45.2	87.0
	2	5	109	112	8	86.7	40.4	13	95.2	72.7
	3	5	107	169	8	95.2	84.2	13	100.0	117
	4	5	109	191	8	97.9	94.9	13	102	132
	5	5	125	167	8	83.4	59.7	13	99.4	109
Condition 4	1	6	10.6	169	6	76.7	63.0	12	43.7	126
	2	6	50.1	103	6	37.4	113	12	43.8	103
	3	6	23.8	114	6	108	69.8	12	66.1	100
	4	6	95.1	183	6	80.2	60.0	12	87.6	130
	5	6	108	222	6	88.6	48.4	12	98.5	153

Note. $p > 0.05$ for all comparisons.

Sagittal Ankle Angle

The statistics for sagittal ankle angle are presented in Appendix A and the means and standard deviations are reported below in Table 9. The results of the repeated measures ANOVA found no significant main effects for trial (F(3, 214) = 0.894, $p = 0.454$), or condition (F(4, 64) = 0.472, $p = 0.756$). However, a between-subject effect was found for gender (F(1, 64 = 20.1, $p = 0.000$). Mauchy's sphericity test ($p \leq 0.05$) did not hold and the Greenhouse-Geisser statistic was reported, $\varepsilon = 0.836$.

Table 9. Means (M) and Standard Deviations (SD) Sagittal Ankle Angles (degrees) for All Participants

		Male*			Female*			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	6	11.5	6.15	10	8.52	3.82	16	9.65	4.86
	2	6	17.1	7.38	10	10.7	5.90	16	13.1	7.02
	3	6	13.0	4.22	10	9.35	6.92	16	10.7	6.17
	4	6	13.6	6.07	10	8.99	2.71	16	10.7	4.70
	5	6	17.3	6.45	10	9.87	3.50	16	12.6	5.90
Condition 1	1	6	18.0	11.5	6	10.9	5.65	12	14.4	9.41
	2	6	13.2	6.03	6	10.5	7.20	12	11.8	6.49
	3	6	17.5	7.33	6	10.9	6.63	12	14.2	7.49
	4	6	17.6	11.4	6	11.5	3.57	12	14.6	8.70
	5	6	8.00	17.8	6	10.0	5.13	12	9.01	12.5
Condition 2	1	7	12.9	1.90	10	7.59	4.18	17	9.77	4.29
	2	7	13.0	4.84	10	9.80	5.66	17	11.1	5.43
	3	7	13.3	5.90	10	9.65	3.82	17	11.1	4.96
	4	7	10.8	5.66	10	9.13	4.52	17	9.83	4.92
	5	7	13.8	4.36	10	8.49	3.47	17	10.7	4.60
Condition 3	1	6	10.1	4.70	8	8.68	4.14	14	9.30	4.27
	2	6	13.3	4.82	8	9.04	2.14	14	10.9	4.02
	3	6	16.0	12.9	8	9.95	4.08	14	12.5	9.08
	4	6	15.2	6.82	8	9.11	2.50	14	11.7	5.57
	5	6	18.1	8.67	8	7.49	4.05	14	12.0	8.20
Condition 4	1	6	13.6	8.65	9	10.5	3.25	15	11.8	5.94
	2	6	14.0	4.88	9	12.1	5.56	15	12.8	5.21
	3	6	15.6	4.95	9	10.6	4.01	15	12.6	4.92
	4	6	16.5	10.3	9	11.6	5.38	15	13.5	7.80
	5	6	17.0	11.1	9	5.63	11.3	15	10.2	12.2

Note. * $p \leq 0.001$ for groups.

Sagittal Hip Angle

The complete ANOVA table for sagittal hip angle is presented in Appendix B and the means and standard deviations are presented in Table 10. The results of the repeated measures ANOVA found no significant main effects for trial (F(3, 212) = 0.917, *p* = 0.439), condition (F(4,1) = 0.179, *p* = 0.948), or by gender (F(1, 4) = 0.146, *p* = 0.703) for the sagittal hip angle, $p \leq 0.05$. A Mauchy’s test was conducted to test the assumption of sphericity ($p>0.05$). Sphericity assumption did not hold and the Greenhouse-Geisser test reported, $\varepsilon=0.077$.

Table 10. Means (M) and Standard Deviations (SD) Sagittal Hip Angles (degrees) for All Participants

		Male			Female			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	7	34.3	12.5	10	36.4	14.8	17	35.5	13.5
	2	7	37.8	10.7	10	43.6	18.3	17	41.2	15.5
	3	7	36.7	14.4	10	45.3	22.0	17	41.8	19.3
	4	7	38.6	11.1	10	40.8	17.5	17	39.9	14.8
	5	7	38.5	13.2	10	39.4	16.4	17	39.0	14.8
Condition 1	1	6	45.3	15.3	6	38.3	16.6	12	41.8	15.7
	2	6	43.3	13.6	6	42.7	9.69	12	43.0	11.3
	3	6	42.6	12.4	6	39.7	8.98	12	41.2	10.4
	4	6	48.6	12.7	6	37.9	12.9	12	43.3	13.4
	5	6	43.0	10.1	6	40.5	11.7	12	41.7	10.5
Condition 2	1	7	37.5	11.0	10	47.5	14.0	17	43.4	13.5
	2	7	36.6	15.5	10	43.8	11.1	17	40.8	13.1
	3	7	37.8	12.1	10	45.6	11.8	17	42.4	12.2
	4	7	37.8	13.7	10	43.9	11.1	17	41.4	12.2
	5	7	38.9	10.9	10	43.9	14.7	17	41.8	13.1
Condition 3	1	6	36.3	11.5	9	45.4	9.99	15	41.8	11.2
	2	6	40.1	13.5	9	42.1	9.92	15	41.3	11.0
	3	6	47.2	35.1	9	42.0	12.4	15	44.0	23.1
	4	6	40.2	16.2	9	44.2	9.70	15	42.6	12.3
	5	6	43.3	13.8	9	41.5	9.22	15	42.2	10.8
Condition 4	1	6	39.3	13.7	9	41.5	10.3	15	40.6	11.4
	2	6	43.0	15.2	9	38.9	10.3	15	40.6	12.1
	3	6	40.3	12.2	9	44.9	13.4	15	43.1	12.7
	4	6	50.5	35.4	9	40.8	11.7	15	44.6	23.5
	5	6	44.7	20.2	9	40.0	10.7	15	41.9	14.7

Note. $p > 0.05$ for all comparisons.

Sagittal Knee Angle

The statistics for sagittal knee angle are presented in Appendix A and means and standard deviations are presented in Table 11. The results of the repeated measures ANOVA found no significant main effects for trial (F(3, 192) =139, $p = 0.782$), or by condition (F(4,

66) = 0.780, $p = 0.542$). However, a significant gender effect was noted (F(1, 4) = 8.37, $p = 0.005$) for the sagittal knee angle, $p \leq 0.05$. A Mauchy's test was conducted to test the assumption of sphericity ($p > 0.05$) and the assumption did not hold. The Greenhouse-Geiser statistic is reported, $\varepsilon = 0.728$.

Table 11. Means (M) and Standard Deviations (SD) Sagittal Knee Angles (degrees) for Participants

		Male			Female			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	7	46.8	11.0	10	40.8	14.5	17	43.2	13.1
	2	7	37.8	46.0	10	49.5	11.2	17	44.7	30.0
	3	7	48.1	10.1	10	51.4	13.9	17	50.0	12.2
	4	7	51.3	7.84	10	46.1	5.70	17	48.3	6.94
	5	7	57.1	16.3	10	46.8	7.32	17	51.0	12.5
Condition 1	1	6	64.1	31.9	6	50.6	10.6	12	57.4	23.7
	2	6	51.8	13.7	6	48.0	7.84	12	49.9	10.8
	3	6	60.0	30.8	6	46.4	8.09	12	53.2	22.6
	4	6	58.2	14.6	6	47.1	6.31	12	52.7	12.2
	5	6	46.2	12.6	6	45.2	7.17	12	45.7	9.77
Condition 2	1	7	48.4	10.2	10	46.2	6.81	17	47.1	8.12
	2	7	47.1	12.9	10	47.5	6.39	17	47.4	9.25
	3	7	46.3	13.8	10	46.7	4.17	17	46.5	9.03
	4	7	45.0	8.53	10	45.9	6.11	17	45.5	6.96
	5	7	47.8	11.8	10	44.6	6.14	17	45.9	8.71
Condition 3	1	6	48.0	10.3	9	44.9	4.53	15	46.1	7.20
	2	6	49.9	12.7	9	43.7	4.23	15	46.2	8.80
	3	6	60.9	41.1	9	44.6	5.53	15	51.1	26.2
	4	6	53.4	8.90	9	44.2	4.30	15	47.9	7.80
	5	6	61.9	27.9	9	40.9	8.54	15	49.3	20.8
Condition 4	1	6	60.0	25.3	9	44.2	5.46	15	50.5	17.6
	2	6	56.2	12.9	9	45.2	7.15	15	49.6	11.0
	3	6	54.0	7.96	9	48.4	15.1	15	50.6	12.7
	4	6	68.9	39.0	9	44.0	9.32	15	53.9	27.4
	5	6	65.6	28.4	9	39.3	9.65	15	49.9	22.8

Note. $p > 0.05$ for all comparisons.

Frontal Knee Angle

The statistics for sagittal hip angle are presented in Appendix B and the means and standard deviations are presented in Table 12. The frontal knee angle of the repeated measures ANOVA found no significant main effects for trial (F(3,204) = 1.82, *p* = 0.140), condition (F(4,63) = 0.147, *p* = 0.964). However, a significant main effect was identified for gender (F(1, 63) = 4.80, *p* = 0.032). Mauchy's test showed that the sphericity assumption did not hold and the Greenhouse-Geisser test reported, ε=0.808.

