5-4-2017

Factors that Effect Lower Extremity Muscle Strains in Collegiate Track and Field

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May 2017

To the Dean of the Graduate School:

We are submitting a thesis written by Syrena Spanburgh-Hess entitled FACTORS THAT EFFECT LOWER EXTREMITY MUSCLES STRAINS IN COLLEGIATE TRACK AND FIELD ATHLETES.

We recommend acceptance in partial fulfillment of the requirements for the degree of Master of Science in Sport and Fitness Administration through the Richard W. Riley College of Education.

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Factors that Effect Lower Extremity Muscle Strains in Collegiate Track and Field Athletes

A Thesis

Presented to the Faculty

Of the

Richard W. Riley College of Education

In Partial Fulfillment

Of the

Requirements for the Degree

Of

Master of Science

In Sport and Fitness Administration

Winthrop University

May, 2017

By

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Abstract

Both the number of recreational and competitive runners and the number of injuries have increased over the past decade. Track and field includes a variety of events, which differ in volume and intensity. The variability of the sport causes both chronic and acute injuries. Although chronic injuries are most prevalent, muscular strains are the most frequent acute injury (Jacobsson et al., 2011). Muscular strains have accounted for approximately 17% of all track and field injuries (Kluitenberg et al., 2014). A variety of predisposing factors for muscular strains have been described. The purpose of this study was to investigate causative factors for muscular strains such as strength and flexibility deficits, previous injury, and leg dominance and their relationship with injury.

The research design used in this investigation included a correlational comparison, to determine if a relationship was present between hip and knee ranges of motion, strength, previous injury, and leg dominance with injury incidence. Twenty male and female collegiate track and field athletes who specialize in a variety of events participated in this study. Subjects completed a pre-participation profile that outlined their demographics, previous injury history, and training protocols. Following a stationary bike warm-up, the participants' ranges of motion were measured with a goniometer. The subjects completed a familiarization period for the isokinetic strength testing. Their peak torques per body weight values was obtained using the Biodex System 3 dynamometer. Three different velocities were incorporated to assess concentric/concentric hip flexion and extension as well as eccentric/concentric knee extension and flexion. The subjects' injuries were then recorded throughout training and competition during their indoor track and field season.

The results displayed a significant negative correlation between peak torque per body weight and injury for right hip extension at 300 degrees per second. These results suggested that decreased hip extension strength, at a faster speed, may predispose an individual to injury. None of the other velocities or motions at the knee or hip showed significant values. A significant negative correlation between injury and range of motion for left hip extension indicated that decreased hip extension range of motion may lead to injury. However, the other ranges of motion obtained at the hip and knee did not produce significant values. There was a strong, significant correlation between previous injury and re-injury, suggesting that there is an increased risk for injury if an individual experienced a previous injury. Leg dominance did not show a significant correlation. A larger sample size and longer injury recording period could influence results. The results suggest that stretching and strengthening protocols could be beneficial in reducing injury incidence.

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Chapter 1

Introduction

Running is the fundamental component in the majority of field and court sports as well as one of the most popular recreational activities across the world. According to The National Collegiate Athletics Association (2016), in the academic year of 2015-16 there were approximately 22,917 indoor and 24,204 outdoor track and field athletes. The number of collegiate track and field participants has grown by almost 18% in the past 10 years. Additionally, there are youth, high school, masters, and elite runners. The increasing intensity and volume at which these athletes train and perform leads to high injury prevalence. Through the non-contact nature of the sport, chronic injuries occur most frequently however, the most prevalent acute injuries are muscular strains. In fact, injury occurrence in track and field has been reported up to 43%, with 16.5% of those injuries being muscular strains (Jacobsson et al., 2011). More specifically, hamstring strains are the most common acute injury (Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002).

Although the most common injuries have been identified, the underlying causes are heavily debated. Research has suggested that strength deficits, muscular imbalances, decreased flexibility, and previous injury are contributing factors, yet the data have been contradictory (Sugiura, Saito, Sakuraba, Sakuma, & Suzuki, 2008; Yeung, Suen, & Yeung, 2009). Other factors have also been examined including gender, demographics, fatigue, event, footwear, and training programs (Opar et al., 2014). The biarticular nature of the hamstring and quadriceps muscles may predispose muscular imbalances, which lead to injury (Malliaropoulos, Isinkaye, Tsitas, & Maffuli, 2011). Injuries have occurred most frequently during the swing phase of running because of the negative forces produced by the hamstrings, yet can happen at any moment (Chumanov, Heiderscheit, & Thelen, 2007; Opar et al., 2014). It has also been proposed that injuries are more likely to occur at greater speeds (Chumanov et al., 2007). With better insight on the predisposing factors, health care providers can improve prevention and treatment techniques.

Statement of Problem

The prevalence of lower extremity injuries, especially muscular strains, is increasing throughout track and field athletes (Huxley, O'Connor, & Healey, 2014). The relationship between muscular injury and the causative factors are highly debated. By exploring and correcting potential strength or range of motion deficits of participants, the total number of lower extremity injuries could be reduced. The high volume and intensity of track workouts as well as previous injuries may predispose an individual to injury. Much of the current research has focused on field or court sports, lacking the emphasis on track related injuries. The hamstring and quadriceps muscles are both biarticular muscles; however, most research has only tested knee isokinetic strength compared to hip and knee. The purpose of this study was to examine the epidemiology of muscular strains during the competitive track and field athletic season, in order to identify potential risk factors for muscular strains.

Hypotheses

H1. Participants with decreased peak torque per body weight percentages at the hip or knee will have a higher risk of injury.

H2. Participants with decreased hip or knee ranges of motion will have a higher risk of injury.

H3. Participants that previously sustained a lower extremity injury will have a higher risk for re-injury.

H4. Participants will be more likely to injure their non-dominant leg compared to their dominant leg.

Delimitations

1. All of the participants were current members of a track and field team from a NCAA Division I university in southeastern United States.
2. All of the participants were a members of the same track and field team.
3. The small sample size due to availability of participants may alter the results of the study.
4. The injury recording period only included the subjects' indoor track and field season.
5. Participants must not have had a previous lower extremity injury that restricted them from activity, within one month prior to testing.

Limitations

1. The researcher could not control the effort given by the participants during testing.
2. Although familiarization testing was completed, the researcher could not control for improper form, especially in regard to compensation, during isokinetic testing.

3. The participants had different strength training, stretching routines, and workouts depending on their specialized track and field event, which may alter the results.
4. The results relied on the honesty of all subject to report injuries that occurred throughout their competitive season or training.

Definition of Terms

Injury. Muscular related injuries are characterized as acute pain resulting from track training or competition combined with palpation point tenderness, weakness of the action of the muscle, and pain with a passive stretch of the involved muscle. The injury requires medical attention and either limits or restricts participation for 72 hours or longer (Kluitenberg et al., 2014; Opar et al., 2014; Yeung et al., 2009).

Isokinetic Exercise. An exercise that is performed at a fixed velocity with measured resistance throughout a range of motion (Prentice, 2011).

Eccentric Contraction. A contraction that causes muscle lengthening while performing its agonist action against resistance (Prentice, 2011).

Concentric Contraction. A contraction that causes muscle shortening while performing its agonist action against resistance (Prentice, 2011).

Peak Torque. The maximal strength produced by a muscular contraction that is measured in foot-pounds (Prentice, 2011).

Peak Torque per Body Weight. The maximal strength value of a muscular contraction in proportion to an individual’s body weight, measured in a percentage (Prentice, 2011).

Side to side ratio. A bilateral comparison of each limb's hamstring to quadriceps strength ratio (Brockett, Morgan, and Proske, 2004).

Flexibility. The quantified range of motion available at a joint while performing a specific motion (Bradley & Portas, 2007).

Running Gait. A full running gait cycle is classified as the moment when one foot comes in contact with the ground and ends when the ipsilateral foot rejoins contact with the ground (Novacheck, 1998).

Swing Phase. The swing phase is known as the time period between toe off and successive foot strike of the same foot (Yu et al., 2008).

Stance Phase. Stance phase is defined as the time period between foot strike and subsequent toe off of the same foot, and is completed when the first foot is no longer in contact with the ground (Yu et al., 2008).

Chapter 2

Review of Literature

Whether for leisure, recreation or competition, running is one of the most common forms of physical activity worldwide. Due to its positive health benefits and stress reducing qualities, running has become a regular activity for approximately 30 million Americans (Novacheck, 1998). Both competitive and leisure running have varying events, ranging from quick sprints to long distance. Running is also a foundational part of most field and court sports. Injury serves as an impediment for running participation. Aside from chronic pain or overuse injuries, acute muscular strains are the most common injury to result from running (Jacobsson et al., 2011). Such injuries prevent individuals from competing at optimal levels; it may limit their speed, training regimen, or their willingness to return to participation. Causative factors for muscle strains have been heavily debated, yet it has been concluded that the predisposing risks are multifactorial. There is not one single factor that serves as the greatest or most recurrent risk for muscular injury. Muscle weakness, muscular strength imbalances, decreased flexibility, lack of a proper warm-up, postural deviations, previous injury, and demographic characteristics are all commonly identified predisposing factors (Kim and Hong, 2011; Yeung et al., 2009). Examining and identifying the cause of muscular strains would provide health care professionals and athletes with the appropriate knowledge to improve injury prevention strategies.

