THE ASSESSMENT OF HAMSTRING RELATED DEFICIENCIES IN COLLEGIATE FOOTBALL ATHLETES WITH A PRIOR HISTORY OF HAMSTRING STRAINS: A RETROSPECTIVE CASE CONTROL STUDY

by

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
HSI	Hamstring Strain Injury
H:Q	Hamstring to Quadriceps
NCAA	National Collegiate Athletics Association
NFL	National Football League
DOMS	Delayed Onset Muscle Soreness
$H:Q_{func}$	Functional Equation of H:Q
ASLR	Active Straight Leg Raise
DPA	Disablement in the Physically Active
ASIS	Anterior Superior Illiac Spine
PSIS	Posterior Superior Illiac Spine
Co	Documented ID for Healthy Group
Hx	Documented ID for HSI Group
ICC	Intraclass Correlation Coefficient
SLHB	Single Leg Hamstring Bridge

ABSTRACT

Objective: To examine commonly established hamstring strain injury risk factors in collegiate football athletes with a history of previous hamstring strain compared to football athletes that have never incurred a hamstring injury. **Design:** Retrospective case-control study. **Participants:** A total of 30 participants that engage in competitive football (age = 20.77±1.22; weight = 214.47±23.33 pounds; height = 72.97±4.09), were screened and evaluated for eligibility to partake in this study. Participants in the HSI group (n=15) suffered from at least one activity-limiting hamstring strain diagnosed by a healthcare professional in the past 2 years but not within 6 months of participation in the study. An activity limiting hamstring strain must have resulted in limitations in practice or competition. The healthy group (n=15) consisted of participants that have never experienced a diagnosis of a hamstring strain. Neither group suffered a lower extremity injury at least 3 weeks prior to testing procedures. **Methods:** Five dependent variables were assessed: 1.) health-related quality of life assessed through a self-reported outcomes assessment instrument, 2.) pelvis position measured with a CHEK Inclinometer, 3.) flexibility measured with the active straight leg (ASLR) test measured in degrees, 4.) hamstring endurance measured during the performance of a single-leg bridge test (SLHB) to fatigue and 5.) isokinetic strength calculation using the functional equation of eccentric hamstring strength, to concentric quadriceps strength ($H{:}Q_{func}$) at 60°/s,180°/s, and 300°/s. **Results:** The baseline disability assessment measured by DPA scores was significantly different between the HSI group and the healthy control (t(14) = -3.66, p=.003) with the HSI group displaying some low levels of disability. There were no significant differences between the HSI and healthy groups in regards to pelvic tilt, ALSR, and $H:Q_{func}$ scores @60°/s, 180°/s, and 300°/s. No statistically significant difference were noted between the two groups in the SLHB scores, but the interaction between group and injured limb approached significance (p=.059). **Conclusions:** This case-control study did not find significant differences in groups (HSI and healthy) in regards to strength, posture, flexibility, and endurance. The demands of other sports primarily researched such as soccer, rugby, and Australian Rules football have different work demands; therefore previous research may have limited applicability to football Although this data was unable to support other statistical findings in previous research, important information regarding future testing considerations, based on sample size and protocol methodology has been acknowledged. **Keywords:** Hamstring strain injury, football, hamstring deficiency, strength, flexibility, endurance, pelvis position.

CHAPTER I

INTRODUCTION

An athlete that experiences sudden pain in the posterior thigh during a movement that involves rapid recruitment of the hamstring muscles is diagnosed with a hamstring strain injury (HSI). Immediate, clinical signs observed in this instance are tenderness about the posterior thigh, swelling, and a potential defect will be present within the muscle belly.[1] Main causes of hamstring strain injury are running and slow speed stretching.[2,3,4] Sprint type hamstring muscle injuries occur during common components of sports like rapid acceleration and deceleration in sprinting, while changing directions, and kicking.[3-8] During high speed running, the inertia of the swing phase makes the hamstrings more vulnerable particularly when the hamstring muscles lengthen from 50% to 90% in the terminal swing phase and then shortened again through the stance phase.[9]

Football athletes playing in positions that require sprinting and cutting type activity like wideouts, defensive backs, and running backs are more susceptible to HSI. This is supported by a study conducted in professional American football from the years 1998-2007, which found that hamstring injuries were most common in running backs (22%), defensive backs/safeties (14%), and wide receivers (12%).[10] Feeley et al.[10] concluded in this particular study that hamstring strains were the most common muscular injury sustained, only second overall to knee sprains. Football athletes were also more likely to sustain a HSI in practice, or in preseason camps (46%) than during a game (22%).

A 10-year study of preseason average time lost demonstrated that a football athlete suffered about an 8-day loss from sport due to hamstring injury.[10] Time lost from hamstring strain injury in competition and practices causes frustration for the athlete, coaching staff, and sports medicine healthcare professionals alike. Given the rate of hamstring injuries and their subsequent effect on athlete participation, a thorough understanding of the factors that lead to hamstring injuries is essential. Unfortunately, it is unknown whether or not the etiologies of hamstring strain is due to the movement alone or if it is due to a predisposing risk factor which elevates the chance of the strain in conjunction with the movement.[2,11] Therefore, to understand risk factors associated with hamstring injury more research is necessary.

Subsequent injury to the hamstring muscles is as problematic as a first-time strain. Remodeling of a strained muscle may take up to 9 months, which can be long after an athlete returns to play.[12] Poor rehabilitation practices can lead to maladaptation from previous hamstring injury, inhibit performance and contribute to further injury.[13] Limited research is available on the rate of recurrent hamstring strains in football, but a recent study in rugby athletes confirms that athletes are at high risk for re-injury during the first month after release to full participation.[5] The most pertinent, current research regarding re-injury conducted by Heiser et al.[1] indicated 13 of the 41 individuals (31.7%) sustained at least one recurrent hamstring strain injury in intercollegiate football athletes in 1984 during an index period of ten years.