Table 12. Means (M) and Standard Deviations (SD) Frontal Knee Angles (degrees) for Participants

		Male*			Female*			Total		
Condition	Trial	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Baseline	1	6	18.2	20.3	9	6.32	12.4	15	11.1	16.4
	2	6	20.4	19.1	9	8.91	9.30	15	13.5	14.6
	3	6	21.4	20.1	9	8.37	9.36	15	13.6	15.4
	4	6	19.9	20.8	9	8.88	10.8	15	13.3	15.9
	5	6	21.6	18.1	9	8.51	10.4	15	13.7	14.9
Condition 1	1	6	16.5	21.9	6	8.88	6.45	12	12.7	15.9
	2	6	15.8	24.3	6	8.85	6.55	12	12.3	17.3
	3	6	18.9	21.5	6	6.90	9.87	12	12.9	17.1
	4	6	18.7	23.5	6	11.7	6.30	12	15.2	16.8
	5	6	15.2	27.1	6	8.47	6.83	12	11.8	19.2
Condition 2	1	7	15.8	20.3	9	7.11	8.10	16	10.9	14.8
	2	7	18.6	19.0	9	6.63	8.86	16	11.9	15.0
	3	7	17.3	21.0	9	8.42	8.91	16	12.3	15.5
	4	7	15.4	19.3	9	7.64	8.94	16	11.0	14.4
	5	7	16.8	21.7	9	8.18	9.01	16	12.0	15.8
Condition 3	1	6	14.5	19.8	9	11.9	9.11	15	12.9	13.8
	2	6	16.9	20.5	9	10.6	10.1	15	13.1	14.8
	3	6	17.8	21.7	9	10.8	10.2	15	13.6	15.5
	4	6	15.2	14.5	9	10.4	9.72	15	12.3	11.6
	5	6	17.6	20.3	9	10.2	9.65	15	13.2	14.7
Condition 4	1	6	9.00	8.67	9	9.62	7.76	15	9.37	7.83
	2	6	11.0	8.92	9	9.88	6.95	15	10.3	7.51
	3	6	8.68	8.65	9	10.8	6.73	15	9.95	7.33
	4	6	13.3	15.9	9	11.3	7.04	15	12.1	11.0
	5	6	14.5	16.9	9	7.98	5.41	15	10.6	11.4

Note. * $p < 0.05$ for group totals.

Chapter 5: Discussion & Conclusion

The purpose of this study was to examine kinetic and kinematic variables during drop landings as risk factors for ACL injury, following repeated bouts of fatigue using a Wingate Anaerobic Test. ACL injury can be decreased by developing better intervention protocols through a better understanding of the role fatigue plays in ACL injury alongside the other risk factors associated with ACL injury risk: neuromuscular, biomechanical, anatomical, structural, and hormonal factors.

Did the Fatigue Protocol Work?

Before talking about the primary research questions of this study, all of which are based on the how fatigue affects various kinetic and kinematic variables surrounding landing mechanics, we want to address how well our fatigue protocol worked in achieving a fatigue state in participants. Enoka and Stuart’s (1992) definition of fatigue states, “an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (p.465). Our study addressed both of these components through the use of Borg’s rate of perceived exertion scale and through calculating relative peak power, relative mean power, relative minimum power, and percent power drop for all fatigue protocols conducted. We found statistically significant increases in fatigue across condition, according to our rate of perceived exertion data, see Figure 2. We also found statistical increases in percent power drop across condition, see Figure 5. However, no significant increases were found across wingate anaerobic tests for relative peak power, relative mean power, or relative minimum power, see Figures 3, 4, and 5.

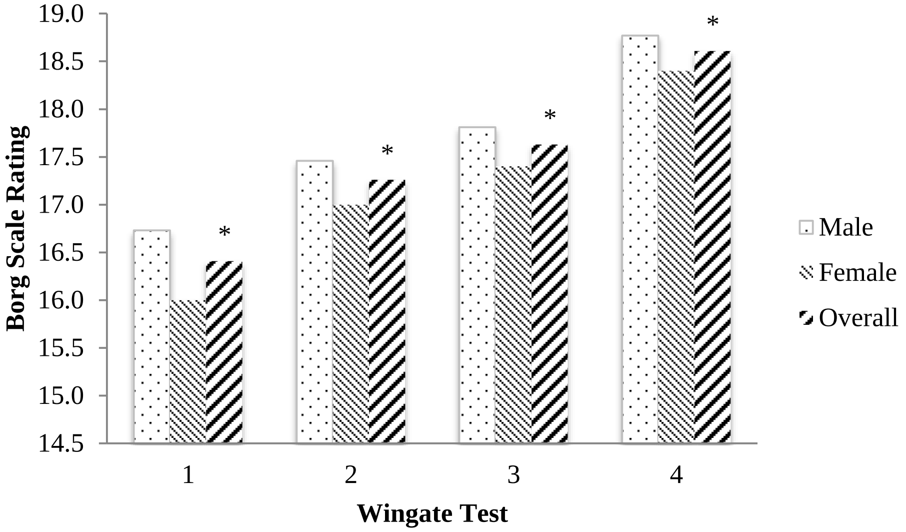


Figure 2. Plotted Values of Borg's Rating of Perceived Exertion across Fatigue

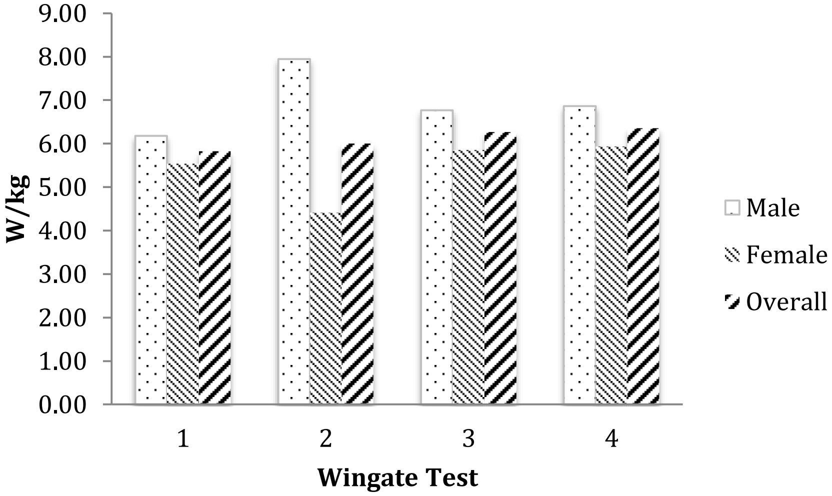


Figure 3. Plotted Values of Relative Peak Power across Fatigue Protocols

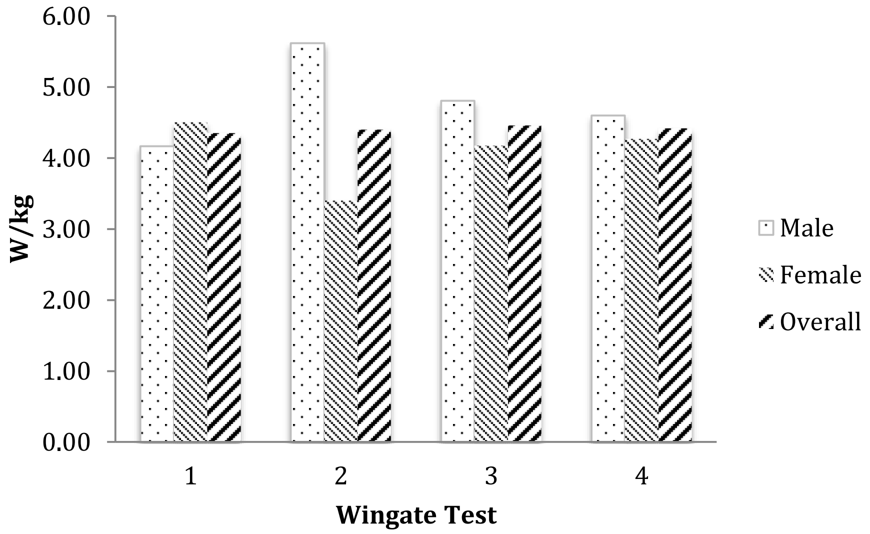


Figure 4. Plotted Values of Relative Mean Power across Fatigue Protocols

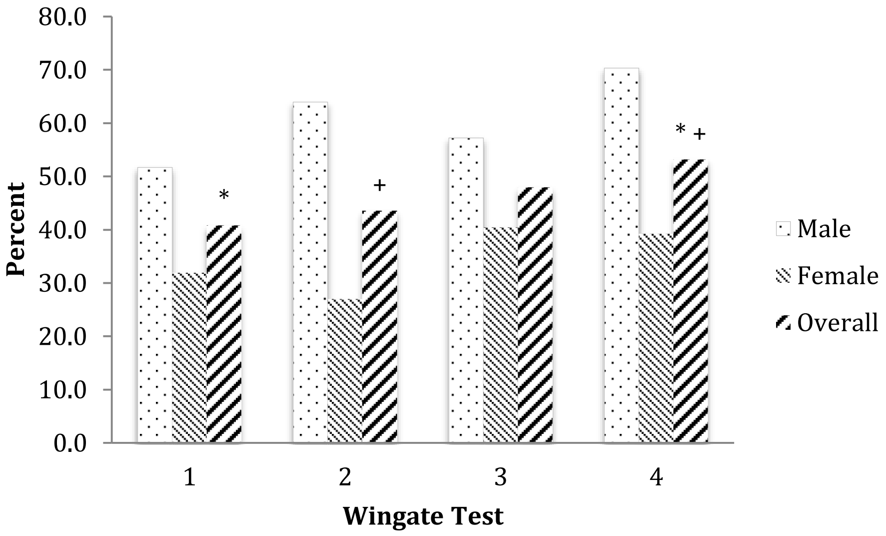


Figure 5. Plotted Values of Percent Power Drop across Fatigue Protocols

The results of the relative peak power and relative mean power did not match our hypothesis of expecting to see a decrease in peak power and mean power. However, we did find a statistical significance in the percent power drop values. We found a statistical significant increase between the first wingate and the fourth wingate; we also found a statistical significant increase between the second wingate and the fourth wingate. These findings matched our hypothesis of anticipating an increase in percent power drop across the wingate tests. The third wingate and the fourth wingate were not statistically significant, however, there continued to maintain an increasing trend. Our statistical significance in percent power drop combined with significant increases in the rate of perceived exertion lead us to believe that we were successful in achieving fatigue.