Injury Prevalence and Risk Factors

Injury Incidence Within Athletics

Injuries in sport related activities are prevalent and can affect competitive preparations or aspirations. In fact, injury is one of the leading reasons for discontinuation of competitive athletics (Huxley et al., 2014). On average, Irish athletes spend 52 days out of the year managing and coping with the effects of an injury (Hennessay & Watson, 1993). An injury can be classified as musculoskeletal damage or pain that is sustained during training or competition, which then prevents an individual from participating in a normal training or competition regimen (Bradley & Portas, 2007; Fourchet, Horobeanu, & Heiko, 2011; Kluitenberg et al., 2014). Injuries withhold athletes from participation anywhere from 24 hours to several months. When an individual returns to full participation, the rate of re-injury is very high (Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002).

Types of injuries and their prevalence rates vary depending on the nature of the sport and training routines. Chronic injuries, those that gradually develop over time without a specific mechanism of injury, are more frequently seen in sports such as track and field due to their overuse tendencies. Whereas, acute injuries, defined as a sudden injury resulting from trauma or distinct mechanism, are seen more often in contact sports (Prentice, 2011; Opar et al., 2014). Muscular strains are the most commonly seen injury in athletics that involve maximal sprinting; more specifically the highest incidence of muscle strains occur in the hamstrings (Chumanov et al., 2007; Chumanov, Heiderscheit, & Thelen, 2011). The mechanisms of injury for hamstring strains include micro damage from repeated stress, failure to produce an adequate eccentric force to counterbalance deceleration, and the rapid transition between concentric and eccentric contractions during running (Cheung, Smith, & Wong, 2012).

Hamstring injuries are seen throughout athletics especially in sports such as soccer, football, rugby, and track and field. It has been determined that hamstring strains account for 50% of all track injuries and 40% of all soccer injuries (Yeung et al., 2009). In professional Australian sports, hamstrings injuries have high incidence rates as well. Hamstring injuries make up 16% of all injuries in professional Australian Football, 12% in professional soccer, and 15% in rugby (Yu et al., 2008). Twenty five percent of all soccer injuries were classified as soft-tissue muscle strains; more specifically, 53% of those muscle strains were experienced at the hip adductors, 42% at the knee flexors and 5% at the knee extensors (Bradley and Portas, 2007). Much of the research on injury prevalence has primarily focused on court or field sports that are considered contact sports such as football or soccer, compared to noncontact sports (Cheung et al., 2012).

Injury Prevalence within Track and Field

Track and field is a very versatile sport due to the wide variety of events included. Although there is not a standardized training profile for this sport, high volumes of work have typically been performed. Appropriate volume and intensities are difficult to establish because there is a lack of clearly set parameters (Huxley et al., 2014). Increasing injury rates, especially in regard to overuse injuries, have a direct relationship with the high intensity and volume training in track and field. Lower extremity injuries occur more frequently than injuries to other parts of the body (Jacobsson et al., 2011).

Examining all injuries that are experienced from participation in track and field activities, Fourchet et al. (2011) found that 40% of the injuries affect the foot, ankle, and lower leg, 30% of injuries occur at the knee, and 10% of injuries affect the thigh. Sprint and jumping events have been reported to cause the most acute injuries, whereas distance events usually have the largest incidence of chronic injuries. (Fourchet et al., 2011; Opar et al., 2014)

The purpose of the research completed by Huxley et al. (2014) was to examine the training profiles of youth track and field athletes and their relationship with injury. One hundred and three athletes were surveyed to identify the age at which they began sport specific training along with their perception on the intensity of their training. All of their injuries throughout their athletic career were also recorded. The average start age was seven years old and their average years of participation was between five and nine years. Through the survey, the participants' training was described as intense by the age of 13 and training intensity would continue to increase with age. As the athletes reached age 13, they were training for 10-12 months out of the year. The results exhibited that 81 out of the 103 participants sustained 200 injuries, with most of the injuries occurring in the lower extremity. Approximately 60% of those injuries were classified as overuse; however, the most frequent acute injury were muscular strains at 39%. Other frequently reported injuries included bone stress fractures, tendinopathies, ligament sprains, fractures, and shin pain. It was concluded that the injured athletes trained at significantly higher weekly intensities and had a greater yearly training load compared to the uninjured athletes (Huxley et al., 2014).

Opar et al. (2014) recorded the number of hamstring injuries that were treated during the Penn Relays over the course of three years. The Penn Relays is one of the largest and most popular outdoor track meets held annually, the participant experience ranges from high school to professional competitors. Throughout those three years, 48,473 athletes competed and a total of 118 hamstring injuries were diagnosed and treated. Those hamstring strains accounted for approximately 24% of all of the reported injuries and for 75% of all lower extremity strains. Hamstrings strains fell amongst the top 10 occurring injuries along with abrasions, spike lacerations, ankle sprains, quadriceps strains, contusions, low back pain, muscle cramps, blisters and severe fatigue. Master's athletes, individuals over the age of 40, had the highest incidence of hamstring strain injuries. Their increased incidence is suspected because of their increased body weight and reduced hip flexor flexibility. High school boys also had a significantly higher prevalence than high school girls. Males, overall, experienced more hamstring injuries compared to females at every age group. The relay events, specifically the 4x400-meter race, reported the highest incidence of injuries. Other events that documented high incidences of injury were the 100-meter race, 110-meter hurdle race, and triple jump; however, none had any statistical significance (Opar et al., 2014).

The prevalence of musculoskeletal injuries in Swedish Track and Field Athletes was studied by Jacobsson et al. (2011). Injuries of 142 youth athletes and 179 adult athletes were recorded over the course of a year, providing an injury incidence rate of approximately 43%. Overuse injuries such as tendinopathy and stress fractures occurred most frequently at the knee and lower leg. Nearly seventeen percent of all injuries were either a lower extremity strain or sprain, with the hip, groin, or thigh experiencing the most strains. Males experienced more injuries than females, with a 50% and 47% injury prevalence rate, respectively. Overuse injuries were determined to be the result of repeated micro trauma whereas, acute injuries were the direct result of executing close to maximal muscular strength during competition (Jacobsson et al., 2011).

Kluitenberg et al., (2014) found that running creates a high injury incidence. The highest reported prevalence of running related injuries has been recorded as 79% of participants. Frequently, injury is what terminates an individual’s running career. The researchers developed a “Start to Run” program in order to further investigate the incidence of injuries in beginner distance runners. There were a total of 1,696 participants between the ages of 18 and 65. The goal of the running program was to prepare the individuals to complete a continuous 20 minute run, with only a maximum of three training sessions per week. At the completion of the six week program, the participants had a weekly running exposure of 49 minutes per week. During the duration of the program, 185 individuals (10.9%) experienced a running related injury. The majority of injuries occurred during weeks two and three. Distance running caused a numerous overuse injuries with 38.4% of all injuries occurring at the knee, 20% at the calf, and 13% at both the achilles tendon and shin. The study concluded that increased age, increased body mass index, previous injury, and less experience all increased the incidence of running related injuries (Kluitenberg et al., 2014).

Risk Factors of Muscular Injuries

Risk factors leading to muscular related injuries have been a highly debated topic throughout research and by clinicians (Yeung et al., 2009). There have been many suggested causative factors that have not been proven to have a direct correlation with injury occurrence. Intrinsic factors such as strength and flexibility are most often argued. However, it has been determined that risk factors are multifactorial (Yeung et al., 2009). The lack of a definitive list of causative factors for injury makes it difficult to develop effective injury prevention protocols.

Aside from tension or an overstretching mechanism, there are a multitude of factors that are suspected to lead to injury. Increased body mass index, age, less running experience, and previous injury have been identified as intrinsic factors that increase risk (Kluitenberg et al., 2014; Opar et al., 2014). Strength deficits or muscular imbalances are also noted as intrinsic factors that lead to both muscular and ligamentous injury. Strength deficits are characterized by a hamstring to quadriceps ratio (H:Q) peak torque that is lower than 60% or one that is significantly lower than the contralateral limb (Cheung et al., 2012; Greco, Da Silva, Camarda and Denadai, 2012). The lower the peak torque per body weight, the greater the risk for injury (Sugiura et al., 2008). Suggestions have been made regarding how improved or normative ranges of motion values can decrease stress on specific muscles, such as the hamstring, but those two factors have not been directly associated to affect injury risk (Bradley & Portas, 2007). Hip and low back pathologies such as leg length discrepancies or lumbar plexus nerve entrapment may also predispose an individual to hamstring injuries (Croisier et al., 2002). Extrinsic factors that influence injury may include running shoes, training programs, and running surfaces, yet they have not been proven (Kluitenberg et al., 2014). Fatigue, especially anaerobic fatigue, and the lack of a proper warm-up have also been identified to lead to injury (Opar et al., 2014). It is important to focus on the modifiable risks while assessing preseason health exams and also during post-injury treatments.