Hamstring injury causes are multifactorial in nature. Current systematic reviews have investigated common causes of hamstring muscle injury and have divided the risk factors into two categories: modifiable and non-modifiable.[2,13] Some modifiable factors include muscular weakness, poor flexibility, and fatigue. Non-modifiable factors include age, ethnicity, and history of HSI.[2,14] Three commonly identified risks that have been cited in previous literature include strength imbalances, hamstring flexibility and pelvic alignment.[2] Strength imbalances are assessed by understanding the hamstring to quadriceps (H:Q) ratios, also known as knee flexor to knee extensor strength.[2] Flexibility is identifiable as a predetermined risk factor for HSI, but more supportive research is necessary to establish the role of flexibility. Research also suggests that pelvic alignment might play a significant role in HSI.[15] Pelvic tilt position can influence the engagement of the hamstrings. This activated and lengthened muscle, when the pelvis is in an anteriorly tilted position, effects hamstring extensibility during functional activity.[16]

Given the high rates of HSI in collegiate football athletes, it is important to establish the risk factors that predispose of hamstring injury or re-injury within the sport. Therefore, performing more research specifically with elite collegiate football athletes can offer pertinent insight. Lack of current research is alarming considering football has specific characteristics and patterns of movement that are different from other sports with a high rate of HSI. This research should also account for the multifactorial nature of HSI and the complex interaction of multiple risk factors associated.

Purpose

The purpose of this study was to examine commonly established HSI risk factors in collegiate football athletes with a history of previous hamstring strain compared to football athletes that have never incurred a hamstring injury. This case-control study is an important first step and will potentially provide insight into some factors that address prospective investigation of HSI in collegiate football athletes.

Research Questions

1. Is there a significant difference in the standing pelvic tilt of collegiate football athletes with a past history of hamstring strain compared to matched controls without a history of hamstring strain?
2. Is there a significant difference in hamstring flexibility in collegiate football athletes with a prior history of hamstring strain compared to matched controls without a history of hamstring strain?
3. Is there a significant difference in quadriceps to hamstring strength assessments in collegiate football athletes between those with history of prior hamstring strain and matched controls without a history of hamstring strain?
4. Is there a significant difference in disablement scores after the completion of the Disablement in the Physically Active Scale, a patient reported outcomes tool, between collegiate football athletes with prior history of hamstring strain and matched controls without a history of hamstring strain?

Significance of Study

Hamstring strains are a common occurrence in many sports that often result in missed playing time in regards to both games and practices. By investigating collegiate football athletes, we can identify some risk factors that can help to provide a starting point to understand HSI in collegiate football athletes. By identifying these differences between those with and without hamstring injury among these modifiable and non-modifiable risk factors, we may be able to identify specific variables that warrant further prospective study in this population. In addition, the identification of these limitations will help healthcare professional to address these risk factors in rehabilitation of HSI and can possibly help with identifying some prevention strategies from further re-injury.

Operational Definitions

1. Hamstring deficiency is defined for the purpose of this research as a lack of flexibility, strength, and pelvis position.

2. Hamstring strain is defined as sudden onset, non-impact pain in the posterior thigh during practice or competition. Strain is identified as an exertional effort on a muscle that causes injury by pulling, stretching, or tearing of muscle fibers.[1]

3. Flexibility is identified as the limb's absolute most range of motion in a joint or series of joints.

4. Pelvis position, also known as pelvic tilt, is the relationship of the pelvis, either anterior or posterior, to the rest of the body in anatomical position.

5. Strength is defined as the forces necessary to resist knee extension and start hip extension during maximal sprinting.[17]

6. Healthcare professional is defined as any licensed, practicing, medical professional including, but not limited to, medical doctors, athletic trainers, or physical therapists.

Delimitations

1. Subjects must be 18-26 years old, and participating in a Division I collegiate football athletics program during the time of study.
2. Subjects in the hamstring group must have a prior history of at least one diagnosed hamstring strain within the past two years, with limitations in either practice or competition, but not within the past 6 months.
3. Athletes in the control group must have no prior history of a diagnosed hamstring strain.
4. In both subject groups, athlete must also have no current inhibiting acute lower extremity injuries affecting performance or measurements of the set tasks to carry out the study (both groups) in the past 3 weeks.

Limitations

1. This study will only gather data from one NCAA Division I football program, thus limiting the generalizations that can be made regarding other NCAA Division I football programs.
2. This study uses a case-control design and thus will investigate the risk factors retrospectively. Therefore, causation cannot be implied by the findings in this study.

Assumptions

1. It is assumed that subjects in the case-history hamstring group have been honest in reporting their past hamstring injury has been correctly diagnosed by a qualified healthcare professional.

2. It is assumed that subjects in both case-history hamstring and control group have been honest in reporting they are not currently limited by an acute lower extremity injury while participating in this study.
3. It is assumed that subjects in the case-history hamstring group have been honest in reporting limitations in competition or practice in time of injury.
4. It is assumed that subjects in the case-history hamstring group have been honest in reporting they have not suffered a hamstring strain, first time or recurrent, in the past 6 months.
5. It is assumed that all instrumentation used to perform this study are correctly calibrated and are the most valid and reliable tests to measure outcomes addressed.

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CHAPTER II

LITERATURE REVIEW

Review of Hamstring Strain Injury in Current Literature

Hamstring strain injuries are one of the most prevalent non-contact, soft-tissue injuries plaguing sports activity.[1,2] Hamstring strain injury most commonly occurs in rugby, football, soccer, track and dance athletes.[3-7] There is limited research relating HSI causation to a singular risk factor.[8,9] Rather, HSI research has indicated that risk factors are likely multifactorial. This retrospective case-control study will be conducted to understand how some commonly cited risk factors differ between competitive football athletes with and without a history of HSI. Understanding potential risk factors is important for developing effective evidence-based practice guidelines for prevention and rehabilitation programs to reduce HSI incidence and reoccurrence in sports activity.[9,10] Given the scope of this project, this literature review will review pertinent concepts including hamstring injury epidemiology; HSI mechanisms, healing and rates of re-injury; rehabilitation trends; risk factors; and risk factors assessment.