The lack of significance in our peak power data we attribute to unfamiliarity with maximal effort testing amongst our participants. We come to this conclusion because not all of the peak power values for our participants happened during the first 5-second interval. Additionally, we found some participants were able to attain slightly higher peak power values with the more practice they had with the repeated wingate tests. The inability to achieve peak power in the first 5 seconds and the variable peak power across the wingate tests increased the variability of our fatigue data and explains why some of our fatigue research hypotheses were not accepted.

Does Fatigue affect VGRF, Joint Moments, and Time to Peak GRF?

The first research question addressed maximum vertical ground reaction forces and if they would be impacted by fatigue, specifically looking for a) progressive increases over time, b) trial differences within a condition, and c) gender differences. This study found that vertical ground reaction forces did not change with repeated measures of fatigue. Other landing studies have also reported insignificant changes to max vertical ground reaction forces across fatigue conditions (Kernozek, Torry, & Iwasaki, 2008; Orishimo & Kremenic, 2006). These findings can be explained through the use of Winter's (1984) rationalization which accounts for this phenomenon through the neuromuscular system. The neuromuscular system adjusts the motor patterns at each joint to allow for a consistent response to ground reaction forces in the presence of fatigue. In Figure 6, you can graphically see that max vertical ground reaction forces did not increase across fatigue conditions and our research hypothesis cannot be accepted.

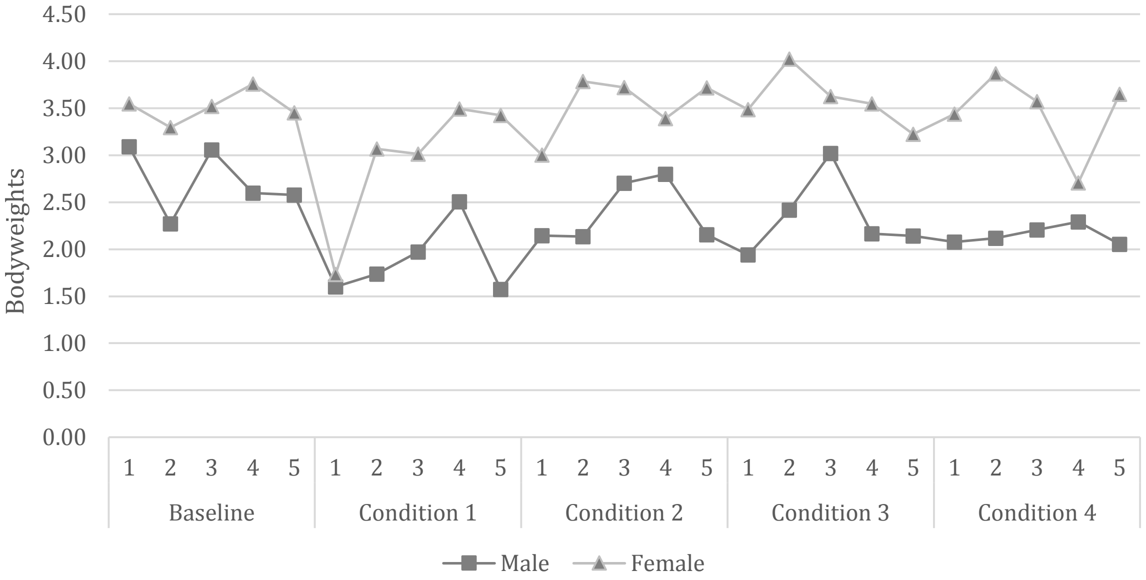


Figure 6. Means of Max Vertical Ground Reaction Forces

Additionally, the research showed no statistical significance within the trials of each condition for max vertical ground reaction forces and we cannot accept our research hypothesis that the first landing trial would elicit increased max vertical ground reaction forces in comparison to the succeeding landing trials. In Figure 6, we noted graphical fluctuations in max vertical ground reaction forces within the conditions and noticed how the female participants elicited a decreased max vertical ground reaction force in the first landing comparison to the succeeding landing trials following each fatigue protocol. We attribute these fluctuations due to a neuromuscular learning effect based off of Winter's (1984) rationalization of the neuromuscular system adjusting motor patterns at each joint to maintain max vertical ground reaction forces. Additionally, increases in ground reaction forces within the fatigue condition could also be explained by muscle recovery. And lastly, our findings did not reflect any statistical differences between genders. While no statistical differences were noted, we did find that on average women exhibited higher max vertical ground reaction forces in comparison to men in both pre-fatigued and fatigued conditions, these findings align with those of Kernozek et al. (2008). While this may not be statistically significant, the clinical relevance is also important to consider as ACL injuries have been reported more frequently in females versus male athletes (Agel, Arendt, & Bershadsky, 2005; Arendt, Agel, & Dick, 1999). Increased max vertical ground reaction forces may clue researchers and clinicians into individuals who are at higher risk for ACL injury, and further, increased max vertical ground reaction forces along with greater Hip Q Angles, fluctuating hormone levels, and other risk factors that predispose individuals to increased risk of ACL injury can further explain this gender disparity.

Another aspect of our first research question was regarding joint moments at the knee and if they a) progressively increase over time, b) differed between trials within a condition, and c) if they highlighted any differences between gender. We anticipated that there would be progressive increases in the joint moments at max vertical ground reaction force primarily in the plane allowing varus/valgus motion over time due to fatigue, however, we found no significant increases over time in our varus/valgus knee joint moments. It is likely that this is due to the inherent level of variability in all drop landings. We also recognize that our study may have been limited because of a bilateral landing protocol, where a single-leg landing protocol may have elicited a greater response with this variable. We also found no significant progressive increases in the knee joint moments in the planes conducting flexion/extension and internal/external rotation.

Additionally, we anticipated significant differences between trials within the different conditions. We were unable to accept our research hypothesis because no statistical differences were identified between trials in any of the three planes of the knee. Also, no statistical significance between the genders was noted in the knee joint moment data. However, we did note that the varus/valgus knee joint moments graphically showed the most differences between men and women than in the other planes (sagittal/transverse), see Figures 7, 8, 9. It is possible that the differences between genders for the maximum vertical ground reaction forces is additionally shown through the varus/valgus knee joint moment data. The females in our study tended to have greater joint moments at the knee in the frontal plane as well as more frequently attaining valgus moments in comparison to the males, see Figure 8. These differences in the frontal plane are clinically significant because a valgus knee angle has been previously identified as a risk factor for ACL injury. Fatigue appeared to be related to this increase in knee valgus moments because over time our data shows that our female's trials moved from a mixture of varus and valgus knee moments towards consistently more valgus knee moments, and by the last fatigue condition, they elicited only valgus knee moments, see Figure 8.