Previous injury has been a substantiated contributor to injury and re-injury. Brockett et al. (2004) identified that hamstring injuries are more likely to occur when an individual has experienced a previous strain. They compared uninjured and previously injured elite sprinters to identify injury predisposition. Contributing factors included muscle weakness, muscle flexibility, fatigue, inadequate warm up, and poor lumbar posture. The group of previously injured participants exhibited lower H:Q peak torque and overall lower side-to-side ratio of peak torque on the injured limb. Jonhagen, Nemeth, and Eriksson (1994) identified strength deficits at multiple angular velocities in previously injured sprinters. Specifically, the greatest deficits presented in eccentric knee flexion strength and concentric hip extension strength. Evidence supports the hypothesis that a previously injured hamstring shows evidence of greater susceptibility for the microscopic damage caused by repetitive eccentric exercise, because the optimum length for tension is decreased (Brockett et al., 2004).

According to Malliaropoulos et al. (2011), re-injury rates for hamstring injuries are extremely high. In fact, it has been reported that the recurrence rate has reached 34% in the year following the initial incidence. Over the course of one year, 165 track and field athletes were monitored after being diagnosed with a first time acute hamstring strain. Twenty-three (13.9%) of the athletes experienced another strain on the same leg. Correlations between decreased active knee range of motion and the severity of the initial injury were found to increase risk of re-injury. The clinicians in this study graded hamstring strains on a scale of I to IV. Grade II strains displayed the highest incidence of re-injury, with 58 initial strains and 14 recurrences. The grade of the strains exerted a significant effect on the time to return to participation following their injury. However, there was no significance between the grade severity and the time lapse between re-injury (Malliaropoulos et al., 2011).

In a study conducted by Croisier et al. (2002), strength profiles and recurring injuries were examined in track and field, soccer, and martial arts athletes that had previously sustained a hamstring injury. The athletes recruited for the study included anyone that was participating without limitations, but had been treated by a medical professional or had a history of prolonged hamstring pain. Through isokinetic testing, the participants displayed strength deficits with their peak torque, bilateral differences, or their H:Q. The deficits confirmed that there is a greater risk for injury in previously injured athletes, compared to an athlete who has never experienced injury (Croisier et al., 2002).

Muscular Injury Evaluation

Identifying and diagnosing muscular injuries that occur during athletic related events is primarily completed by athletic trainers, physiotherapists, physical therapists, and sports medicine doctors. Muscular related injuries are characterized by acute pain combined with palpation point tenderness, weakness of the action of the muscle, and pain with a passive stretch of the involved muscle (Opar et al., 2014). In order to differentiate between soreness and injury, an injury is classified as a musculoskeletal disorder requiring medical attention or treatment for longer than 72 hours (Kluitenberg et al., 2014). Most often, symptoms and clinical assessments are used to diagnose such injuries; although, magnetic resonance imaging (MRI) is also a popular diagnostic tool (Prentice, 2011). MRI is typically used to confirm clinical findings. Clinicians rely on manual muscle tests to determine a strength deficit of a particular muscle (Yeung et al., 2009). Manual muscle tests are specific to each action that a muscle produces. When testing a specific action, a muscle can earn a grade ranging between five and zero based on the strength of the produced contraction. According to Prentice (2011), all assessments should be compared bilaterally. Five exemplifies full strength against gravity, whereas a zero is given when no contraction is produced.

Muscle strains are classified as an overstretching of, tearing of, or rupture of muscle fibers. Strains develop from a tension overstretch or a forceful contraction against too much resistance (Chumanov et al., 2007; Prentice, 2011). Depending on the severity of a damaged muscle, there are three different classifying grades. A grade one muscle strain, the least severe, results from some muscle fiber stretching or tearing. Pain is present, yet an athlete is able to withstand some resistance and can contract through a full range of motion. A larger number of muscle fibers are involved in a grade two muscle strain, which limits the range of motion in an active contraction and causes a greater amount of pain. Grade three muscle strains, the most severe, are described as a complete rupture in some area of a muscle belly. Movement is extremely restricted in the instance of a grade three strain. Healing time is directly affected by the severity of a strain (Prentice, 2011; Jacobsson et al., 2011).

Treatment of Muscular Injuries

Although the treatment of a muscular injury may differ depending on its severity, research has shown that proper care reduces the rate of reinjury. Recurrent hamstring strain injury rates are high and have been reported up to 34% (Malliaropoulos et al., 2011). In order to reduce the number of hamstring re-injuries, the mechanism and causative factors must be understood. Acute injury treatments during the inflammatory phase does not usually have much variation between health care providers; however, the long term rehabilitation or therapeutic exercise protocols vary and could have the most effective results.

In a study completed by Brockett et al. (2004), greater susceptibility to a hamstring strain is caused from microscopic damage during repeated eccentric exercise; therefore, they suggest completing eccentric strengthening programs following injury. It was also concluded that concentric exercises reduce the number of sarcomeres leading to a decrease in optimum angles during running, which is an adverse goal during rehabilitation (Brockett et al., 2004; Croisier et al., 2002). Running biomechanics illustrate that the hamstring muscles undergo a great amount of eccentric stress, which also explains why eccentric strengthening is a pivotal point in the rehabilitation process (Yu et al., 2008).

In addition to strengthening the hamstring muscles, some researchers advise focusing on the flexibility and strength of surrounding musculature during treatment.

Iliopsoas and quadriceps tightness were correlated to hamstring injury by Bradley and Portas (2007). They suggested that part of the treatment process should focus on stretching of the hip flexors. Both Chumanov et al. (2007) and Malliaropoulos et al. (2011) propose targeting neuromuscular control of the abdominis oblique, erector spinae, and iliopsoas muscles during rehabilitation to reduce the stress placed on the hamstring muscles. Weak gluteus and adductor muscle groups have also shown to increase the risk factors of a hamstring strain (Kluitenberg et al., 2014). Combining stretching techniques with strengthening may lead to optimal results.

After identifying strength deficits in previously injured athletes, Croisier et al. (2002) also assessed the effectiveness of rehabilitation protocols. Those who possessed muscle imbalances were prescribed individualized treatment protocols that targeted weak muscles revealed by their strength profiles. The number of treatment sessions varied between 10 and 30 depending on the demands of the specific deficit. However, at the completion of each athlete's treatment protocol, they were retested isokinetically; all but one athlete established isokinetic normalization. Not only was their strength improved, but their perceived pain had also decreased following rehabilitation. Once their strength deficits were corrected, they were tracked for 12 months, none of them sustained another hamstring injury during that time. Improving treatment strategies so that they are more specific to the mechanism of injury and biomechanics will decrease the risk of reinjury, especially in regard to hamstring strains (Croisier et al., 2002).

Biomechanics of Running

Anatomy

The biarticular nature of the hamstring muscle group is another characteristic of the commonly injured muscle (Malliaropoulos et al., 2011). Three individual muscles make up the hamstring muscle group that performs actions at both the hip and the knee. The biceps femoris is the lateral hamstring that originates at the ischial tuberosity, a bony prominence on the ischium, and attaches at the head of the fibula. At the knee, the biceps femoris is responsible for knee flexion and external rotation. It also assists hip extension, lateral rotation of the hip and posteriorly tilts the pelvis. The medial hamstring muscles include the semitendinosus and the semimembranosus. Both of them attach proximal to the hip joint, to assist hip extension and medial rotation, and also flex and medially rotate the knee. The powerful antagonist muscle group, is the quadriceps femoris, comprised of four different muscles. Crossing both the hip and knee as well, the quadriceps is primarily responsible for flexing the hip and extending the knee (Prentice, 2011). The hamstring muscle group is weaker than the quadriceps. A healthy, normative hamstring to quadriceps strength ratio ranges between 60-80%. The closer to 100%, the less risk of muscular imbalances or injury (Yeung et al., 2009).

Running Gait

While running, the quadriceps and hamstring muscle groups perform opposing actions. Throughout the running gait, the quadriceps muscles predominantly contract concentrically; whereas the hamstring muscles are quickly switching between eccentric and concentric activity (Chumanov et al., 2007). Concentric contractions are classified as the shortening of a muscle while it is performing the agonist action against resistance. On the other hand, eccentric contractions are characterized by muscle lengthening during antagonist actions against resistance. Eccentric contractions require more strength and are considered more stressful (Pontaga, 2004).

Although walking, running, and sprinting occur naturally and are learned at a young age, the actions are in fact very complicated. Walking or running at different speeds require different biomechanical contractions. A full gait cycle begins when one foot comes in contact with the ground and ends with that same foot reuniting contact with the ground (Novacheck, 1998). There are three main phases of running gait that include the stance phase, the swing phase, and lastly the flight or mid swing phase. Stance phase is defined as the time period between foot strike and subsequent toe off of the same foot, and is completed when the first foot is no longer in contact with the ground. The swing phase is known as the time period between toe off and successive foot strike of the same foot; whereas, mid swing is the time between toe off and contralateral foot strike (Yu et al., 2008). A key difference between running and sprinting is the ground contact. Rearfoot strike is more common during long distance running and midfoot strike is present with sprinting. The knee also moves throughout a greater arc of motion at greater speeds (Novacheck, 1998).