Epidemiology of Hamstring Strain Injury Rates in Sports

A number of studies have investigated the epidemiology of HSI in sports and found HSI to be a pervasive injury and problem. Cross et al.[10] conducted an inclusive study of HSI in sports in the National Collegiate Athletic Association (NCAA) from 2004-2007. This was the largest study to date, providing rates of HSI all sports in the collegiate setting, including football. Rate of HSI in football (.604 per 1000 athlete exposures) was only second to soccer (.691 per 1000 athlete exposures), which had the highest rate of HSI per exposure of both genders and all sports.[10]

Elliot et al[11] conducted a study, also in a span of 10 years, from 1989-1998 examining the HSI rate in National Football League (NFL) professional athletes. Of the HSI reported, an injury rate was determined of .77 per 1000 athlete exposure, out of the 1716 total. Overall, more HSI were reported during passing plays (36.8%, n=295) than running plays (18.4%, n=147). In regards to mechanism of injury, the most prevalent HSI were deemed noncontact; in passing plays at 77% (n=225) and rushing plays had a rate of 45% (n=69). This study is in agreement with Feeley et al[7] which also recorded more HSI occurred in the 7 week span of preseason football before in season competition.

Common Mechanism of Hamstring Strain Injury in Sport

To understand the biomechanical characteristics cited as the most common mechanisms of hamstring strain injury, it is necessary to implement the best prevention and rehabilitation strategies. Evidence suggests that there are at least two different types of injury mechanisms in HSI: during high speed running and during stretching exercises carried into extreme joint positioning.[12,4]

Hamstring strains are the most common injury that occurs in sporting activity that involves sprinting.[13] The most detrimental phase of the running cycle is the terminal swing phase.[14,15] This is where the knee extends and the hip flexes, lengthening the muscle to a point in which a tear is possible.[16] For 75-85% of the cycle, the combination of hip flexion and knee extension cause repeated eccentric contractions of the hamstrings.[17] In deceleration, the antagonist muscles will contract while simultaneously lengthening causing an eccentric contraction of the hamstring. An eccentric contraction is able to produce more force with 20% less oxygen consumption, carbon dioxide production than an equal bout of concentric work.[18] This overproduction of force is what makes the hamstrings vulnerable and susceptible to injury.

Stretching type activities such as dancing involves specific movements of hip flexion and knee extension, which can induce strain in the proximal portion of the posterior thigh as the muscle lengthens.[12] Similar to the sprinting type mechanism of HSI, the athlete will experience pain and loss of function.[4] However, the two mechanisms may result in a HSI that manifests differently. A stretch type mechanism typically results in tenderness and injury closer to the origin of the hamstring muscle at the ischial tuberosity.[12] Sprint type mechanism can effect the hamstring closer to the ischial tuberosity, but more often than not it is the belly of the biceps femoris that is typically disturbed.[12,4] Although, over course of the injury it is not uncommon for point tenderness and pain to travel proximal, closer to the ischial tuberosity. In regards to stretch, it is often the case that more than one muscle-tendon complex is involved including at least one of the following: the semimbembranosus, quadratus femoris, and adductor magnus.[4]

Recovery time in slow speed stretching type of HSI is typically, on average, 3 times longer than high-speed running type of HSI that is common in sprinting activities.[12] It is unknown exactly as to why recovery is longer and more strenuous. Askling et al.[19] speculates that those suffering from slow speed stretch mechanism of HSI will have more than one muscle-tendon complex involved, therefore lengthening healing process and recovery.

Hamstring Strain Recovery and the Healing Process

During the healing process, microscopic tears in the hamstrings over time lead to macroscopic tears, which inevitably lead to tendon weakening through repetitive trauma. This repeated inflammatory response inhibits healing and potentially predisposes the athlete to tendon avulsion.[20] As the stages of healing progress, applying an appropriate stress, like stretching, to the newly repaired area will determine the stress lines where collagen will develop. Remodeling of a strained muscle may take up to 9 months, which can be long after an athlete returns to play.[12] An individual that has undergone recurrent hamstring strain injury could potentially lack proper flexibility due to viscoelastic changes brought on by repetitive HSI. Injured muscles undergo a change in viscoelasticity that require a longer stretch with more repetition to obtain the same benefit and plastic deformation to elongate tissues.[21] Histological changes such as re-torn tissue, scar tissue formation, muscle atrophy, and poor tissue organization affect tensile strength and can lead to altered biomechanics, chronic pain, loss of function, weakness and risk of re-injury.[21,23] Proper management and rehabilitation of HSI are necessary to decrease the risk of recurrent injury. The role of the healthcare provider is to protect the healing tissue while also providing rehabilitation exercises that aid in strengthening the injured muscle tissue. Understanding common range of motion, strength, endurance and functional limitations in athletes is important to limit the potential for HSI re-injury.

Athletes typically desire a speedy return to play following any activity limiting injury.[24] However, HSI re-injury rates are as high as 31.7% in intercollegiate football athletes according to Heiser et al.[1] The primary objective of rehabilitation is to return the athlete as soon as possible with minimal risk of injury recurrence, and as close to preinjury level of performance as possible.[25] Hamstring injury has a high recurrence rate, as mentioned by Heiser et al.[1] which suggest that current trends in preventative programs and rehabilitation protocols may not be effective.[26] Advocates for hamstring injury prevention incorporate principles such as strength training, flexibility training, and running drills into programs and for future prevention, into rehabilitation protocols.[26,27,28] A number of intervention studies have tried to understand the effects of eccentric exercise for hamstring strain prevention in soccer, sprinting and Australian Rules football.[13,25,26] However, none have been completed in collegiate football.