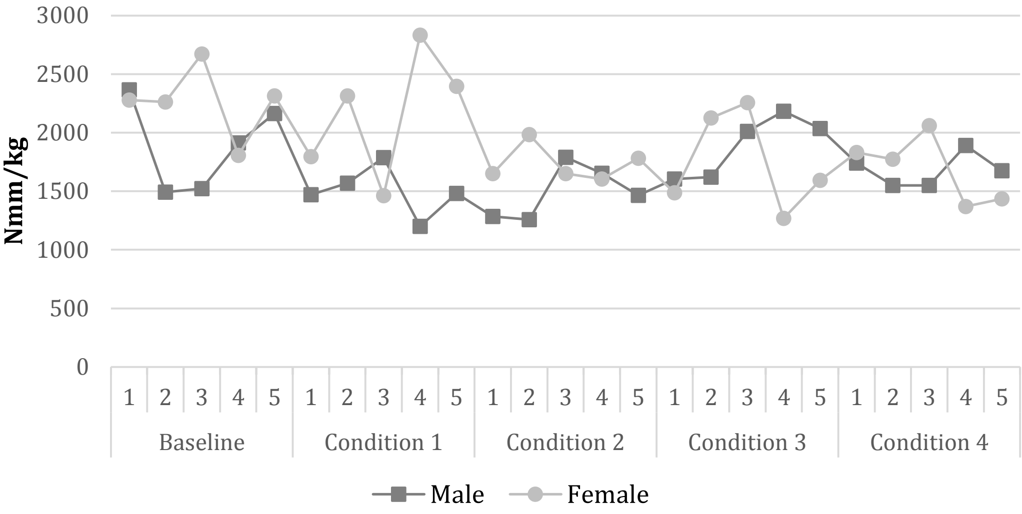


Figure 7. Means of Knee Joint Moments in Flexion and Extension

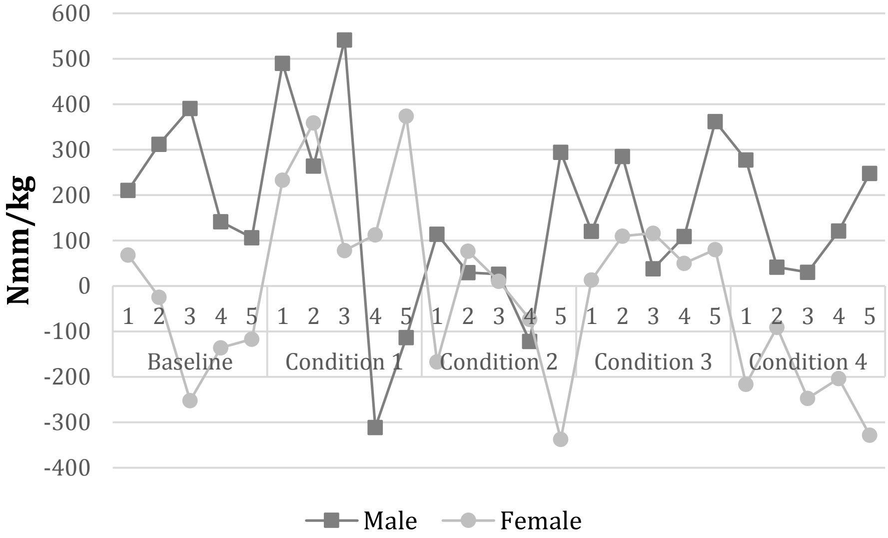


Figure 8. Means of Knee Joint Moments in Varus and Valgus

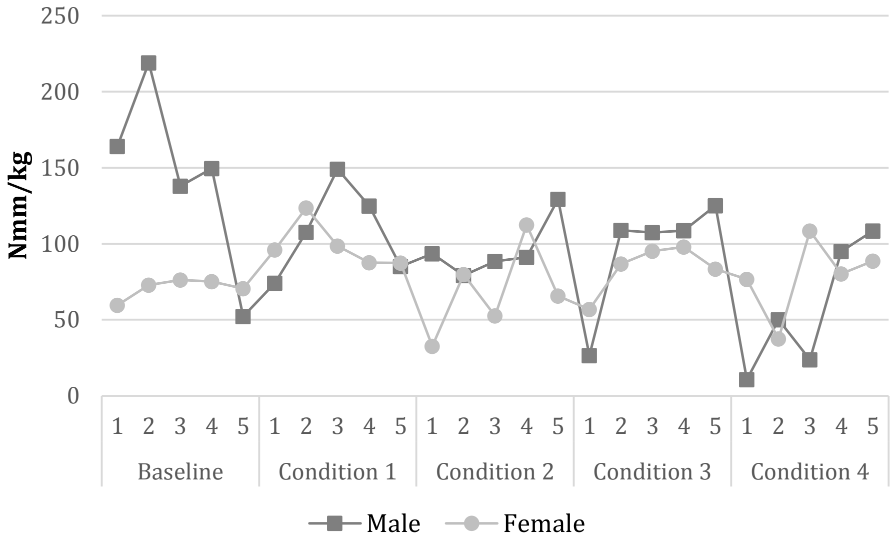


Figure 9. Means of Knee Joint Moments in Internal and External Rotation

Our study is limited in scope because hip and ankle joint moments were not included. Other studies have shown and alluded to fluctuations in both hip and ankle extensor moments accounting for the stabilization of peak VGRF between pre-fatigued and fatigued conditions (Orishimo & Kremenic, 2006; Coventry, O'Connor, Hart, Earl, & Ebersole, 2006). Orishimo & Kremenic (2006) specifically noted that ankle extensor moments changed first, followed by hip extensor moments. They attributed this order due to ankles being the first joint used to absorb ground reaction forces and when the ankles fatigue, the hip joint compensated for the ankles. Another interesting note found through the work of Coventry et al. (2006) is that the only joint with significance in ROM between pre-fatigued and fatigued conditions was the ankle (p=0.020), both the hip and knee did not significantly change range of motion values between conditions. If the ankle and hip moments are strategically varied as a movement strategy to maintain VGRF when fatigue is introduced to the system, it might be that when the ankle is not able to absorb enough of the forces it could lead to more internally rotated and valgus moments at the hip and knee to compensate. Further research looking to understand why a knee valgus landing strategy is adopted should include: the degree of ankle dorsiflexion, hip and ankle joint moments, hip abduction, hip internal rotation, knee valgus, and increased foot progression angles. (Sigward & Powers, 2007)

And finally, the last aspect our first research question regarded the time to peak ground reaction forces and if they a) progressively decreased over time, b) differed between trials within a condition, and c) if they highlighted any differences between gender. The time to peak ground reaction forces remained statistically insignificant along with the rest of our kinetic analysis variables. We attribute this finding to a lack of decrease in peak power across fatigue conditions and to the fact that time to peak ground reaction forces changes are more likely to be seen through a single-leg landing study. There were no significant differences across trial either, no recovery effect was identified, and no differences were noted between genders.

Does Fatigue affect the Hip, Knee, and Ankle in the Sagittal Plane?

The second research question addressed flexion angles in the sagittal plane of the hip, knee, and ankle during the max ground reaction force and if they would be impacted by fatigue. Specifically we were expecting to see a) progressive increases in flexion angles across fatigue conditions with all three joints, except we expected to see a decrease in flexion angles for women at the knee, b) variation between landing trials within each condition with an increase in flexion angles as the condition progressed for women and an decrease in flexion angles for men, and c) gender differences. We were not able to accept our research hypotheses, because no significant findings were discovered at the hip or knee across fatigue conditions, landing trials, or gender see Figures 10 and 11. Despite not finding statistical significance, our data graph does match what we were expecting to see with men achieving slightly greater knee flexion angles and women maintaining and slightly decreasing their knee flexion angles. At the ankle, no significant findings were noted across fatigue conditions or landing trials, however, there was a significant difference noted between genders at the ankle with females exhibiting less ankle flexion at max ground reaction forces than males regardless of fatigue, see Figure 12. These differences show that there are potentially different strategies at the ankle between genders. Additionally, we noticed greater fluctuations at the ankle in comparison to the other joints. This could be due to the wingate tests fatiguing the hip and knee extensors more than ankle extensors. With the ankle extensors less fatigued than the other extensors more of the landing was absorbed through the muscles surrounding the ankle joint.

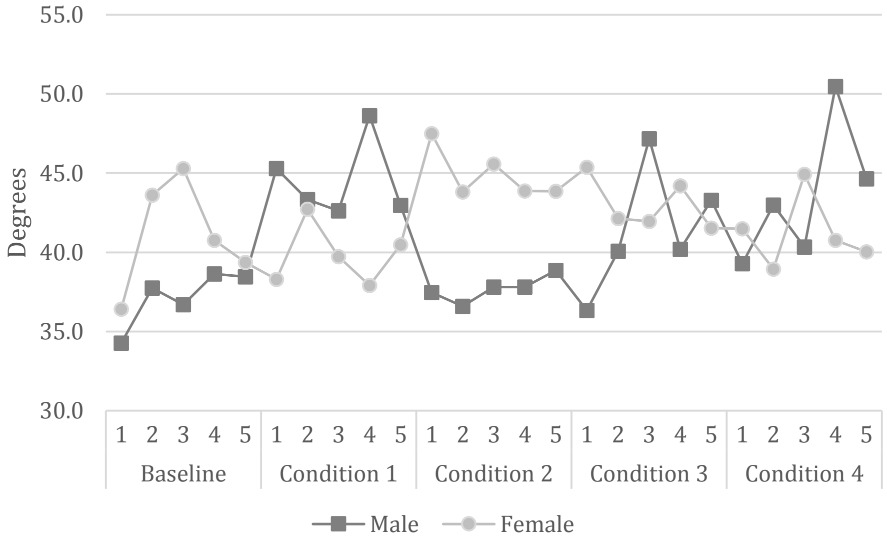


Figure 10. Means of Sagittal Hip Angles in Degrees

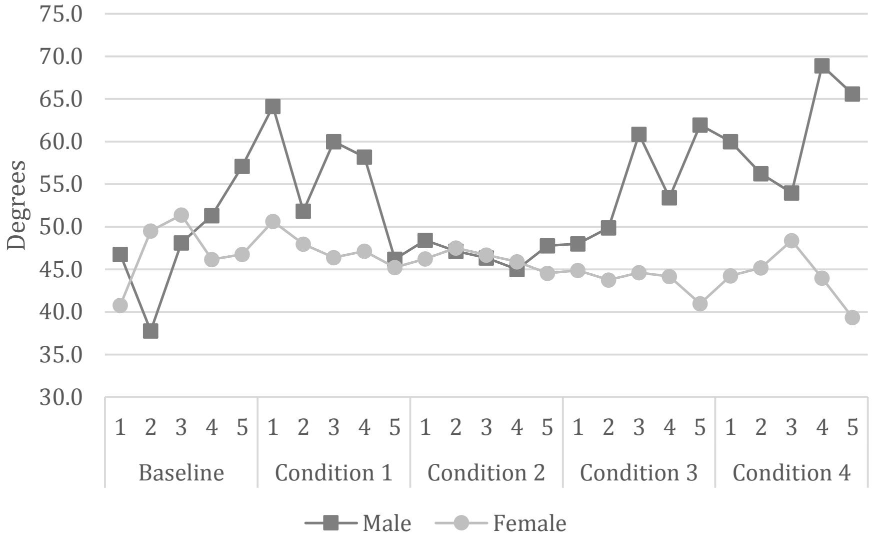


Figure 12. Means of Sagittal Knee Angles in Degrees

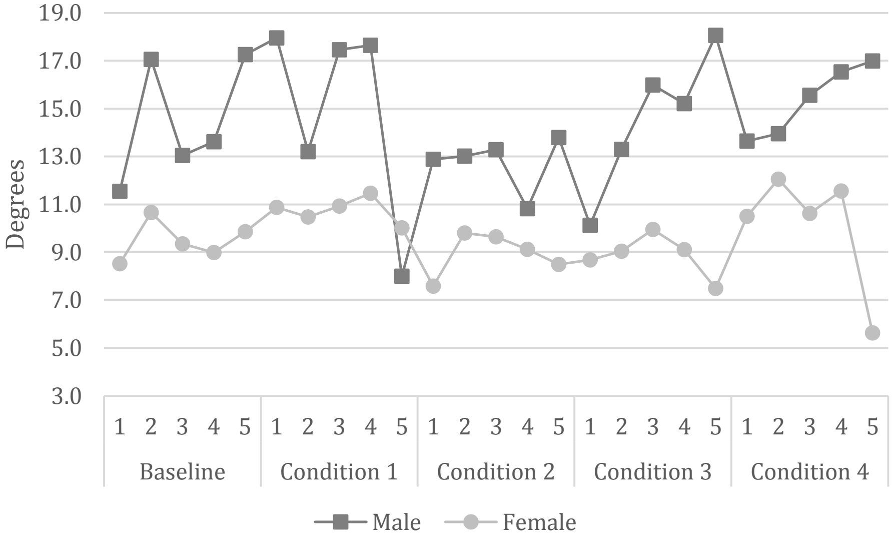


Figure 11. Means of Sagittal Ankle Angles in Degrees

Does Fatigue affect Frontal Knee Angle?