Running places a demand on the entire body; however, the most active joints during running are the hip, knee and ankle. The most action and power while running occurs in the sagittal plane. At the hip joint, the quadriceps fires from late swing up until midstance in order to prepare the lower leg for ground contact. During the swing phase, the rectus femoris is only active to restrain posterior translation of the tibia as the knee flexes. Maximal hip extension takes place just before toe off, while maximal hip flexion occurs in the mid swing phase. In order to generate a greater stride during sprinting, maximal hip flexion occurs. Consequently, the hamstring undergoes more stress because it is required to lengthen. Hip extension then reoccurs at the second half of the swing phase in order to prepare for initial contact with the ground. The hamstring works both concentrically and eccentrically while the other hip extensors (gluteal muscles) only contribute concentrically (Sugiura et al., 2008). The hamstring muscles are also responsible for the deceleration of the tibia as the knee extends. At the ankle, the tibialis anterior performs a concentric contraction to allow ground contact at the hindfoot and then transitions to an eccentric contraction for the lowering of the forefoot to the ground (Novacheck, 1998).

Injury Occurrence During Running Gait

Any slight biomechanical abnormality experienced during running may result in injury (Novacheck, 1998). Research has compared injury occurrence during both the stance phase and swing phase. Although injuries have been proven more prevalent during the swing phase, there is potential for injuries to take place at any point during the gait cycle (Chumanov et al., 2007; Chumanov et al., 2011). As previously stated, the hamstring muscles are the most commonly injured muscle during running (Chumanov et al., 2007). More specifically, the biceps femoris is the most frequently injured out of the entire hamstring group. The hamstring muscles, compared to the quadriceps, are active throughout the entire gait cycle. However, the hamstrings produce an eccentric contraction during the late swing phase as well as the late stance phase. During the late swing phase, the activation of the hamstring muscle is approximately three times greater than activation during the early swing phase and late stance phase. The muscle-tendon length curve of all hamstring muscles provided a peak torque during both phases as well. However, the muscle-tendon length was the shortest during the late swing phase. Due to the results, Yu et al. (2008) concluded that hamstring injuries are more likely to occur at the muscular tendon junction during the late stance phase. However, injuries in the late swing phase are more likely to happen in the muscle belly. The greater incidence of injury throughout the late swing phase has been associated with the increased peak muscle tendon length and eccentric contraction (Yu et al., 2008).

Pontaga (2004) investigated the intricate biomechanics of the hamstring muscle group because of its ability to influence movements at the knee and hip. After analyzing the running gate of eight elite male sprinters, ground reaction forces were found to produce a large knee extension torque and a large hip flexion torque during the initial stance phase. The knee extension torque created by the quadriceps stretched the ipsilateral hamstring fibers in opposite directions. In order to counteract the ground reaction force, the hamstrings rapidly fire from a concentric contraction into an eccentric contraction during the swing phase. The hamstring also produced substantial knee flexion and hip extension torques in order to oppose the powerful hip flexor group. If the hamstring muscle group does not counteract those forces, injury often results. Although an immense load is borne by the hamstrings in both the initial stance and late swing phases, maximal lengthening and increased peak torque produce more injuries in the swing phase (Pontaga, 2004).

Conversely, Chumanov et al. (2011) found that negative, or eccentric, work was only produced during the swing phase of running. The musculotendon length of the hamstrings are lengthened and perform eccentric contractions from approximately 50-90% of the entire gait cycle; subsequently they shorten and produce a concentric contraction from 90% through the completion of the stance phase. The hamstrings do however, yield an increase force from the contact load during the stance phase. Two of the largest peak torques were produced from the hamstrings during both late swing and stance phase. Injury while sprinting has been conclusively linked to the repeated lengthening of the hamstrings through the swing phase (Chumanov et al., 2011).

The research completed by Schache, Wrigley, Baker, and Pandy (2009) compared the biomechanics of running in an individual with a history of recurrent hamstring injuries, before and after an acute hamstring injury. Previously, the subject sustained injuries to the right hamstring. A series of 30-meter sprints were performed and an injury, confirmed through MRI, was experienced on the tenth trial. Following the injury, more sprint trials were completed. Deviations were observed at the trunk, pelvis and right hip. The peak degree of hip flexion, hip and knee torques, and power on the right side were all significantly lower than the pre-injury sprint trials. More importantly, the peak knee power absorption on the injured leg substantially decreased, which explains the hamstrings inability to work eccentrically after injury. Not only do these results exhibit differing kinematics following injury, but they also outline that previous injuries predispose an individual to a greater risk of re-injury (Schache et al., 2009).

Influence of Speed on Running Gait

The influence of speed on injury has been widely investigated because muscular strains occur more frequently in the sprinting population compared to long distance runners (Chumanov et al., 2007; Opar et al., 2014). Increased speed has demonstrated a greater production of peak torques, ground reaction forces, and power in the lower extremity and trunk (Schache et al., 2009). As the hamstrings demonstrate both eccentric and concentric contractions throughout multiple phases of the running gait, it has been noted that both negative and positive work increase significantly with speed. However, the negative forces created by the hamstrings increased more quickly than the positive work did. The amount of peak force produced had a direct correlation with greater speeds during the swing phase; however, the peak force was independent of speed at the stance phase. Breaking it down by individual hamstring muscle, the biceps femoris was found to have a greater peak torque in the swing phase compared to the stance phase, at faster speeds. Whereas, the semimembranosus peak torque was consistent at all speeds (Chumanov et al., 2011).

Acute hamstring strains have been associated with maximal running speeds. Chumanov et al. (2007) examined how speed influenced hamstring mechanics throughout the swing phase. Nineteen athletes completed treadmill sprints comparing whole body kinematics and hamstring work at both 80% and 100% maximal speed. The results displayed that hamstring muscle excitation was initiated at approximately 70% of the running gait and elevated throughout the remainder of the swing phase. The maximal peak torque took place at about 90% of the gait cycle. Musculotendon units lengthened from 50-90% of the gait cycle; however, the peak hamstring stretch was independent of speed. Since speed significantly increases the amount of negative work produced by the hamstrings, it magnifies the influence of stretch that the lumbo-pelvic muscles place on the hamstrings as well. In conclusion, there are two suggested theories that explain why increased speed increases injury. First, there is a large amount of repeated, negative work completed during running that causes an accumulation of micro damage. Secondly, the neuromuscular control fluctuates at increasing speeds that create a variation from stride to stride (Chumanov et al., 2007).

Strength Deficits and Injury

Muscular strength is examined as a potential risk factor for injury because it is an important factor in achieving optimal performance. The hamstring and quadriceps muscle groups are both biarticulate and produce opposing actions at both the hip and knee. An imbalanced H:Q has been correlated to increase the incidence of injury within the lower extremity. The H:Q is used often due to its examination of strength on the agonist and antagonist musculature of the knee and hip joint during running or other explosive activities (Cheung et al., 2012). Normative values of H:Q peak torque range between 50-80%. Patients with H:Q peak torque values that are below 60% typically have higher injury exposure rates; while patients with values closer to 100% do not experience as many lower extremity pathologies (Yeung et al., 2009). A significant force is produced by both muscle groups while running. The hip extensors work concentrically during the swing phase and initial stance phase, while the knee flexors act eccentrically throughout the swing phase (Schache et al., 2009). On the other hand, the hip flexors and knee extensors produce a concentric force throughout the running gait (Pontaga, 2004). The rapid rate of change from eccentric to concentric contractions along with the ability for constant muscle excitation requires appropriate strength (Chumanov et al., 2007). Although most research does suggest a correlation between strength deficits and injury, deficits have not been consistently predictive for injury (Cheung et al., 2012; Greco et al., 2012; Sugiura et al. 2008; Yeung et al. 2009).

Sugiura et al. (2008) identified strength deficits present at both the hip and knee joints and their relationship with injury. In order to assess strength, their testing mimicked the same contractions produced during running in order for the results to be more functional. Utilizing the Biodex at three different speeds, hip extension and flexion were tested in a concentric/concentric motion and knee flexion and extension were tested in an eccentric/concentric setting. For the year following strength testing, hamstring injuries that the sprinters sustained while running were documented. Six sprinters (20%) experienced hamstring injuries during the year. Deficits at 60 degrees per second with eccentric knee flexion and concentric hip flexion were identified in the injured population. Comparing the limbs bilaterally, the injured limb had a weaker strength profile. The H:Q was also reduced in those that were injured. The results confirmed that poor hamstring strength predisposes sprinters to injury (Sugiura et al., 2008).

In a study conducted by Yeung et al. (2009), the incidence of hamstring muscle strains and potential preseason risk factors were explored. Prior to the start of the season, hamstring flexibility and H:Q were recorded in 44 sprinters. The participants completed isokinetic Biodex testing that consisted of concentric hamstring contractions, eccentric hamstring contractions, and concentric quadriceps contractions at the knee. Each person completed five contractions at 60, 180 and 240 degrees per seconds, with two minutes of rest between each activity to avoid fatigue. Following testing, athletes were instructed to report any injury that resulted from athletic competition to their coach throughout the duration of the season. Overall, 24 injuries occurred, half of them were hamstring strains. Most of the injuries took place within the first half of the season. The results exhibited that the participants whose eccentric hamstring to concentric quadriceps ratio (H_{ecc}:$Q_{con)}$, below 0.6 at the speed of 180 degrees per second, had an increased risk for injury. Identifying a strength imbalance present in sprinters prior to the season served as a predictor for injury (Yeung et al., 2009).