Popular strength training programs include the incorporation of eccentric exercise. Best supported by Brockett et al.[26] this was the first report of a long-lasting change in length-tension property of human limb muscle brought by a period of eccentric exercise. Beginning eccentric-based exercise training causes microscopic muscle fiber damage, delayed onset muscle soreness (DOMS), and transient length change. Long term changes with continued performance include a decrease in soreness, and less transient change in length. As the sarcomeres increase, less force is required to elongate the muscle therefore increasing optimum length.[29] This optimum length will create less stress on the hamstrings in the most stressful phase of the running cycle that can cause HSI.[17]

Cameron et al.[28] incorporated a running based program labeled as "HamSprint" drills along with the use of functional movements in patterns to correct posture. This included various balance tasks, open chain and closed chain kinetic exercises in addition to a running component. All subjects with baseline level of low initial leg swing in the running cycle improved after the completion of this program.[28] This coincides with the belief that training must resemble actual sport conditions to achieve adaptations post injury in optimal performance and can help limit the risk of injury recurrence in functional sport activity.[30]

Role of Risk Factors in Hamstring Strain Injury

Risk factors for HSI are commonly divided into intrinsic and extrinsic categories. The characteristics of an individual directly relating to biomechanics or anatomy that increase injury predisposition are considered intrinsic risk factors[31-33], while extrinsic factors are identified as contact from opposing players or environmental factors like time of the game, weather conditions, or player position which can all increase injury susceptibility.[10,31-33] A combination of both intrinsic and extrinsic risk factors are required for predisposition to the event of a HSI.[10]

We can break down intrinsic risk factors pertaining to HSI more specifically into modifiable or non-modifiable. Modifiable influences include imbalances in strength, flexibility, and fatigue.[34] Strength training is relevant in football athletes for neuromuscular development, and the adaptation to eccentric and explosive demands in competition. In relationship to HSI, traditional lower extremity strength training programs neglect to incorporate equal hamstring and quadriceps training exercises, thus creating muscular imbalances that are destructive to performance and lead to an increased risk of injury.[35] More protocols should incorporate unilateral exercises to designate “elongated stress” to the affected leg, also known as eccentric strengthening, therefore the dominant leg will be unable to compensate.[29]

Further research implemented a rehabilitation program for HSI that included a warm-up period, eccentric and concentric contraction exercises performed on an isokinetic testing device.[36] There was a significant reduction of strength deficits between the uninjured side and injured side in this protocol. In a previous study, Bennell et al.[37] believed hamstring muscle injury risk was unidentifiable using isokinetic muscular strength testing in Australian Rules football players. However, findings suggest that a significantly larger percentage of athletes that underwent the isokinetic muscular testing reported a hamstring strain compared to those who did not report a hamstring strain. Orchard et al.[38] contradicts this statement by stating preseason isokinetic testing can in fact identify those who are susceptible to risk for developing a hamstring strain injury.

A low hamstring to quadriceps ratio (H:Q) is a good indicator of the inability for the hamstring muscles to act as a braking mechanism in the terminal swing phase of running.[34] Alarmingly, athletes with strength imbalances between the quadriceps and hamstrings are 4 to 5 times more likely to sustain a hamstring injury compared to those without.[36] To evaluate this, the gold standard to measure strength of the hamstrings relies on the isokinetic H:Q assessment.[40] The conventional test is a calculation of concentric quadriceps muscle action to concentric hamstring muscle action (3:2). The ratio that will be evaluated will be the functional ratio; this consists of eccentric hamstring actions compared to concentric quadriceps actions. A healthy H:Q functional ($H:Q_{func}$) ratio[41] is reported to be 1:1 and ratios below 0.80-.89 were associated with a higher rate of HSI.[36] This functional ratio is thought to best mimic striding or kicking. By mimicking functional activity, we can evaluate simultaneous actions of the quadriceps and hamstrings.[41] Fousekis et al.[42], and Sugiura et al.[43] used the $H:Q_{func}$ ratio in identifying strength imbalances in their research. Significance was achieved by conducting the test at 60°/s, identifying a decrease in the ratio is indeed a risk factor of HSI.[44]

Another pertinent measureable risk factor that influences potential HSI is flexibility. There is no definitive answer for the role of flexibility in HSI. It is documented as a risk; for example, there is research from Henderson et al.[44] that there is significance between lack of flexibility and HSI rates in elite soccer players. Hennessy et al[45] refutes another significant study by Mallaropoulos et al.[21], by countering the lack of flexibility as a risk factor for HSI, by explaining there was no difference in flexibility between subjects with a history of hamstring strain injury and those without. Both groups studied an athletic population; but again, there has yet to be research to evaluate the role of flexibility in collegiate football athletes. The flaws in methodology for measuring hamstring flexibility can explain the inconsistency in findings.[34] As long as stabilization occurs at the hip and lumbar spine, an array of testing is available including the sit-and-reach test, straight leg raise, and toe touch; there is no set gold standard. The most valid and reliable tests are the active knee extension test and straight leg raise.[46] In theory, a consistent flexibility program is likely to improve the mobility of the hamstrings, therefore reducing injury.[21]

Fatigue leads to a decrease in athletic performance.[47] HSI rates typically occur more often in the late stages of competition, which is what makes this a modifiable risk factor.[48-51] Tired muscles absorb less energy.[46] By controlling the activity based on the onset of fatigue, the risk is either increased or decreased accordingly. Fatigued muscles exposed to repeated periods of over lengthening are more likely to suffer a strain injury.[53] Zjivac et al.[39] used a fatigue index to assess another risk factor for hamstring strain injury. Based on the isokinetic data of concentric H:Q ratio, the fatigue index was greater in professional football athletes that missed a significant amount of practices and competition due to injury. The correlation was weak (r^2=0.029), but should not be ruled out as a potential factor to identify the association between fatigue and HSI risk.

Non-modifiable influences have been identified as age, gender, previous injury, postural alignments and ethnicity.[34] The influence of age has been researched using Australian football players and soccer players. Not yet identified in collegiate football, Australian footballers[52] exceeding the age of 24 and soccer players[53] exceeding the age of 23 were elevated for risk of a HSI. Each year additional has increased the risk of HSI as much as 3.1 times the norm.[24] This could potentially be explained by an increase in body weight, reduction of hip flexion, decrease in muscle mass, and strength loss.[36,53]

Collegiate soccer has the best known research evaluating the role of gender differences in relationship to the rate of hamstring strain.[10] This is the only known study that exits to study HSI between gender at the collegiate level. Both sexes have had higher incidence rates of HSI in preseason compared to in-season rates. Men were 2.42 times more likely to sustain a hamstring strain than women in a competitive setting.[10]

A history of previously injured muscle tissue leads to variability in intrinsic characteristics of the hamstring muscle.[10] There is bias to consider previous injury as a risk factor by individual predisposition to injury.[54] Injury history acts as a host for an individual's unique predisposition to a specific injury, like a hamstring strain.[10] This is typically due to the initial predisposing modifiable risk factors from the first-time strain that typically have not been sufficiently corrected in rehabilitation. This lack of evidence based research is the reason for the continuously increasing rate of HSI in athletics.