The last research question addressed knee angles in the frontal plane during max ground reaction force and if they would be impacted by fatigue. Of all the dependent variables we included in this study, the frontal knee angle was the variable we thought would provide the most evidence of whether fatigue is a risk factor for ACL injury. We expected to see a) progressively greater valgus knee angles across fatigue condition, b) variation between landing trials within each condition with a decrease in valgus knee angles as the trials progressed, and c) gender differences.

The frontal plane knee angles did not achieve significant increases in valgus knee angles across fatigue conditions, nor did a significant change happen between the trials within the condition. However, we did find that women were significantly different from men, in that as they reached max ground reaction forces women had a less varus knee angle than men, see Figure 13.

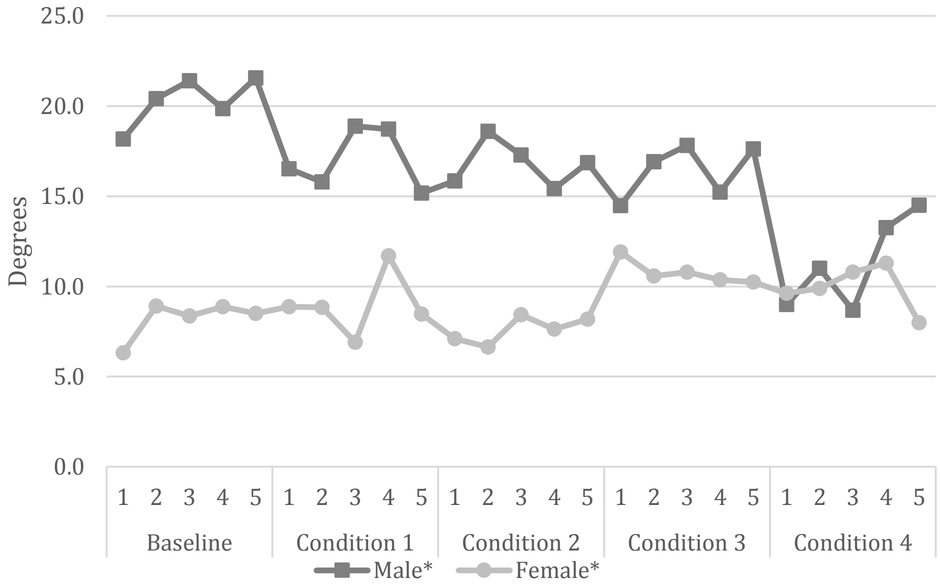


Figure 13. Means of Frontal Knee Angles in Degrees

In Figure 13, we are unsure why the data shows such a change during the baseline landings for both genders. As all participants were taken through familiarization with the landings before starting the study, we speculate that the participants were not given enough familiarization and there was still quite a bit of variability in landings. Unfortunately, this could have greatly impacted our ability to find statistical significance in the frontal knee angles between genders.

Similar to our findings, Kernozek et al. (2008) found that women demonstrated larger peak valgus angles overall regardless of fatigue condition in comparison to men, however, they did not find any changes between gender or post fatigue. This disagrees with Borotikar et al. (2008), who found their women increased their valgus angle as an additive fatigue effect. These differences within the research, could be attributed to different landing protocols. Overall, the literature is not all in agreement on how fatigue affects the knee in the frontal plane. The inconsistent findings of prior research as well as the findings of this study show the importance of future research including frontal plane kinematics when trying to understand differences in gender and how repeated bouts of fatigue affects landings and why the research disagrees.

Conclusion

The results of this study lead to the following conclusions.

1. It is still unclear if fatigue plays a role in predicting ACL injury.
2. Care should be taken in designing a fatigue protocol to be able to confirm an increase in rate of perceived exertion and a decrease in the ability to be able to continue to maintain force. Additionally, all aspects of the lower limbs should be fatigued, including the calf muscles, as they contribute in absorbing forces when landing from a jump.
3. Further research should look to understand if a knee valgus landing strategy is related to limitations of ankle dorsiflexion in a fatigued state. Dependent variables should include: hip abduction, hip internal rotation, knee valgus, and increased foot progression angles along with joint moments for hip and ankle extensors. Additionally, it would be advantageous for future research to capture kinematic angles at touch down and if a fatigue system doesn’t allow for as much range of motion to absorb landing forces.

This study attempted to examine biomechanical variables during drop landings known to be risk factors for ACL injury in the presence of fatigue and looked at the change in variables as fatigued increased through multiple bouts. This study utilized a standardized test for fatigue and was able to use the resulting fatigue calculations and compare them to normative of fatigue data associated with the wingate anaerobic test. Also, this is one of the few studies to combine both kinematic and kinetic data variables to a fatigued landing study and highlighted ankle dorsiflexion as a key variable that future research should be concerned with as fatigue research in combination with ACL injury prevention research progresses. As ankle dorsiflexion may be a key in understanding differing landing strategies between genders, future fatigue research should use a fatigue protocol that fatigues the ankle extensors. We assume the Wingate test predominately focuses on thigh and gluteal work, and we were not completely successful in fatiguing the entire landing system. Additionally, studies looking to fatigue only part of the leg might provide further insight into how landing strategies are modified in the presence of fatigue. Therefore in summary, future fatigued landing research should aim to capture the ankle dorsiflexion angles and moments along with hip and knee angles and moments to get a better picture of all the neuromuscular adaptations that fatigue can present.

References

Agel, J., Arendt, E. A., & Bershadsky, B. (2005). Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer. *The American Journal of Sports Medicine, 33*(4), 524-531.

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

Al-Turaiki, M. H. (1986). Anatomy of passive structures. In *The human knee: functional anatomy, biomechanics, and instabilities & assessment techniques* (pp. 6-9). Al-Zulfi Saudi Arabia: The author.

Arendt, E. A., Agel, J., & Dick, R. (1999). Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training, 34*(2), 86-92.

Baecke, J. A., Burema, J., & Frijters, J. E. (1980). A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *The American Journal of Clinical Nutrition, 36*(5), 936-942.

Bar-Or, O. (1987). The wingate anaerobic test: An update on methodology, reliability and validity. *Sports Medicine, 4*(6), 381-394.

Barry, B. K., & Enoka, R. M. (2007). The neurobiology of muscle fatigue: 15 years later. *Integrative and Comparative Biology, 47*(4), 465-473.

Behnke, R. S. (2006). The Knee. In R. S. Behnke, *Kinetic Anatomy* (pp. 189-206). Champaign: Human Kinetics.

Borotikar, B. S., Newcomer, R., Koppes, R., & McLean, S. G. (2008). Combined effects of fatigue and decision making on female lower limb landing postures: Central and peripheral contributions to ACL injury risk. *Clinical Biomechanics, 23*(1), 81-92.

Brazen, D. M., Todd, M. K., Ambegaonkar, J. P., Wunderlich, R., & Peterson, C. (2010). The effect of fatigue on landing biomechanics in single-leg drop landings. *Clinical Journal of Sport Medicine, 20*(4), 286-292.

Coventry, E., O'Connor, K. M., Hart, B. A., Earl, J. E., & Ebersole, K. T. (2006). The effect of lower extremity fatigue on shock attenuation during single-leg landing. *Clinical Biomechanics , 21*(10), 1090-1097.

Dominguese, D. J., Seegmiller, J., & Krause, B. A. (2012). Alterations in peak ground-reaction force during 60-cm drop landings cause by a single session of repeated wingate anaerobic tests. *Journal of Sport Rehabilitation, 21*(4), 306-312.

Faul, F., Erdfelder, E., Lang, A. -G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

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

Kernozek, T. W., Torry, M. R., & Iwasaki, M. (2008). Gender differences in lower extremity landing mechanics caused by neuromuscular fatigue. *American Journal of Sports Medicine, 36*(3), 554-565.

Laurent, C., Meyers, M. C., Robinson, C. A., & Green, J. (2007). Cross-validation of the 20- versus 30-s wingate anaerobic test. *European Journal of Applied Physiology, 100*(6), 645-651.

Mediguchia, J., Ford, K. R., Quatman, C. E., Alentorn-Geli, E., & Hewett, T. E. (2011). Sex differences in proximal control of the knee joint. *Sports Medicine, 41*(7), 541-557.

Nasher, L. M. (1977). Adapting reflexes controlling the human posture. *Exp Brain Res*, 13-24.

Orishimo, K. F., & Kremenic, I. J. (2006). Effect of fatigue on single-leg hop landing biomechanics. *Journal of Applied Biomechanics, 22*(4), 245-254.