Delextrat, Baker, Cohen and Clarke (2013) investigated strength deficits influenced by fatigue. The researchers suspected that injuries would occur in participants who had a H_{ecc}:Q_{con} below 0.7. The maximal aerobic capacity was assessed in 14 female collegiate soccer players, followed by baseline strength measurements. The subjects then completed a Loughborough Intermittent Shuttle Test (LIST), an exercise designed to promote fatigue. Following completion of the exercise program, the athletes' strength was recorded again and compared to the baseline values. Peak torque values for the hamstrings were the only values with a significant decrease after subjects participated in the LIST. Reduced H_{ecc}:Q_{con} values were also exhibited following the exercise program.

Most importantly, it was concluded that the quadriceps muscle group does not fatigue as easily as the hamstring musculature with strenuous exercise (Delextrat et al., 2013).

The primary focus of the study performed by Cheung et al. (2012) was to investigate the significance of muscular strength in a variety of sports. Strength differences between dominant versus non-dominant legs were also explored. A substantial H:Q peak torque value was determined to range between 0.5 and 0.8. The study included 23 male collegiate soccer athletes and compared their results to 5 male basketball and 12 male volleyball players. Isokinetic Biodex testing was completed by all athletes at 60 and 300 degrees per second. The different speeds were used in order to stimulate muscles that were activated during functional movements. Results highlighted that field players exhibited lower hamstring strength in their dominant legs, compared to court players. The difference in results was explained through training adaptations of each sport (Cheung et al., 2012).

Rather than comparing strength imbalance to injury, the goal of the research completed by Greco et al. (2012) was to examine the different factors leading to varying H:Q. Their research was influenced by the explosive activities in soccer; in fact, they did not believe that solely the concentric peak torque value was an appropriate determinant of soccer players' strength. Alternatively, the researchers analyzed the rate of torque development. Thirty-nine uninjured, male professional soccer players underwent isokinetic Biodex testing at the velocity of 60 degrees per second. Their concentric H:Q values were ranked in order from highest to lowest. The results demonstrated that those with higher concentric torque values also obtained a greater rate of torque development values. However, the correlation between the two values did not show any statistical significance (Greco et al., 2012).

Dominant vs. Non-dominant Legs

Asymmetrical muscle strength has proven to be a possible risk factor for lower extremity injuries; specifically, some research has explored the differences between dominant and non-dominant legs (Cheung et al., 2012; Delextrat et al., 2013; Kim & Hong, 2011). Injuries are more likely to occur on the non-dominant leg due to decreased neuromuscular control and strength deficits (Chumanov et al., 2007). Although, if one limb has previously experienced an injury their risk of injury is increased on the ipsilateral limb, regardless of the leg dominance (Malliaropoulos et al., 2011). A low side-to-side ratio of peak torque predisposes individuals to muscular injuries (Brockett et al., 2004). Measuring bilateral muscular strength has given health care providers insight on how to establish appropriate prophylactic and post-injury treatment protocols.

Results gathered from Cheung et al. (2012) discovered an increased risk for injury when there is a bilateral difference in muscle strength. Specifically, if the non-dominant hamstring was 15% weaker when compared bilaterally, then the rate of injury was greater. In the study conducted by Delextrat et al. (2013), strength profiles of both legs were recorded. All of participants that sustained injuries on their non-dominant leg had a H:Q that was lower than 0.6 prior to the injury. On the other hand, the dominant leg did not reveal any significant results. Both legs drastically decreased H:Q when fatigued. It was concluded that women more commonly injure their non-dominant leg while men are more likely to injure their dominant leg (Delextrat et al., 2013).

Aginsky, Neophytou, and Charalambous (2014) aimed to establish strength profiles in South African soccer athletes, due to the overwhelming occurrence of lower extremity injuries. The strength profiles were created using isokinetic Bidoex testing at 60 and 180 degrees per second to measure concentric and eccentric values for both the hamstring and quadriceps muscle groups. Comparing the results bilaterally, there were many differences. Twenty-eight percent of the participants' dominant leg concentric H:Q was below 60%. However, 57% of the participants had a decreased concentric H:Q on their non-dominant leg. The eccentric values had very similar results in regards to the reciprocal ratio. Thirty-two percent had below average non-dominant leg values. The peak torque to body weight ranges were also evaluated, displaying that the dominant hamstring muscle was substantially stronger at both velocities. When measuring the relative fatigue ratio, there were not any significant results for the dominant versus the non-dominant side (Aginsky et al., 2014).

Flexibility Deficits and Injury

A lack of flexibility within hip and knee musculature has also served as a plausible risk for muscle strains. Flexibility is quantified by the range of motion available at a joint while performing a specific motion (Bradley & Portas, 2007). Decreased range of motion or flexibility reduces optimal, synergistic muscle function. Primarily, the quadriceps muscle is responsible for hip flexion and knee extension. Normal range of motion for hip flexion is 120 degrees while knee extension is zero degrees. Conversely, the main action of the hamstring muscle is to extend the hip and flex the knee. The average value for range of motion of hip extension is 15 degrees and knee flexion is 135 degrees (Prentice, 2011). When the flexibility of these muscles was compromised, there was an increased risk of injury (Devan, Pescatello, Faghri, & Anderson, 2004, Yeung et al., 2009).

The study performed by Yeung et al. (2009) examined the correlation between injury and hamstring flexibility. In order to assess hamstring flexibility, the straight leg test (SLR) was utilized. Subjects underwent a warm-up protocol prior to the flexibility testing. The SLR required patients to lay supine on a treatment table, the investigator then passively flexed the patient's hip to its end range, while maintaining knee extension. A goniometer was used to measure the range of motion. Although 24 total hamstring injuries were reported during the athletic season, there was no significant difference on the influence on flexibility (Yeung et al., 2009).

Bradley and Portas (2007) examined the relationship between preseason range of motion values and muscle strains within elite soccer players. Range of motion measurements decrease with training due to hypertrophy and frequent use of muscles at a high intensity, therefore the researchers collected six static ranges of motion prior to the start of training. Hip extension, hip flexion, knee extension, knee flexion, ankle dorsiflexion, and ankle plantar flexion were all measured. Throughout the duration of the season, 32 out of the 36 (88.9%) subjects experienced an injury. Knee flexor strains were the most common injury, followed closely by hip flexor strains. Injured participants displayed significantly decreased ranges of motion in their hip and knee flexors, compared to the uninjured group. Increased iliopsoas tightness was more evident in those injured that season. The range of motion values in the injured group were approximately three degrees less than the uninjured, concluding that decreased range of motion creates a greater risk for injury (Bradley & Portas, 2007).

Comparing healthy sprinters to previously injured sprinters, Jonhagen et al. (1994) found range of motion deficits. Hamstring flexibility was measured through passive hip flexion. The uninjured sprinters had an increased range of motion at the hip, with an average difference of seven degrees between the groups. The results exhibited that previously strained hamstrings led to tighter musculature (Jonhagen et al., 1994).

Sports medicine professionals commonly perceive decreased ranges of motion or postural deviations as a predisposition to injury, yet the supporting evidence has been inconclusive. Hennessay and Watson (1993) compared the flexibility and posture in a group of 16 previously injured subjects and 16 individuals with no history of injury, in order to identify hamstring injury risk. No differences were displayed between left or right legs, injured or uninjured legs, or for the average flexibility rates in either group. There were also no significant postural deviations found between the two groups. In conclusion, Hennessay and Watson (1993) were unable to find any correlations between posture and flexibility on previously injured individuals.

Devan et al. (2004) also observed structural deviations as a risk factor for overuse injuries of the lower extremity. Using a goniometer, the examiner looked for the presence of genu recurvatum. Genu recurvatum, or increased knee extension, was present in nine of the participants. It was concluded that patients with genu recurvatum measurements greater than or equal to 10 degrees, accompanied by a strength imbalance at 300 degrees per second, had a higher exposure to overuse knee injury (Devan et al., 2004).

Summary of Literature

The incidence of injury, especially muscular strains, is common among athletes. Fifty percent of track and field athletes experience a hamstring injury each season (Yeung et al., 2009). The risk factors have been debated and it has been concluded that the causes of muscle strains are multifactorial. One substantiated risk factor includes previous injury (Brockett et al., 2004). While running, the hamstrings repetitively switch between eccentric and concentric contractions. When the forces produced by the hamstring cannot withstand the forces produced by the quadriceps, injury results (Novacheck, 1998). Throughout the running gait, injury is most likely to occur during the swing phase because the hamstrings are lengthened while producing a large negative force (Chumanov et al., 2011). Injuries occur more frequently at greater speeds as well due to a greater production of peak torque (Schache et al., 2009). Research has investigated strength deficits as a potential risk factor (Sugiura et al., 2008). Injuries are more likely to occur in individuals with hamstring to quadriceps ratios that fall below the suggested range of 60-100%. Lower peak torque per body weight values, especially as speed increases, has been shown to increase the risk of injury as well. Concentric hip extension and eccentric knee flexion have exemplified weaker profiles in individuals that have experienced injuries (Sugiura et al., 2008). When comparing leg dominance, the non-dominant leg is weaker and has a greater injury prevalence (Cheung et al., 2012; Deletxtrat et al., 2013; Kim & Hong, 2011). Flexibility has also been a heavily debated factor because the research is inconsistent (Bradley & Portas, 2007; Hennessay and Watson 1993; Yeung et al., 2009). Bradley and Portas (2007) found that athletes with decreased hip and knee flexion flexibility experience injuries more often. Considering muscle strains account for approximately 50% of injuries in runners, an emphasis of research should be conducted on track athletes in comparison to field sports (Yeung et al., 2009). Identifying the causative factors of muscle strains would promote stronger and more effective injury prevention plans throughout athletics.