Postural alignment, relating to pelvis position, has been identified as a non-modifiable risk factor.[55] This pertains to recognizing either a posterior or an anterior pelvic tilt. Pelvic imbalances increase the functional load on the hamstrings by defascilitating the gluteus maximus and increasing stress on the origin of the biceps femoris.[55] The pelvis' primary function is to transfer the loads generated during functional movements such as walking, standing, and sitting. [55] This particular risk factor will be assessed as it relates to sports specific function in football most identified with the terminal swing phase of the running cycle. In this cycle, the contralateral hip extends allowing minimal pelvis oscillation in movement. An athlete with a posterior pelvic tilt will have decreased flexibility and overall shortened length in extension. [55] The standing position of an anteriorly tilted pelvis has a predetermined lengthening in the hamstrings by placing tension on the origin of the hamstrings at the ischial tuberosity.[55] Taking into account the detriment of the terminal swing phase this is directly relatable to the event of HSI.

Prior research has tried to establish the relationship between ethnicity and risk factors for HSI.[47,56,57] Ethnicities that have been studied independently include Aboriginal[56], Black African, or Carribean.[47,57] Only the study including participants of Aboriginal decent[56] reported significance in relationship to HSI. Currently, all data collected at this point is determined as unsubstantial evidence, but might pertain to high portions of type II fibers[58,59] and excessive anterior pelvic tilt.[45]

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CHAPTER III

METHODS

Research Design

This study is a retrospective case-control that investigated established hamstring injury risk factors in collegiate football athletes with a history of previous HSI when compared to collegiate football athletes without HSI history. This provides insight into some factors that can be further investigates in a prospective study of HSI injury risk factors in collegiate football athletes. This study was meant to identify potential deficits in football athletes with HSI history even after they have returned to full practice and competition. Significant factors could be emphasized in rehabilitation protocols. The independent variable was based on group assignment (HSI versus Healthy groups). There are 5 dependent variables that were assessed in this study: 1.) flexibility measured with the active straight leg (ASLR) test measured in degrees, 2.) isokinetic strength calculation of $H:Q_{func}$ at 60°/s,180°/s, and 300°/s, 3.) pelvis position measured with a CHEK Inclinometer, 4.) hamstring function measured during the performance of a single leg bridge test and 5.) health-related quality of life assessed through a self-reported outcomes assessment instrument.

Participants

Once the study was reviewed and approved by the Institutional Review Board at Texas State University (IRB #2014H193), we recruited participants from Texas State University using a variety of recruitment methods including IRB approved tear- off tab flyers, and team announcements. A potential participant who expressed interest in participation met with the primary investigator to discuss the study procedures, sign an informed consent and complete a demographic questionnaire to determine whether the potential participant meets the inclusion criteria.

Participants in the HSI group (n=20) must have suffered from at least one activity-limiting hamstring strain in the past two years diagnosed by a healthcare professional. An activity limiting hamstring strain must have resulted in limitations in practice or competition. However, the injury could not occur within the previous 6 months of participation in the study. The healthy group (n=20) consisted of participants that have never experienced a diagnosis of a hamstring strain. These participants were matched demographically to the HSI group based on height, weight and position type. In addition, all participants were between 18-26 years of age and participate in competitive football. Competitive football was defined as those athletes who practice, at minimum, 20 hours a week in season and compete in scheduled games during a defined season. Participants were excluded if they are currently experiencing an acute lower extremity injury, or had an acute lower extremity injury in the past 3 weeks that would have affected performance of the tasks set out in the study.

After successful completion of the demographic survey (Appendix A), which includes questions regarding height, weight, age, ethnicity, general questions relating to the lower extremity and prior hamstring injury, participants completed the Disablement in Physically Active (DPA) Scale.[1] Participants were asked to wear comfortable athletic clothing the day of testing. Athletic clothing includes compression shorts suitable for sport activity and a t-shirt. Clothing that restricts movement is unacceptable for testing, which is inclusive of pants, belts, hoodies, etc. determined by the researcher as inappropriate.

Data was acquired in the Biomechanics and Sports Medicine Laboratory at Texas State University and at the Bobcat Stadium Endzone Complex Athletic Training Room. Data collection was performed by a licensed and certified athletic trainer (ACW). Volunteers that satisfy inclusion criteria were made aware of the risks and significance of the study. Consent given by the volunteers was obtained before any participation in the study. Each participant was given an identification code to record data depending on group assignment: Either "Co" for the Control or "Hx" for Case, and then numbered accordingly in the order upon which participants are available for testing. (Example: Control group, second person of the control group to complete demographic paperwork= Co2). Participants that completed the study in its entirety will receive $10.00 in the form of a gift card in compensation.

Instrumentation

The patient-reported outcome measure used to assess impairment of musculoskeletal injury was the DPA (Appendix B). The DPA is a 16-item, patient-report questionnaire, which was administered to both groups, and scored upon completion. The instrument is scored from a 0-64 point scale with a higher score indicating greater levels of disablement. This outcome measure was administered once and indicated the participant's current level of disablement. The scale has excellent validity ($r=.-.751$, $p<.001$), reliability ($ICC>0.75$), and responsiveness ($AUC>.702$, $p=.017$). Values established from the score of a total of possible 64 points was used to assess disablement differences between both groups.[1,2]

Pelvic tilt was assessed using an inclinometer designed by Paul Chek of the CHEK Institute. The CHEK Inclinometer is used to measure first rib angle, pelvic tilt, general goniometry, as well as anthropometric measurements to assess angle in degrees according to the relationship of the ASIS to the PSIS. A reading is obtained by placing the anterior end of the caliper on the anterior superior iliac spine (ASIS) and the posterior caliper on the posterior superior iliac spine (PSIS), and taking a measurement in degrees displayed on the device. Using 10 pilot subjects, the principal investigator (AW) completed an intra-rater reliability pilot test. Pilot participants were measured on 2 occasions within a 24 hour period and produced acceptable reliability estimates of ($ICC_{3,1}$=0.981). For the purpose of this study, the degrees obtained using similar instrumentation by use of the CHEK Inclinometer will be differentiated by using standards of measurement between an anterior or pelvic tilt. Positive degrees, were used to describe an anterior pelvic tilt and negative degrees, were used to describe a posterior tilt in the sagittal plane.[4]