Pappas, E., Hagins, M., Sheikhzadeh, A., Nordin, M., & Rose, D. (2009). Peak biomechanical variables during bilateral drop landings: Comparisons between sex (female/male) and fatigue (pre-fatigue/post-fatigue). *North American Journal of Sports Physical Therapy, 4*(2), 83-91.

Shultz, S. J., Schmitz, R. J., Benjaminse, A., Chaudhari, A. M., Collins, M., & Padua, D. A. (2012). ACL Research Retreat VI: An Update on ACL Injury Risk and Prevention. *Journal of Athletic Training, 47*(5), 591-603.

Shultz, S. J., Schmitz, R. J., Nguyen, A.-D., Chaudhari, A. M., Padua, D. A., McLean, S. G., & Sigward, S. M. (2010). ACL Research Retreat V: An update on acl injury risk and prevention, March 25-27, 2010, Greensboro, NC. *Journal of Athletic Training, 45*(5), 499-508.

Sigward, S. M., & Powers, C. M. (2007). Loading characteristics of females exhibiting excessive valgus moments during cutting. *Clinical Biomechanics, 22*(7), 827-833.

Stickley, C. D., Hetzler, R. K., & Kimura, I. F. (2008). Prediction of anaerobic power values from an abbreviated WAnT protocol. *Journal of Strength and Conditioning Research*, 958-965.

Williams, G. N., Chmielewski, T., Rudolph, K. S., Buchana, T. S., & Snyder-Mackler, L. (2001). Dynamic knee stability: Current theory and implications for clinicians and scientists. *Journal of Orthopaedic & Sports Physical Therapy*, 546-566.

Woon, C., & Hughes, M. (2015, May 8). *Ligaments of the knee*. Retrieved from Orthobullets: http://www.orthobullets.com/sports/3001/ligaments-of-the-knee

Appendix A: Participant Forms

Consent Form

The University of Idaho Institutional Review Board has approved this project.

Title of Research:

The Effects of Repeated Bouts of Fatigue on Kinetics and Kinematics during Drop Landings in Recreational Athletes

IRB PROTOCOL NUMBER: 13-086

Researcher: Danielle Lawson
Faculty Sponsor: Dr. Jeffrey Seegmiller

The purpose of this study:

The purpose of this research is to investigate the effect of fatigue on kinematic, kinetic, and muscle activation variables while landing from a 60 cm landing platform. Muscular fatigue will be achieved through 4 bouts of a Wingate test, which includes pedaling a stationary bike as hard as possible against 7.5% of body weight resistance for 20 seconds. Kinematic and kinetic variables will include joint angles, ground reaction forces and joint torques. In order to measure these variables we will record high-speed video images of the subject's movements as they step off a 60 cm box and land onto 2 force plates. This involves placing small reflective markers at several prominent anatomical landmarks on the body including the head, shoulders, arms, back, collarbone, sternum, pelvis, and legs. To calibrate these measurements, we will collect simple measurements of body weight, height and the length and diameter of leg and arm segments. Muscle activity will be recorded via an external measurement technique known as electromyography (EMG). This will involve placing electrodes on the skin over various muscles.

Description of the study:

You will be asked to provide us with information regarding your fitness level and exercise regimen along with taking some measurements that are important for our data interpretation such as height and weight. You will be screened for contraindications. You will be invited back for two sessions that will be separated by at most a week. During the first session you will be introduced to the study's protocol and get to practice the maximal cycling test along with the proper procedures for the landings. During the second visit we will ask that you will be barefoot and in tight fitting clothing. We will prepare you for the data collection process by first taking simple measurements of body weight, height and the lengths and circumferences of leg/arm segments, shoulder offset, and wrist width. This data will be used to calibrate kinematic and kinetic measures. We will then place small reflective markers at several prominent anatomical landmarks on the subject's pelvis, legs, and upper body, which will allow their motion to be digitally analyzed. Lastly, EMG electrodes will be placed on the skin of the legs over the specific muscles to be analyzed, which will allow for muscle activity to be measured.

You will then perform 5 landings from a 60 cm platform prior to and following each of the four cycling bouts. We will allow five minutes of rest between each cycling bout to allow the 5 landings to be completed between each of the four cycling bouts. Cycling bouts will include 20 seconds of stationary cycling at maximal effort with a resistance calculated at 7.5% of his/her body weight. During the protocol, your heart rate will be measured using a Polar Heart monitor. Immediately after every exercise bout, you will be asked to provide us your rating of perceived exertion (RPE) based on a 20-point scale.

During your trials, your movements will be recorded by digital video. The camera will be oriented so that only the torso and lower body are visible; images of your face will not be recorded. The movements recorded in the video will be converted to animations during data processing and the animations will be used for subsequent analysis.

The study should be completed in three visits that would require an accumulation of no more than four hours.

Risks and Discomforts

Depending on individual's differences, drop landing from a 60-cm height or exercising on a bicycle might present a variation in responses. As with any other physical activity, there is a slight risk that mild musculoskeletal injuries may occur. As a safety mechanism that protect against overexertion is the short duration of the activity of the exercise bout. We will take measures to ensure that the risk of injury is extremely minimal and no greater than the risk associated with any other physical activity. However in the event that any injuries occur, immediate first aid will be provided at no charge (all researchers in the lab are first aid and CPR certified). In the unlikely event that any more serious injury occurs, the participant will be responsible for seeking and paying medical expenses.

Benefits

You will benefit from this project by understanding how you react to fatigue and how you can eliminate any risk of injury and how to perform better. Society will benefit from increasing understanding of how repeated bouts of fatigue affect the body's ability to perform physical tasks of landing. Many musculoskeletal injuries occur during a fatigued state are poorly understood. This research study would be unique in that few studies measure the effects of fatigue on landing tasks and no studies have quantified biomechanical and neuromuscular responses following fatigue.

If you found that participating in our study are creating stress or emotional difficulty to you, please let us know and we will do our best to accommodate you, or in extreme cases, we will dismiss you. Your participation is your choice. However, we have the right to remove you without your consent if you do not follow our important instructions or if we noticed signs of medical conditions that might affect our study data analysis.

Confidentiality and Records

All personal information will be kept confidential and will be placed in secured files that will be accessed only by the researchers. You will be given an identity for our data purposes that do not have your name in it. This study will be published for scientific purposes.

We will provide you with the Borg’s scale to quantify Rated Perceived Exertion (RPE), the PAR-Q form, the screening form, and Baecke Physical Activity Questionnaire to learn about your ability and exercise habit to help us qualify you to participate for this study and that you are healthy and able to participate in our research.

Contact Information

Please do not hesitate to ask the investigator(s) if you have any questions during the orientation session or anytime throughout the study.

Investigator	Faculty Sponsor
Danielle Lawson	Dr. Jeffrey Seegmiller
University of Idaho	University of Idaho
Movement Sciences	WWAMI/Movement Sciences
Moscow, ID 83844-2401	Moscow, ID 83842
Ph. 208-608-8947	Ph. 208-885-0355

During the course of this study, you may stop at any time with no penalty, if you do decide to stop, you will still receive what you agreed on for your participation up to the point that you decided to withdraw from the study.

If you do stop your participation in the study, there will be no penalties associated with your withdrawal. All you need to say is that I no longer wish to participate.

I have reviewed this consent form and understand and agree to its contents.

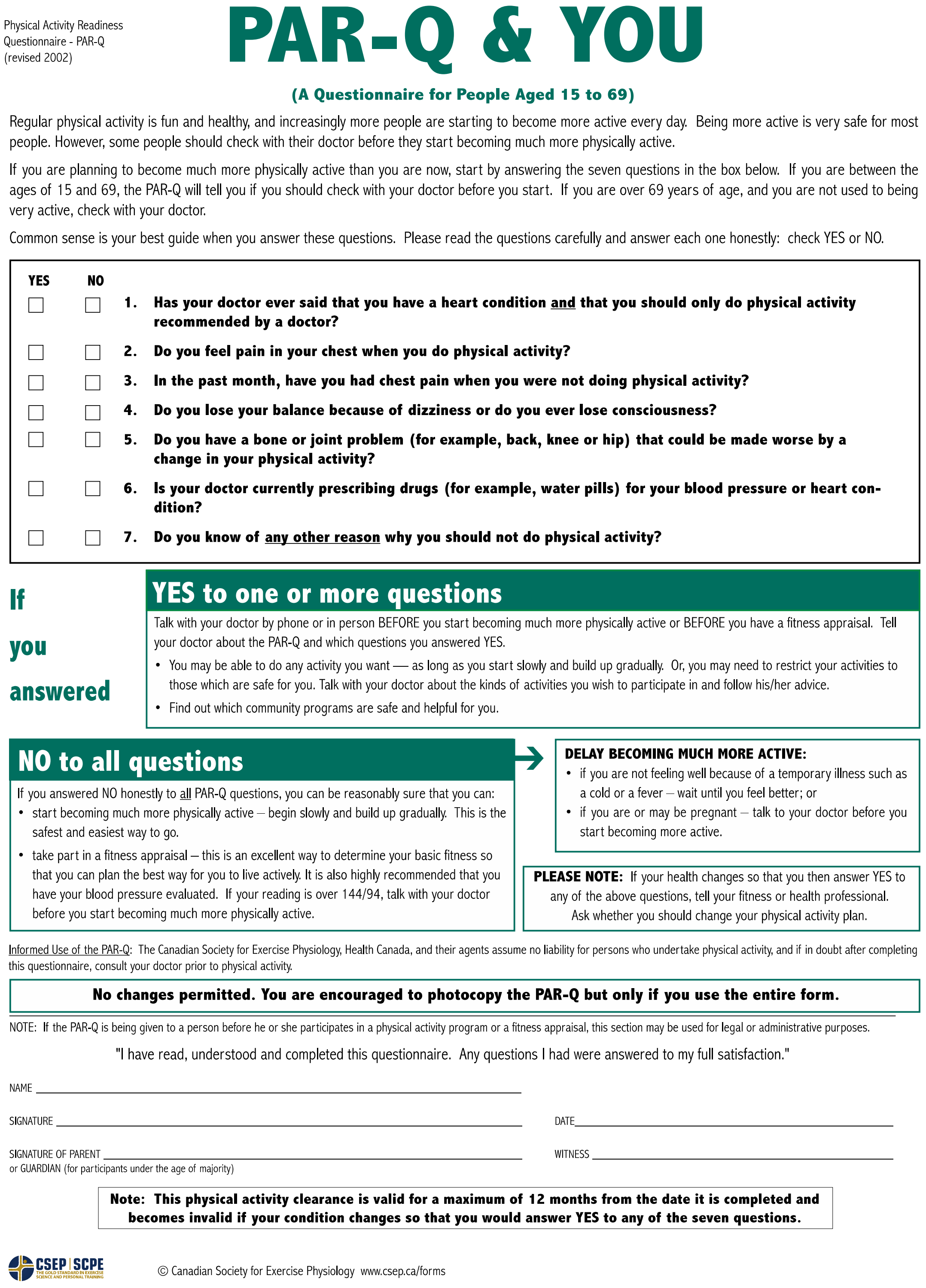
Participant Name ____________________________Date _________________