Chapter 3

Methods and Procedures

Participants

Twenty track and field athletes that specialize in sprinting, jumping, or distance events from a Division I institution in the southeastern United States were recruited for the study. There were six male and 14 female participants. The ages of the participants ranged between 18 and 22, with the average age being 19.6 years old. The subjects had a mean of 7.80 years of track and field experience, ranging between five and fourteen years. Specifically, there were nine sprinters, six jumpers, and five distance runners. On average, the individuals practiced five days a week, participated in strength training 3.30 days per week, and completed a stretching protocol 4.95 days per week. Participants were excluded if they had experienced a lower extremity muscle strain within the past month or if they had a current injury or condition that prevented them from appropriately completing the testing procedure.

Research Design

The research design used for this study was correlational in order to determine if a relationship was present between hip and knee ranges of motion or strength with injury occurrence. Correlations between previous injuries as well as non-dominant and dominant leg injuries and injury prevalence were also analyzed. All data were analyzed using a Pearson correlation coefficient as well as a Spearman *rho*. The independent variables were the ranges of motion, strength, previous injuries, and leg dominance and the dependent variable was the presence of a lower extremity muscle strain. The

Statistical Package for the Social Sciences (SPSS) program was used to analyze all collected data.

Procedures

Prior to participant recruitment, permission to complete the study was obtained by the institutional review board (IRB). An email was sent to the athletic director, head track and field coach, and associate head coach asking for permission of the student athletes to participate in the study. Recruitment consisted of an email to the track and field team explaining the purpose of the research, a brief description of the methods, along with the benefits and risks. Participation was voluntary and the participants had the right to withdraw from the study at any time, without consequence.

Participants completed an informed consent form and a debriefing form was provided before testing took place. All of the subjects filled out a Health Insurance Portability and Accountability Act (HIPPA) form to ensure confidentiality. Individuals were then instructed to fill out a pre-participation survey. The survey summarized their leg dominance, years of experience, personal track events, strength training regimen, stretching regimen, and their previous injury history. Each subject was assigned a number, which was placed on all of their paperwork in order to assure confidentiality.

Following the paperwork, subjects warmed up by riding a stationary bike for 10 minutes. In order to assess flexibility, ranges of motion were measured with a standard goniometer at both the hip and knee. Intra- and inter-rater reliability were both confirmed by having the participants complete warm-up motions, taking an average of three trials, and by recording all measurements by the researcher. Hip flexion was measured while the subjects lay supine and raised their leg upward, whereas hip extension was completed in a prone position and by lifting their leg backwards. Knee flexion was also measured in a prone position while they bent their knee. The subjects laid supine, with a bolster supporting their feet, while knee extension was measured. Each motion was explained ahead of time and the individuals were encouraged to complete the range of motion until they reached their end range, without compensating.

Manual muscle tests were also included in testing to compare values pre- and post- injury. The same assessments were used during injury evaluations. Each movement was graded on a scale of zero through five, depending on their ability to sustain manual resistance against gravity and compared bilaterally. Again, inter-rater reliability was confirmed by having the tests completed by the same researcher during both testing and post-injury. The motions tested at the hip include flexion (both supine and short-seated), extension, abduction, and adduction. The motions tested at the knee included extension and flexion with a neutral foot, internally rotated foot, and externally rotated foot.

Isokinetic strength for both hip and knee flexion and extension, was measured using the Biodex System 3 dynamometer (Shirley, New York). The parameters chosen mimicked the actions of the hamstring and quadriceps muscle groups during the running gait. The testing protocols were explained to the patients prior to testing and maximal effort was encouraged. Each subject completed a familiarization procedure for the isokinetic strength testing at each velocity approximately two weeks before testing. On the testing day, the individuals warmed up on a stationary bike for 10 minutes.

Knee isokinetic strength testing was completed first on both legs. Participants were seated for this testing protocol with straps crossing over their torso, waist, and thigh in order to avoid compensating movements. The dynamometer and the chair positions were adjusted between each subject to ensure that individuals were seated upright, with the dynamometer aligned at their knee joint, and the attachment arm secured just below the belly of their calf muscle. The subjects were asked to perform three sets of eccentric concentric knee flexion at three different velocities. The first set included eight maximal repetitions at 60 degrees per second, followed by six repetitions at 180 degrees per second, and lastly 12 repetitions at 300 degrees per second. A minute of rest was given between each set to avoid fatigue or muscle cramping. Testing was completed on their dominant leg first and their non-dominant leg second.

Hip isokinetic strength testing was completed immediately after the knee was tested. The testing protocol required the subjects to stand with the dynamometer aligned at their greater trochanter. The attachment arm was secured at the mid thigh and their knee was bent as they performed both movements. A balance stick was provided to limit trunk motions and assist with the single leg position. The subjects were asked to perform three sets of concentric hip flexion and extension at three different velocities. Again, the first set included eight maximal repetitions at 60 degrees per second, six repetitions at 180 degrees per second, and 12 repetitions at 300 degrees per second with a minute of rest between each set. Their dominant leg was tested first, followed by their non-dominant leg. All of the isokinetic testing was completed by one researcher.

Throughout the entirety of the participants' competitive indoor track and field season, their lower extremity muscle strains were recorded. The subjects were instructed to inform their athletic trainer of any pain or discomfort that resulted from athletic participation. If an individual suspected an injury, the athletic trainer performed a complete evaluation including a subjective history along with an objective clinical assessments. Lower extremity muscle strains were characterized by palpation point tenderness, weakness of the action of the muscle, and pain with passive stretch of the involved muscle that limited or restricted participation for three days or longer (Opar et al., 2014). Both the subject and athletic trainer completed a post-injury questionnaire that described their mechanism of injury, injury details, diagnosis, and the amount of time it took them to return to full participation. Although they competed in indoor track facilities, their training was performed on an outdoor track or in the university's weight room; any injury that occurred in any of those places were included.

Chapter 4

Results

Data were collected on 20 Division I track and field athletes. During the competitive indoor track and field season, six (30%) of the participants sustained a lower extremity muscular injury. Two of the injured participants were jumpers and four were sprinters. No distance runners sustained an injury. Four subjects strained their non-dominant hamstring, one injured their dominant hamstring, and one person strained their non-dominant quadriceps. Two of the injuries took place during competition in the 200-meter sprint and the triple jump. One of the injuries occurred during practice in the 60-meter hurdles and three of them occurred while practicing relay events. During testing, all of the participants scored a five on the manual muscle tests at both the hip and knee motions. All six of the participants had decreased manual muscle test grades following injury.

Previous injury and the effect on injury prevalence

There was a strong significant correlation between previous injury and injury occurrence in a two-tailed Spearman's *rho* (rho= .592, p< .006). This supports the hypothesis that participants who previously sustained a lower extremity muscular injury have an increased risk to injury exposure.

Injuries sustained on dominant leg compared to non-dominant leg

There was no significant correlation between injury and leg dominance (rho=.218, p<.355).

Ranges of motion in correlation with injury

The Spearman's *rho* displayed a significant negative correlation with left hip extension range of motion and injury, identifying that decreased range of motion will lead to higher risk of injury (rho= -.496, p< .026). There were no significant correlations between hip flexion, knee extension, or knee flexion ranges of motion on either leg.

Knee peak torque/body weight in correlation with injury

Neither the Spearman's *rho* nor the Pearson correlations exhibited statistically significant correlations between injury and eccentric knee flexion, for both right and left legs at 60, 180, and 300 degrees per second.

Hip peak torque/body weight in correlation with injury

There was a significant negative correlation between peak torque per body weight on right hip extension at 300 degrees per second; indicating that decreased values lead to higher risk of injury using a Spearman's *rho* correlation (rho= -.454, p< .044). However, there were no statistically significant correlations between injury and right hip extension at 60 or 300 degrees per second, right hip flexion at any, or left hip extension or flexion at any of the three velocities.