The method used to gather data regarding flexibility was the measurement of an ASLR.[5] A Digital Absolute + Axis Goniometer, measured in degrees available from 0-180, will quantify performance of the ASLR. This device, using an LCD screen, with a feature to freeze angles of measurement also incorporates integral absolute vertical and horizontal levels into the digital goniometer arm. This device is powered from a brand new, 9 volt battery. The material of the goniometer is powder-coated steel that has inch/cm marks screened onto the measurement arms. This device is also equipped with vertical levels to indicate a leveled or plumb starting point of 0°. The principal investigator (AW) used a pilot procedure using 10 random subjects to establish intra-rater reliability for the goniometric measurements and established appropriate reliability estimates ($ICC_{3,1}$=.996). The axis of the goniometer was aligned with the greater trochanter of the testing leg. The moveable arm ran parallel with the femur up to the greater trochanter and was repositioned as the procedure is carried out. The non-moveable arm was aligned parallel to the participant's torso and plinth. The participant actively raised their leg as high as it could comfortably go without rotation of the hip or pelvis. Rotation of the hip was determined by the visual assessment during the procedure of the participants testing foot inverting or everting. Rotation of the pelvis was determined by the participant's lifting of either the right or left hip and breaking contact with the plinth. In the event that this happened, the participant was instructed to lower the leg until the hip is returned to neutral, and then measured. Measurements were performed bilaterally, for three repetitions per limb. A limitation of the ASLR test was the difficulty in keeping the knee extended at the end-range of hip flexion.[6]

Using a single leg hamstring bridge (SLHB) to assess the hamstrings is a valid and reliable test of functional strength and endurance. The test will requires a 60 cm wooden box and a wooden dowel rod. The participant was positioned supine on a flat surface, with one heel on the wooden box. The testing leg's knee was flexed to 20° and confirmed with a standard goniometer. The contralateral leg was in a stationary vertical position so that the hip was flexed to 90^{o}. Prior to testing, the 0^{o} position was assessed by using a wooden dowel rod to assess the ability of the participant to reach the neutral position by aligning it with the landmarks of the testing limb's knee, greater trochanter, and glenohumeral head. The participant was instructed to push through the testing leg to raise the torso off the ground to attain a 0^{o} position where the body is a flat plane from the shoulders to the pelvis and return back down to the floor. This was the position needed to have one countable repetition. The participant repeated the maneuver as many times as possible without rest between repetitions until they could not attain the neutral 0^o position on two consecutive repetitions. A score less than 20 was poor, 25 was average, and 30 was good. The intratester (ICC=0.77-0.89) and the intertester (ICC[7]=.089-0.91) reliability are both acceptably high.[7]

Isokinetic strength testing was performed using $H:Q_{func}$ analysis.[8] An isokinetic dynamometer (Biodex System 4 Pro™, Biodex Medical Systems, Shirley, NY) was used for testing purposes. This most valid and reliable, open chain test permits isolation of the quadriceps and hamstring muscles and ultimately allows for assessment of strength or deficits.[8,9,10] Maximal concentric and eccentric quadriceps and hamstrings strength was measured by torque values during isokinetic knee extension and flexion. Participants were seated and strapped to the device to restrict excess movement, including the upper thigh of the testing limb. The axis of rotation of the dynamometer was aligned with the femoral condyle, and the lower leg was attached to the lever arm of the dynamometer at the lateral malleolus. Allowable joint motion during testing will be set based on participant's ability to flex and extend the knee through a full range of motion. Concentric and eccentric torques were measured at 3 velocities: 60°/s, 180°/s, and 300°/s (5 repetitions each), in that order.[8,11] Participants were asked to perform concentric action for knee flexion and extension, followed by eccentric action for knee flexion and extension. They were permitted 15 seconds of rest between contractions and 1 minute rest between velocities.[8,11] The strength data provided by the test was used to determine the functional ratio ($H:Q_{func}$) by diving the maximal eccentric hamstring peak torque by the maximal concentric quadriceps peak torque. A ($H:Q_{func}$) of 1.00, during active knee extension, indicates a significant capacity of the hamstrings to provide successful joint stabilization.[8]

Procedures

Prior to data collection the researcher completed pilot testing of the testing procedures on 10 consenting persons that will not be involved or recorded in the case-control study. Participants were individually scheduled with the researcher to complete all of the testing procedures. The pilot participants provided feedback to the researcher regarding testing instructions clarity.

Participants that fit the inclusion criteria and signed a consent form were given a demographic questionnaire that was used to gauge pertinent information and medical history. The demographic questionnaire also included the DPA. Verbal clarification was provided upon request and each participant was given clarification with the same response for consistency. Participants sat in a separate room to permit freedom from extrinsic distraction, with the researcher present. Next, pelvic position was assessed in standing and data collected was calculated to establish an anterior or posterior pelvic tilt. Participants then completed flexibility testing in the form of an ASLR. Following flexibility assessment, the SLHB protocol was discussed and immediately performed. The final assessment of $Q:H_{func}$ ratio using the isokinetic dynamometer was completed at least 72 hours after the initial testing session. This is so any delayed onset muscle soreness (DOMS) from the SLHB protocol does not affect the results of the isokinetic testing.[7]

To accurately assess pelvic tilt, participants were instructed to stand, unshod with feet no wider than shoulders-width apart. After verbal communication relaying the procedure, the researcher palpated the location of the ASIS and PSIS bilaterally. The participant was instructed to remain as still and relaxed as possible during the measurement period. The participant was fully aware and verbally instructed that there was no “good” or “bad” measures.[4] The calipers of the CHEK Inclinometer were placed from the sagittal position, on the ASIS and PSIS, and the angle of inclination as read on the device was recorded in degrees. The width in which the depth caliper is open to, to reach the ASIS and PSIS effectively, was not recorded and did not serve a purpose for this measurement. Measurements were recorded for each participant for both the right and left sides, one time through, and data was collected in degrees separately according to side, and then averaged together for the total tilt of the pelvis as a whole, also in degrees. As stated, positive degrees, was used to describe an anterior pelvic tilt and negative degrees, was used to describe a posterior tilt in the sagittal plane.[4]