Witness name (if appropriate) ____

Date of Birth _____________________

Experimenter Name ____

PAR-Q Form



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	**1.**	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	**2.**	**Do you feel pain in your chest when you do physical activity?**
☐	☐	**3.**	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4.**	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5.**	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6.**	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7.**	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ______________________________

SIGNATURE OF PARENT ____ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

Baecke Physical Activity Questionnaire Form

Name:____________________ ID: _______ Date:___________

Baecke Physical Activity Questionnaire

		Investigator use only
1. What is your main occupation?		1 – 3 – 5
2. At work I sit:	never seldom sometimes often always	1–2–3–4–5
3. At work I stand:	never seldom sometimes often always	1–2–3–4–5
4. At work I walk:	never seldom sometimes often always	1–2–3–4–5
5. At work I lift heavy loads:	never seldom sometimes often always	1–2–3–4–5
6. After work I am tired:	very often often sometimes seldom never	5–4–3–2–1
7. At work I sweat:	very often often sometimes seldom never	5–4–3–2–1
8. In comparison with others of my own age, I think my work is physically:	much heavier heavier as heavy lighter much lighter	5–4–3–2–1
9. Do you play a sport?	Yes No	
If yes, which sport do you play most frequently? ____________________		
How many hours a week?	< 1 1-2 2-3 3-4 >4	
How many months per year?	<1 1-3 4-6 7-9 >9	
If you play a second sport, which sport is it? ____________________		
How many hours a week?	< 1 1-2 2-3 3-4 >4	
How many months per year?	<1 1-3 4-6 7-9 >9	
10. In comparison with others of my own age, I think my physical activity leisure time is:	much more more as much less much less	5–4–3–2–1
11. During leisure time I sweat:	very often often sometimes seldom never	5–4–3–2–1
12. During leisure time I play sport:	never seldom sometimes often always	1–2–3–4–5
13. During leisure time I watch television:	never seldom sometimes often always	1–2–3–4–5
14. During leisure time I walk:	never seldom sometimes often always	1–2–3–4–5
15. During leisure time I cycle:	never seldom sometimes often always	1–2–3–4–5
16. How many minutes do you walk and/or cycle per day to and from		
17. work, school and shopping?	< 5 5-15 15-30 30-45 >45	1–2–3–4–5
Work Index =	Sport Index =	Leisure-time index =

Additional Screening Form

Screening Form

Subject Number: ______________________

1. Please tell us whether or not you have had any surgeries in the last six month. If so, what kind of surgery?

2. Please tell us whether you have had any history of any orthopedic, pain or discomfort particularly in the lower extremities or the back in the last six months.

3. Please keep us informed if you noticed any pain or comfort while participating in our study.

Selected additional questions from PAR-Q FORM and AHA/ACSM questionnaires

Please mark YES, No or “I do not know” to the following:

1. Do you have any cardiorespiratory diseases/disorders, systematic chronic illness, injuries, additional orthopedic or musculoskeletal problems or any other health problems that causes you pain or Physical limitations while exercising (i.e, Asthma, diabetes, osteoporosis, high blood pressure, high cholesterol, arthritis, anorexia, bulimia, anemia, epilepsy, respiratory ailments, back problems, bursitis, neck, wrist, shoulders, bad knee, etc.)?

Yes ____________ NO __________ I do not know______________

2. Do you have any concerns about the safety of exercise?

Yes ____________ NO __________ I do not know______________

- If you have marked **YES** to any of the above, please elaborate and specify below, If you marked “I do not know”, it is important that you know before you can participate in this study:

3. Are you pregnant now or have you given birth within the last 6 months?

Yes ____________ NO __________ I do not know______________

4. Do you take any medications, either with prescription or without prescription?

Yes___ No____

a) What is the medication for?

____

b) How does this medication affect your ability to exercise or achieve your fitness goals?

____

Lifestyle Related Questions:

1) Do you smoke? YES___NO___ If yes, at what rate?__________

2) Do you drink alcohol? YES___NO___ If yes, how many glasses per week?__________

3) How many hours do you regularly sleep at night? ___________

4) Describe your job: ○ Sedentary ○ Active ○ Physically Demanding

Please describe?

____

5) Does your job require travel? YES___NO____

6) On a scale of 1-10, how would you rate your stress level (1=very low 10=very high)?

______

7) List your 3 biggest sources of stress:

a. ______________________ b. ______________________

c.______________________

8) Is anyone in your family overweight? ○Mother ○Father ○Sibling ○Grandparent

9) Were you overweight as a child? YES NO If yes, at what age(s)?______________

Appendix B: ANOVA Summaries

Fatigue ANOVA Table Summary

Relative Peak Power Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	3.377	2.144	1.575	.262	.786	.014	.561	.089
Condition * Sex	27.374	2.144	12.768	2.120	.131	.105	4.546	.423
Error(Condition)	232.381	38.592	6.021					

a. Computed using alpha = .05

Relative Peak Power Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	757.987	1	757.987	145.946	.000	.890	145.946	1.000
Sex	11.178	1	11.178	2.152	.160	.107	2.152	.285
Error	93.485	18	5.194					

a. Computed using alpha = .05

Relative Mean Power Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	.364	2.07	.176	.046	.958	.003	.096	.057
Condition * Sex	17.4	2.07	8.43	2.23	.121	.110	4.61	.432
Error(Condition)	141	37.2	3.79					

a. Computed using alpha = .05

Relative Mean Power Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	390	1	390	127	.000	.876	127	1.00
Sex	2.50	1	2.50	.816	.378	.043	.816	.137
Error	55.2	18	3.07					

a. Computed using alpha = .05

Relative Min Power Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	.364	3	.121	.091	.965	.005	.272	.065
Condition * Sex	7.712	3	2.571	1.922	.137	.096	5.765	.469
Error(Condition)	72.232	54	1.338					

a. Computed using alpha = .05

Relative Min Power Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	143.295	1	143.295	73.779	.000	.804	73.779	1.000
Sex	1.716	1	1.716	.883	.360	.047	.883	.145
Error	34.960	18	1.942					

a. Computed using alpha = .05

Power Drop Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	1811.620	3	603.873	3.577	.020	.166	10.730	.760
Condition * Sex	1335.859	3	445.286	2.637	.059	.128	7.912	.614
Error(Condition)	9117.215	54	168.837					

a. Computed using alpha = .05

Power Drop Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	45101.022	1	45101.022	129.458	.000	.878	129.458	1.000
Sex	3386.964	1	3386.964	9.722	.006	.351	9.722	.838
Error	6270.902	18	348.383					

a. Computed using alpha = .05

Results of Wingate RPE Data Within-Subject Effects (Greenhouse-Gieser Values)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
WAT	57.3	1.91	29.9	26.1	.000	.554	50.0	1.00
WAT * Sex	.453	1.91	.237	.206	.805	.010	.395	.079
Error(WAT)	46.1	40.2	1.15					

a. Computed using alpha = .05

Results of Wingate RPE Data Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
Intercept	27525	1	27525	3757	.000	.994	3757	1.00
Sex	5.48	1	5.48	.748	.397	.034	.748	.131
Error	154	21	7.33					

a. Computed using alpha = .05

TTPGRF ANOVA Table Summary

Within-Subject Effects (Greenhouse-Gieser Values)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	.000	3.10	.000	1.05	.373	.016	3.25	.287
Trial * Condition	.001	12.4	.000	1.22	.270	.070	15.1	.692
Trial * Sex	.000	3.10	.000	.825	.485	.013	2.55	.230
Trial * Condition * Sex	.001	12.4	.000	1.25	.252	.071	15.4	.704
Error(Trial)	0.017	201	.000					

a. Computed using alpha = .05

Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.012	1	.012	294	.000	.819	294	1.00
Condition	.000	4	.000	.992	.418	.058	3.97	.297
Sex	.000	1	.000	7.69	.007	.106	7.69	.780
Condition * Sex	.000	4	.000	1.02	.403	.059	4.09	.305
Error	.003	65	.000					

a. Computed using alpha = .05

Max Vertical Ground Reaction Force ANOVA Tables

Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	10.053	4	2.513	2.179	.071	.024	8.716	.641
Trial * Condition	25.084	16	1.568	1.359	.159	.057	21.748	.842
Trial * Sex	8.526	4	2.131	1.848	.119	.020	7.392	.560
Trial * Condition * Sex	13.425	16	.839	.728	.766	.031	11.640	.503
Error(Trial)	415.207	360	1.153					