Table 1
Descriptive Statistics of Pre-Participation Profile

	Number	Mean	Standard Deviation
Age	20	19.65	1.23
Males	6		
Females	14		
Jumpers	6		
Sprinters	9		
Distance	5		
Years of Experience		7.80	2.40
Days/Week Strength		3.30	1.22
Days/Week Stretch		4.95	1.54
Injured Participants	6		

Table 2
Range of Motion Descriptives

	Minimum	Maximum	Mean	Std. Deviation
R Hip Extension	8	19	13.10	2.78
L Hip Extension	8	19	12.65	2.75
R Hip Flexion	68	116	93.60	12.36
L Hip Flexion	55	59	114.00	92.80
R Knee Extension	-2	2	-.35	.87
L Knee Extension	-3	2	-.40	.99
R Knee Flexion	116	133	124.30	4.47
L Knee Flexion	111	133	123.55	5.56

Note. All values were measured in degrees per range of motion

Table 3
Knee Strength Descriptives (Peak Torque/Body Weight)

	Minimum	Maximum	Mean	Std. Deviation
R Flexion 60	25.40	99.10	48.82	19.87
R Flexion 180	23.69	77.10	39.31	12.78
R Flexion 300	20.40	62.50	38.72	10.06
L Flexion 60	17.80	64.90	39.45	12.57
L Flexion 180	21.90	56.60	35.21	8.63
L Flexion 300	21.20	56.60	35.00	8.95

Table 4
Hip Strength Descriptives (Peak Torque/Body Weight)

	Minimum	Maximum	Mean	Std. Deviation
R Flexion 60	19.60	56.10	40.33	8.97
R Flexion 180	15.60	58.90	39.82	11.46
R Flexion 300	18.30	61.10	40.82	12.26
L Flexion 60	26.90	58.10	40.87	8.16
L Flexion 180	18.30	61.60	39.99	10.47
L Flexion 300	22.50	59.70	40.56	11.54
R Extension 60	13.40	52.30	34.46	9.83
R Extension 180	13.80	44.60	28.73	8.72
R Extension 300	13.10	59.00	29.67	11.38
L Extension 60	19.90	70.80	37.76	12.49
L Extension 180	13.90	61.60	31.83	11.62
L Extension 300	17.30	57.00	33.94	11.98

Chapter 5

Discussion

The purpose of this study was to investigate predisposing factors of lower extremity muscle injuries in collegiate track and field athletes. Specifically, correlations between hip and knee strength, ranges of motions, previous injury, and leg dominance were examined. Muscular injury prevalence is high within track and field, which has led to the exploration of many different intrinsic and extrinsic factors. Previous research has suggested relationships between increased injury risk to strength deficits, decreased flexibility, age, gender, experience, previous injury, training programs, fatigue, and speed (Kluitenberg et al., 2014; Opar et al., 2014). However, injury predisposition may actually be multifactorial (Yeung et al., 2009). Injury can occur throughout any point in the running gait, yet they most commonly occur within the swing phase. During the swing phase, the hip extensors are working concentrically while the knee flexors produce eccentric contractions (Yu et al., 2008). The biarticular nature of both the hamstrings and the dominant quadriceps can create an imbalance, which consequently causes injury.

In this study, strength results for right hip extension at 300 degrees per second were consistent with previous research (Sugiura et al., 2008). A decreased peak torque value during hip extension can ultimately lead to a lower extremity muscular injury. As stated by Yu et al. (2008), injuries are more likely to occur at a greater speed. Although in the data collected, there was no significance between injury and hip flexion or hip extension at the slower speeds. The results could have been limited by a small sample size. Hip extension strength positively influences sprinting mechanics; therefore, when weak it may lead to injury.

A hamstring to quadriceps ratio is often examined at the knee joint in order to determine strength deficits and their contribution to injury. An ideal H:Q has been defined as 66%, a range falling between 60-80%. Injuries are more likely to occur when the ratio is below 60% and less likely to occur when the values are closer to 100% (Delextrat et al., 2013; Yeung et al., 2009). However, in the present study the concentric action of the quadriceps could not be accurately obtained due to the eccentric/concentric testing procedure of the hamstrings. The hamstring muscles endure greater stress during faster speeds, which is why peak torque may decrease as the velocity increases (Chumanov et al., 2007; Opar et al., 2014). The current study did not illustrate any significance between peak torque per body weight values and their correlation with injury. The peak torque values also did not decrease with increased velocities. The contrasting results from this study compared to previous research may rely on a limited sample size. Although there is not a standardized peak torque measurement, a decreased peak torque per body weight, especially compared bilaterally, may predispose athletes to injury (Aginsky et al., 2014).

The normal range of motion for knee extension is zero degrees while knee flexion typically measures to 120 degrees. At the hip joint, the normal range for extension is 15 degrees and flexion is 120 degrees (Prentice, 2011). In this study, the participants' mean right knee extension was -.35 degrees, their average left knee extension was -.4, their mean right knee flexion measured 124 degrees, and their average left knee flexion was

123 degrees. All of their knee ranges of motion surpassed the standardized averages and were similar bilaterally. There were no significant findings in the current study between knee ranges of motion and injury. Participants' right hip extension mean measurements were 13 degrees, their left hip extension averaged 12 degrees, their mean right hip flexion was 94, and their average left hip flexion measured 93 degrees. The ranges of motion at the hip were all lower than the standardized ranges, but again they were similar bilaterally. Left hip extension was the only range of motion with a significant negative correlation with injury. The results suggest that decreased hip extension may lead to higher injury predisposition. Bradley and Portas (2007), found significant results with injured limbs and a three-degree deficit. It was also explained that ranges of motion should be obtained prior to training due to hypertrophy and delayed onset of muscle soreness during training. Previously injured limbs have also led to decreased ranges of motion when compared bilaterally (Jonhagen, 1994). Most injuries happen during the swing phase of running while hip flexion is increased, which subsequently increases the length of the hamstring muscle (Williams & Welch, 2015). However, some researchers did not find any correlation between flexibility and injury (Hennessay & Watson, 1993; Yeung et al., 2009).

Consistent with previous research, stating that previous injury is a substantive risk factor toward injury, the current data exhibited a strong significant correlation between previous injury and re-injury (Brockett et al., 2004). Recurring hamstring strains are very common, with the recurrence rate reaching 34% (Malliaropoulos et al., 2011). It has also been established that strength deficits and decreased flexibility have been identified in previously injured musculature, which explains the high incidence of recurrence. (Croisier et al., 2002). The treatment of muscle strains is an uncontrollable factor, which may also lead to reinjury (Brockett et al., 2004). Understanding the underlying cause of both the initial injury and the recurrent injury will help clinicians decrease the rate of muscular injuries.

When comparing leg dominance to injury, the data was insignificant and inconsistent with previous research. The limited sample size of injured participants could have negatively influenced the results. Previous research elucidated the non-dominant leg as the most commonly injured leg (Cheung et al., 2012; Delextrat et al., 2013). The increased likelihood of injuring the non-dominant leg is explained by its strength (Cheung et al., 2012; Jonhagen, 1994).

More significant results may have been drawn from the data if there was a larger sample size of participants and injured subjects. All of the participants were also on the same collegiate track and field team. A variety of participants from other universities or varying ages and experience could have provided better results. Another factor that may have affected the results of the study includes the length of time that injuries were recorded; if the injury recording period included their off season training and their outdoor season, then more participants may have sustained injuries. Limitations of the study include effort of athletes during the testing protocol and throughout their season, which could be improved through encouragement from the researcher and coaches. The results were also dependent of the participants' honesty regarding injury during the season. Subjects were monitored by coaches and athletic trainers, but results may have been altered by the failure of subjects to report injury. Also, dependent on the subject's event, their training intensity or volume could have varied. Although the participants completed a familiarization period for the testing protocol, their compensatory movements and improper technique may have affected their strength results.

Future Recommendations

For future research, a larger sample size should be utilized for better data analysis. The small population of injured participants in the current study did not include enough data to allow correlations. A longer injury recording period could also affect the correlations. Future testing protocols should also include concentric/concentric isokinetic testing at the knee for all velocities in order to obtain a hamstring to quadriceps ratio. The current study only analyzed the peak torque per body weight values, which do not have a standardized value. In order to have accurate results regarding substantiated risk factors, other variables should be controlled throughout the season. Volume, intensity, and fatigue could be controlled by limiting weekly mileage or hours per week that the athletes train.

Conclusion

Muscular injuries are extremely common among track and field athletes, and the risk factors of muscular injuries are multifactorial. Strength deficits and decreased flexibility are often proposed as risk factors, however research findings are mixed. Much of the research conducted on strength and flexibility profiles and non-contact injuries is completed on athletes that participate in field sports, leaving an area of uncertainty for track and field injuries (Yeung et al.,2009). Abundant research has confirmed that previously injured individuals possess a higher predisposition to recurrent injury

(Malliaropoulos et al., 2011; Croisier et al., 2002). Although contrary to the current study, the non-dominant leg has higher potential for injury due to weakness and tightness (Cheung et al., 2012). This study determined that decreased hip extension strength at 300 degrees per second, decreased hip extension range of motion, and previous injury were all risk factors for injury. The data collected provides health care clinicians with the appropriate knowledge of the underlying cause of injuries, which can be used to improve preventative protocols. Although the current study had few statistically significant findings, further investigation can lead to a better understanding of risk factors in order to decrease injury incidence.

Appendices

Appendix A

"Subject: Permission to use Student-Athletes for Graduate Thesis Research"

"Good Evening Dr. Halpin and Coaches!