The assessment hamstring flexibility by performance of an ASLR was performed immediately after the pelvic tilt measurements. Participants were given directions prior to the evaluation. A 10-minute, timed, self-administered warm-up of static and dynamic stretching of the lower extremity was permitted before testing. The use of a stationary bike was also be permitted, if desired. Testing procedure for data collection began with the participant lying supine on a plinth. Straps secured the pelvis, and cross the thigh of the non-tested limb to stabilize and minimize excess movement not related to ASLR performance. The researcher used the digital goniometer to measure each repetition. As stated, the axis of the goniometer was aligned with the greater trochanter of the testing leg. The moveable arm ran parallel with the femur up to the greater trochanter and was repositioned as the procedure is carried out. The non-moveable arm was aligned parallel to the participant's torso and plinth. When instructed, the participant actively raised their leg as high as it could comfortably go without rotation of the hip or pelvis. Measurements were performed bilaterally, for three repetitions per limb. The average of the three scores for each leg was recorded for statistical analysis in degrees.

Prior to the SLHB, participants were allowed to complete an additional timed, self-directed warm up. Questions about the protocol were welcomed; a thorough explanation and visual demonstration of proper form was performed for the participants benefit. When ready, the participant was positioned supine on the ground, with one heel on a 60 cm wooden box. The test leg was positioned on the wooden box with the knee flexed to 20° and confirmed with a standard goniometer. The contralateral leg was in a stationary vertical position so that the hip was flexed to 90°. When instructed to begin, the participant kept their arms crossed over their chest and pushed through the heel of the test leg to lift their bottom off the ground, and extend the hip to as close to 0° as possible. Prior to testing, the 0° position was assessed by using a wooden dowel rod to verify the ability of the participant to reach the neutral position, therefore giving the participant a countable repetition. The aim of the test was to complete as many repetitions as possible until failure. With each repetition the participant must return their bottom to the ground before performing another, but no rest is allowed between repetitions. The non-test leg was required to be stationary in a vertical position to ensure that momentum is not gained by swinging their leg during the test. In the event of incorrect test performance, participants received one verbal warning with feedback to fix testing performance. In the event of the inability to correct testing performance after one warning, a second fault was be recorded and the test ceased to continue. Repetition max was performed and recorded bilaterally for both groups. This protocol and testing procedure is consistent with Freckleton et al.[7] After a 72 hour recovery period the participant reported to the Texas State Sports Medicine/Biomechanics lab for isokinetic testing.

Isokinetic strength testing began with familiarization with the testing equipment prior to use and were allowed to ask questions to clarify the task at hand. Participants were allowed to perform a 10-minute warm-up as soon they felt comfortable with the procedure. This warm up consisted of a bout on the stationary bicycle, as well as any dynamic or static stretching as the participants saw fit.[8] Following warm up, the participant was seated in the isokinetic dynamometer testing chair. Maximal contraction of the hamstrings and quadriceps was taken by obtaining peak torque during isokinetic knee flexion and extension through the available range of motion in the participants' testing limbs.[8] Testing was performed concentrically and eccentrically at 60°/s, 180°/s and at 300°/s for 5 repetitions for consistent protocol.[8,11] Fifteen seconds of rest was given between trials to ensure recovery, and as well as 1 minute between velocities.[8,11] The monitor was not facing the participants as they perform the testing, but verbal encouragement was provided by the researcher. This test was performed once between both case and control groups, bilaterally.

Statistical Analysis

IBM SPSS software version 22 (Chicago, IL) was used to perform all statistical analyses. Five mixed 2 X 2 ANOVAs were used to determine statistical differences between the two groups (HSI and healthy) and within the testing legs (injured and uninjured) for 5 variables: ASLR, $H:Q_{func}$ at 60^o, $H:Q_{func}$ at 180^o, $H:Q_{func}$ at 300^o and SLHB. Two independent samples t-tests were used to assess differences between groups in pelvic tilt values and DPA scores. An a-priori alpha of $p=.05$ was used to determine statistical significance. Cohen's d effect sizes (ES) was calculated and the strength of the effect will be assessed using Cohen's guidelines.[12]

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CHAPTER IV

MANUSCRIPT

Introduction

Abrupt pain experienced in the posterior thigh during an athletic movement involving rapid recruitment of the hamstring muscles is diagnosed as a hamstring strain injury (HSI).[1] Hamstring strain injury is regarded as one of the most established non-contact injuries in sports such as football[2] , rugby[3], soccer[4-8], Australian rules football[9-13] and sprinting.[14,15] The two leading causes of HSI are running and slow speed stretching.[16,17,18] In most sports, sprint type hamstring muscle injuries occur during movements that require rapid acceleration and deceleration in sprinting, while changing directions, and kicking.[3,5,9, 10,16,17] For the duration of high speed running, the inertia of the swing phase makes the hamstrings more vulnerable to HSI, particularly the long head of the biceps femoris, when the hamstring muscles lengthen from 50% to 90% in the terminal swing phase and shorten again through the stance phase.[19] In contrast, slow speed stretching activities that move the lower extremity into extreme joint position are more likely to cause HSI in athletes such as performance artists and dancers. This is mechanism is most often characterized by injury to the proximal free tendon of the semimembranosus.[17]

A study conducted in professional American football from the years 1998-2007 found that that HSI were the most common muscular injury sustained, only second overall to knee sprains. Football athletes were also more likely to sustain a hamstring strain in practice, or in preseason camps (46%) than during a game (22%). Football athletes are more susceptible to this because their positions require sprinting and cutting type activity. In particular, the study conducted by Feeley et al.[2] found that HSI were most common in running backs (22%), defensive backs/safeties (14%), and wide receivers (12%).[2]

Besides the alarming rate of HSI in football, a 10-year study of preseason average time lost demonstrated that a football athlete suffered about an 8-day loss from sport due to hamstring injury.[2] Time lost from hamstring strain injury in competition and practices causes frustration for the athlete, coaching staff, and sports medicine healthcare professionals alike. It is unknown as of present whether or not the etiologies of HSI is due to the movement alone or if it is due to a predisposing risk factor which elevates the chance of the strain in conjunction with the movement.[16,20] Therefore, through more pertinent, currently conducted research we hope to understand the role of these risk factors associated with HSI.