a. Computed using alpha = .05

Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	778.976	1	778.976	782.721	.000	.897	782.721	1.000
Condition	5.545	4	1.386	1.393	.243	.058	5.572	.418
Sex	29.498	1	29.498	29.640	.000	.248	29.640	1.000
Condition * Sex	.742	4	.186	.186	.945	.008	.746	.088
Error	89.569	90	.995					

a. Computed using alpha = .05

Sagittal Ankle Angle ANOVA Tables

Within-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	96	3.35	29	.894	.454	.014	2.99	.257
Trial * Condition	86	3.35	26	.801	.507	.012	2.68	.233
Trial * Sex	558	13.4	42	1.30	.212	.075	17.4	.754
Trial * Condition * Sex	504	13.4	38	1.18	.298	.068	15.7	.699
Error(Trial)	6864	214	32					

a. Computed using alpha = .05

Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	10209	1	10209	509	.000	.888	509	1.00
Condition	404	1	404	20.1	.000	.239	20.1	.993
Sex	37.9	4	9.47	0.472	.756	.029	1.89	.155
Condition * Sex	8.98	4	2.25	.112	.978	.007	0.447	.072
Error	1285	64	20.1					

a. Computed using alpha = .05

Sagittal Knee Angle ANOVA Tables

Within-Subject Effects (Greenhouse-Geiser Statistics)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	404	2.91	139	.782	.502	.012	2.28	.214
Trial * Condition	2179	11.7	187	1.06	.400	.060	12.3	.592
Trial * Sex	1153	2.91	396	2.24	.087	.033	6.51	.551
Trial * Condition * Sex	2363	11.7	203	1.14	.327	.065	13.3	.637
Error(Trial)	34056	192	177					

a. Computed using alpha = .05

Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	178555	1	178555	1383	.000	.954	1383	1.000
Condition	403	4	101	.780	.542	.045	3.12	.237
Sex	1080	1	1080	8.37	.005	.113	8.37	.813
Condition * Sex	703	4	176	1.36	.257	.076	5.45	.402
Error	8522	66	129					

a. Computed using alpha = .05

Sagittal Hip Angle ANOVA

Within-Subject Effects (Greenhouse-Geiser Statistics)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	223	3.22	69.2	.917	.439	.014	2.95	.259
Trial * Condition	555	12.9	43.1	.572	.874	.033	7.36	.337
Trial * Sex	334	3.2	104	1.38	.249	.020	4.43	.377
Trial * Condition * Sex	992	12.9	77.1	1.02	.430	.058	13.2	.609
Error	16007	212	75.4					

a. Computed using alpha = .05

Between-Participants Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	124989	1	124989	768	.000	.921	768	1.00
Condition	117	4	29.1	.179	.948	.011	.716	.086
Sex	23.8	1	23.8	.146	.703	.002	.146	.066
Condition * Sex	328	4	81.9	.503	.734	.030	2.01	.163
Error	10745	66	163					

a. Computed using alpha = .05

Frontal Knee Angle ANOVA Tables

Within-Participants Effects (Greenhouse-Geisser)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	86.0	3.23	26.6	1.82	.140	.028	5.88	.488
Trial * Condition	199	12.9	15.4	1.05	.402	.063	13.6	.626
Trial * Sex	67.1	3.23	20.8	1.42	.236	.022	4.59	.389
Trial * Condition * Sex	252	12.9	19.5	1.33	.197	.078	17.2	.755
Error(Trial)	2980	204	14.6					

a. Computed using alpha = .05

Between- Participants Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	11394	1	11394	58.8	.000	.483	58.8	1.00
Condition	114.0	4	28.5	.147	.964	.009	.588	.079
Sex	930	1	930	4.80	.032	.071	4.80	.578
Condition * Sex	235	4	58.7	.302	.875	.019	1.21	.113
Error	12216	63	194					

a. Computed using alpha = .05

Knee Flexion/Extention Joint Moments ANOVA Tables

Within-Participants Effects (Sphericity Assumed)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	611126	4	152782	.275	.894	.005	1.10	.110
Trial * Condition	6286425	16	392902	.708	.785	.050	11.3	.478
Trial * Sex	3131197	4	782799	1.41	.232	.025	5.64	.435
Trial * Condition * Sex	12886930	16	805433	1.45	.120	.097	23.2	.860
Error(Trial)	119906524	216	555123					

a. Computed using alpha = .05

Between-Participants Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	198320450	1	198320450	234	.000	.812	234	1.00
Condition	1734114	4	433529	.511	.728	.036	2.04	.163
Sex	797081	1	797081	.939	.337	.017	.939	.159
Condition * Sex	1083931	4	270983	.319	.864	.023	1.28	.116
Error	45829199	54	848689					

a. Computed using alpha = .05

Knee Varus/Valugs Joint Moments ANOVA Table

Within-Participants Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	1020130	4	255033	1.93	.107	.034	7.71	.576
Trial * Condition	1369607	16	85600	.647	.843	.046	10.4	.435
Trial * Sex	663379	4	165845	1.25	.289	.023	5.01	.389
Trial * Condition * Sex	3349477	16	209342	1.58	.075	.105	25.3	.896
Error(Trial)	28576738	216	132300					

a. Computed using alpha = .05

Between-Participants Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	296642	1	296642	1.08	.304	.020	1.08	.175
Condition	447360	4	111840	.406	.804	.029	1.62	.137
Sex	496804	1	496804	1.80	.185	.032	1.80	.261
Condition * Sex	318981	4	79745	.289	.884	.021	1.16	.109
Error	14884177	54	275633					

a. Computed using alpha = .05

Knee Internal/External Rotation Joint Moments

Within-Subject Effects (Sphereicity Assumed)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Trial	39142	4	9786	1.63	.168	.029	6.52	.497
Trial * Condition	104394	16	6525	1.09	.368	.075	17.4	.713
Trial * Sex	4741	4	1185	.198	.939	.004	.790	.092
Trial * Condition * Sex	115882	16	7243	1.21	.264	.082	19.3	.770
Error(Trial)	1295980	216	6000					

a. Computed using alpha = .05

Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	495259	1	495259	56.3	.000	.510	56.3	1.00
Condition	12685	4	3171	.360	.836	.026	1.44	.126
Sex	6262	1	6262	.712	.403	.013	.712	.132
Condition * Sex	15470	4	3868	.440	.779	.032	1.76	.145
Error	475144	54	8799					

a. Computed using alpha = .05

Appendix C: IRB Approval Letter

University of Idaho
Office of Research Assurances
Institutional Review Board
PO Box 443010
Moscow ID 83844-3010

Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

April 18, 2013

To: Seegmiller, Jeffrey
Cc: Lawson, Danielle

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Title: 'The Effects of Repeated Bouts of Fatigue on Peak Kinetics and Kinematics during Drop Landings in Recreational Athletes'

Project: 13-086
Approved: 04/16/13
Expires: 04/15/14

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project is approved as offering no significant risk to human subjects.

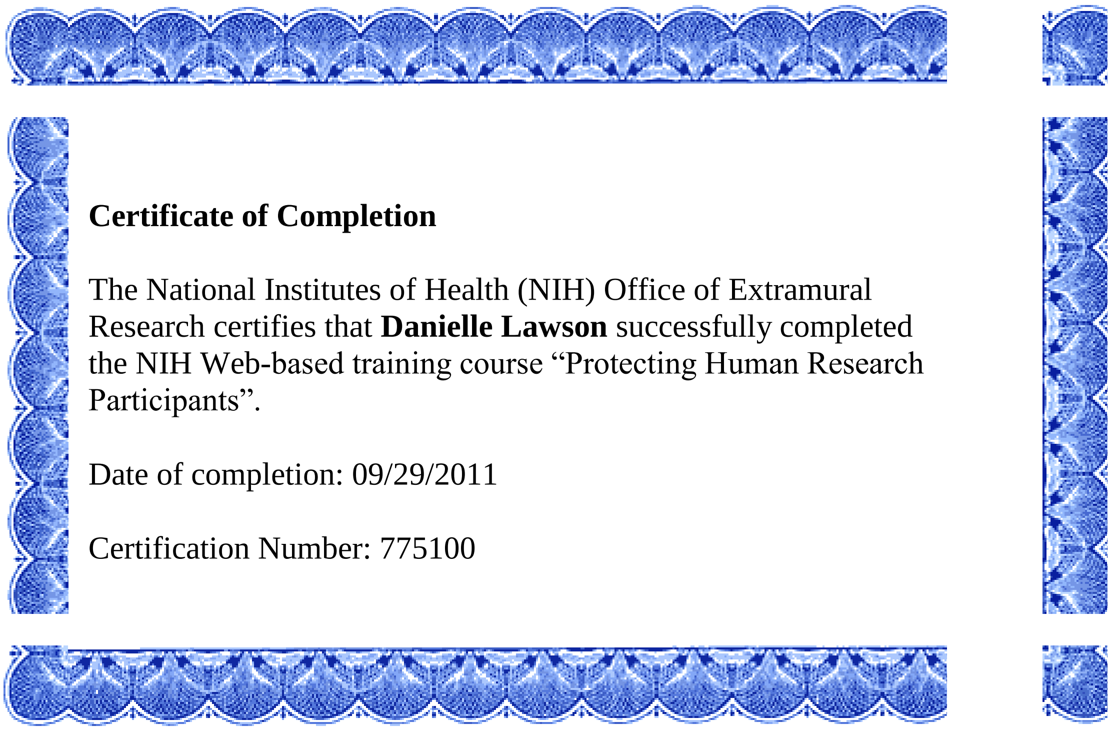
This approval is valid for one year from the date of this memo. Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Traci Craig

University of Idaho Institutional Review Board: IRB00000843, FWA00005639

Appendix D: NIH Certificate



Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Danielle Lawson** successfully completed the NIH Web-based training course “Protecting Human Research Participants”.

Date of completion: 09/29/2011

Certification Number: 775100