I am the graduate assistant athletic trainer for the cross country and track and field teams! As a part of my graduate curriculum, I will be completing a thesis (The Effect of Strength Imbalances and Decreased Muscle Flexibility on Lower Extremity Muscle Strains in Collegiate Track and Field Athletes). I am contacting you in regards to gaining permission to use the student-athletes for my research. Specifically, I am interested in using the distance runners, the sprinters, and the jumpers as participants. The purpose of this study is to determine whether or not an existing strength imbalance between the hamstrings and quadriceps muscle groups or a lack of flexibility in those same muscles will predispose a collegiate track and field athlete to a lower extremity muscular injury. The study will also aim to identify whether there is a difference between the incidence of injury in the type of track and field athlete due to their strength or flexibility profile. I have already received permission from the coaching staff and the student-athletes' participation will be completely voluntary. I have attached a document that outlines a brief description of the methods, possible risks and possible benefits for the study.

If you have any further questions or would like more information, please feel free to contact me!

Thank you!

Syrena Spanburgh-Hess, LAT, ATC, SCAT
Graduate Assistant Athletic Trainer
Men and Women's Cross Country/ Track and Field"

Appendix B

“Subject: Graduate Thesis Research- Participant Recruitment”

“Good Evening Everyone!

As most of you know, I am currently working on completing my Master’s of Science, which requires me to also complete a thesis (The Effect of Strength Imbalances and Decreased Muscle Flexibility on Lower Extremity Muscle Strains in Collegiate Track and Field Athletes). I am contacting you all to ask if you would be interested in being subjects for the study.

The purpose of this study in to determine whether or not an existing strength imbalance between the hamstrings and quadriceps muscle groups or a lack of flexibility in those same muscles will predispose collegiate track and field athletes to a lower extremity muscular injury. The study will also aim to identify whether there is a difference between the incidence of injury in the type of track and field athlete, die to their strength or flexibility profile. Participation in the study would be completely voluntary and you would have the option of withdrawing from the study at any time, without consequence. The study will not interfere with your normal training regimen nor will it alter any injury treatments. Your voluntary participation would include filling out a pre-participation questionnaire, one testing day including strength and flexibility assessments, and then injury tracking throughout the remainder of the school year. I have attached a word document that outlines a brief description of the methods being used for the study, potential risks, and the benefits of participating.

If you would like more information or if you are interested in being a participant, please feel free to contact me!

Thank you!

Syrena Spanburgh-Hess, LAT, ATC, SCAT
Graduate Assistant Athletic Trainer
Men and Women's Cross Country/ Track and Field”

Appendix C

IRB 9/21/2007

Informed Consent Agreement Researcher: Syrena Spanburgh-Hess Researcher's Position: Graduate Student Title of Study: The Effect of Strength Imbalances and Decreased Flexibility on Lower Extremity Muscle Strains You are invited to take part in a research study. Before you decide to be a part of this study, you need to understand the risks and benefits. This consent form provides information about the research study. I will be available to answer your questions and provide further explanations. If you take part in this research study, you will be asked to sign this consent form. Your decision to take part in this study is voluntary. You are free to choose whether or not you will take part in the study. If you should decide to participate, you may withdraw from the study at any time. **Purpose of the research study:**
The purpose of this study is to determine whether or not an existing strength imbalance between the hamstrings and quadriceps muscle groups, or a lack of flexibility in those same muscles, are potential predisposing factor to lower body muscular injuries during track and field training. The study will also aim to identify whether there is a difference between the incidence of injury in the type of track and field athlete, due to their strength and/or flexibility profile.
Procedures or methods to be used in the study:
Participants will complete a pre-participation questionnaire in order to establish both their track experience and previous injury history. There will be one testing day used to assess the flexibility and strength of the hip and knee. A stationary bike warm-up will be completed prior to the assessments. Flexibility tested will be done using a goniometer and will measure hip flexion, hip extension, knee flexion and knee extension. Strength testing will be recorded through the use of a manual muscle test and an isokinetic Biodex test. Manual muscle testing includes hip flexion, hip extension, hip abduction, and hip adduction. The participants will complete an active movement against light, manual resistance. Hip flexion/extension and knee flexion/extension will be assessed using the Biodex machine at three different velocities in order to test for strength, power and endurance. All testing will be completed on both legs. Following the testing day, subjects will resume their normal training regimen and will be instructed to report any injury to their athletic trainer. Once an injury is suspected, the individual will fill out a subjective post-injury questionnaire used to identify the location of injury, mechanism of injury, previous history, fatigue, and any other potential causative factors. The athletic trainer will also objectively evaluate the participant and record their clinical findings along with their time to return to play.
Number of questions in the survey/questionnaire and anticipated time to complete the survey/questionnaire: The pre-participation questionnaire has 12 questions that

summarize their track experience, training profiles, and previous injury history. The post-injury questionnaire, contains 22 questions that identify the scope of their injury along with other potential factors that may lead to injury. Both of the questionnaires should not take any longer than 15 minutes.
IRB 9/21/2007

Possible Risks/Benefits Associated with Participating in Study:

Possible risks included with participation of the testing protocol of this study include fatigue, delayed onset muscle soreness, shortness of breath, lightheadedness, or muscle strains. The testing protocol is no more strenuous than the typical track and field workouts or warm ups. Injuries that occur during participation of the study will follow the university athletic training policy. Potential benefits may include aiding research that focuses on the causative risk factors for muscular injuries in collegiate track and field athletes. Individuals will also have access to their results, one the study is completed, which may serve as insight on how to improve their individual flexibility and/or strength.

Possible Costs/Compensation Associated with Participating in Study:

There will be no compensation associated with participation in the study. There will also be no cost for the individuals involved in the study. If the subjects do undergo injury while participating in athletic activity, they will be treated per the university athletic training policy.

Right to withdraw from the study:

You have the right to withdraw from the study at any given time without reason or any consequence. You also have the right to refuse participation without reason.

Privacy of records or other data collected in the study:

All records and files will be kept in a locked cabinet in my advisor's office. The only people that will have access to the files are the researchers. All records will be shredded 3 years (2020) after the study is completed.

Questions – contact information:

If you have any questions about this study, you may contact me at the following address:
Address: Dr. Alice McLaine
Winthrop University West Center
Classroom 116
Work Phone: 803-323-2177 Email: mclainea@winthrop.edu
Syrena Spanburgh-Hess
spanburghhesss2@winthrop.edu
You may also contact:
Deborah Broome, Compliance Officer 803-323-2398 broomed@winthrop.edu
Sponsored Programs and Research
Winthrop University
Rock Hill, SC 29733

Signatures:

By signing this consent agreement, you agree that you have read this informed consent agreement, you understand what is involved, and you agree to take part in this study. You will receive a copy of this consent form.

Appendix D

Debriefing Form

Thank you for participating in our *The Effect of Strength Imbalances and Decreased Flexibility on Lower Extremity Muscle Strains in Collegiate Track and Field Athletes* study!
Research has identified that muscular injuries are one of the most common amongst track and field athletes. However, there are many controversial predisposing factors. The purpose of this study is to determine whether or not an existing strength imbalance between the hamstrings and quadriceps muscle groups or a lack of flexibility in those same muscles will predispose a collegiate track and field athlete to a lower extremity muscular injury. The study will also aim to identify whether there is a difference between the incidence of injury in the type of track and field athlete due to their strength or flexibility profile.
If you are interested in learning the results of this study, please contact the researchers after May 1st, 2017.
Researchers:
Syrena Spanburgh-Hess; spanburghhesss2@winthrop.edu
If you have any concerns regarding this study, please contact the faculty advisor or the Director of Sponsored Programs and Research.
Faculty Advisor: Sponsored Programs & Research:
Dr. Alice McLaine Deborah Broome, Compliance Officer
803-323-2177 (803) 323-2398
mclainea@winthrop.edu broomed@winthrop.edu
If anything about this survey caused you to feel uncomfortable, health and counseling services are available to you on the 2nd floor of Crawford. You can reach Counseling Services at (803) 323-2233 or get information at
http://www.winthrop.edu/hcs/counselingservices-home.htm.

All counseling services are free and confidential.

Appendix E

Pre-Participation Profile

- Gender:
- Age:
- Dominant Leg:
- Events:

- How long have you been participating in track?

- How often do you complete lower extremity strength training?

- How often do you complete a lower extremity stretching routine?

- Have you ever had any previous lower extremity injury?
    - When was this injury?
    - Did you see a physician, athletic trainer or any other health care provider?
    - What was the injury? Which leg?
    - How long was your recovery?

Appendix F

Post-Injury Questionnaire

- Chief Complaint:
- Signs/Symptoms:
- Mechanism of Injury/When did it occur?:
- Relevant Previous History?
    - Which leg?
    - What was the injury?
    - How long ago was it?
    - Brief description of recovery:
- Did you complete a warm-up today? How long before participation? Briefly explain warm-up.
- How far into the season is it?
- Were you wearing flats or spikes?
- Did this happen at practice?
    - What event were you participating in at the time the injury occurred?
    - How far into practice did the injury occur?
- Did this happen at a meet?
    - What event were you participating in?
    - How many events did you participate in at the meet prior to injury?
    - How much recovery time did you have between the event where the incident occurred?

- What type of track were you running on?
    - How many meters is the track?
    - Indoor or outdoor track?
    - Long or short curve?

Injury Description

- Diagnosis:
    - Description of clinical findings:

- Was the athlete completely removed from participation or was he/she limited? How long? Please explain.

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