Subsequent injury to the hamstring muscles is as problematic as a first-time strain. The remodeling of a strained muscle may take up to 9 months which, is more often, long after an athlete returns to play.[21] Maladaptation from previous HSI inhibits performance and contributes to further injury due to poor rehabilitation practices.[22] Limited research is available on the rate of recurrent HSI in football, but a recent study in rugby athletes confirms that athletes are at high risk for re-injury during the first month after release to full participation.[3] The most pertinent, current research regarding re-injury conducted by Heiser et al.[1] indicated 13 of the 41 individuals (31.7%) sustained at least one recurrent hamstring strain injury in intercollegiate football athletes in 1984 during an index period of ten years.

Multiple systematic reviews have reported the common, multifactorial causes of HSI. Causes are divided into two categories of risk factors: modifiable and non-modifiable.[16,22] Some modifiable factors include muscular weakness, poor flexibility, and fatigue. Non-modifiable factors include age, ethnicity, and history of HSI.[16,23] Three commonly identified risks cited in previous literature include strength imbalances, hamstring flexibility and pelvic alignment.[24,25,26] Although research has been conducted to understand the multifactorial causes of HSI in sport, the most recent and majority of research has been conducted in Australian Rules football, sprinting, soccer and rugby.[3-15] A thorough understanding of factors leading into HSI in football athletes is essential, given the rate of hamstring injuries and their subsequent effect on athlete participation. By assessing known risk factors, a potential relationship could be identified giving practitioners direction in HSI treatment and prevention. The lack of current research is alarming considering that football has specific characteristics and patterns of movement that are different from other sports with a high rate of HSI. Therefore, the purpose of this study is to examine commonly established hamstring injury risk factors in collegiate football athletes with a history of previous hamstring strain compared to football athletes that have never incurred a hamstring injury. This case-control study is an important first step and will potentially provide insight into some factors that address prospective investigation of HSI in collegiate football athletes.

Methods

Participants

A total of 30 participants that engage in competitive football (age = 20.77±1.22; weight = 214.47±23.33 pounds; height = 72.97±4.09), were screened and evaluated for eligibility to partake in this study. Participants in the HSI group (n=15) suffered from at least one activity-limiting hamstring strain diagnosed by a healthcare professional in the past 2 years. An activity limiting hamstring strain must have resulted in limitations in practice or competition. However, the injury could not have occurred within 6 months of participation in the study. The healthy group (n=15) consisted of participants that have never experienced a diagnosis of a hamstring strain. These participants were matched demographically to the HSI group based on height, weight and football position. Inclusion criteria for both the HSI history group and the healthy group included all participants between 18-24 years of age who participate in competitive football. Competitive football, for the purpose of this study was defined as those athletes who practice, at minimum, 20 hours a week in-season and compete in scheduled games during a defined season. Participants were excluded if they experienced an acute lower extremity injury during the time of the study up until 3 weeks prior to study start that would have affected performance of the tasks set out in the study. Participant demographics are provided in table 4.1. Volunteers that satisfied inclusion criteria were made aware of the risks and significance of the study before informed consent was given to participate. This study was reviewed and approved by the Institutional Review Board at Texas State University (IRB #2014H1983).

Study Design

This retrospective case-control study investigated specific commonly reported HSI risk factors in football athletes with HSI history when compared to healthy controls. The independent variable was group assignment (HSI versus healthy groups). Five dependent variables were assessed in this study in the following order: 1.) health-related quality of life assessed through a self-reported outcomes assessment instrument, 2.) pelvis position measured with a CHEK Inclinometer, 3.) flexibility measured with the active straight leg (ASLR) test measured in degrees, 4.) hamstring endurance measured during the performance of a single-leg bridge test (SLHB) to fatigue and 5.) isokinetic strength calculation using the functional equation of eccentric hamstring strength, to concentric quadriceps strength ($H:Q_{func}$) at 60°/s,180°/s, and 300°/s.

Procedures

After participants were identified and consented to participate in the study, they completed a demographic survey (Appendix A), regarding height, weight, age, race, general questions relating to the lower extremity and prior hamstring injury. The participants then completed two testing sessions. The initial testing session included measuring the first 4 dependent variables in this study. Isokinetic testing was completed at least 72 hours after the initial testing session. This was to limit the possibility of delayed onset muscle soreness (DOMS) from the SLHB protocol as to not affect the results of the isokinetic testing.[27]

The patient-reported outcome measure used to assess the current level of impairment of musculoskeletal injury in regards to the hamstrings was the Disablement in Physically Active (DPA) Scale (Appendix B).[28,29] The DPA is a 16-item, patient-report questionnaire, scored from a 0-64 point scale with a higher score indicating greater levels of disablement. This scale has excellent validity ($r=.-.751$, $p<.001$), reliability ($ICC>0.75$), and responsiveness ($AUC>.702$, $p=.017$).[28,29]

Pelvic tilt was assessed using an inclinometer designed by Paul Chek of the CHEK Institute. Prior to testing the principal investigator (AW) completed an intra-rater reliability pilot test with 10 participants that did not participate in the HSI study. Participants were measured on two occasions separated by at least 24 hours with acceptable reliability estimates produced ($ICC_{3,1}$ = 0.981). A reading of pelvic tilt was obtained by placing the anterior end of the caliper on the anterior superior iliac spine (ASIS) and the posterior caliper on the posterior superior iliac spine (PSIS), and taking a measurement in degrees displayed on the device (see figure 4.1, figure 4.2, and 4.3). Degrees obtained by use of the CHEK Inclinometer are differentiated by using standards of measurement between an anterior or pelvic tilt. Positive degrees, describe an anterior pelvic tilt and negative degrees, are used to describe a posterior tilt in the sagittal plane.[30] To accurately assess pelvic tilt, participants were instructed to stand, unshod with feet no wider than shoulders-width apart, and markers were applied to the ASIS and PSIS bilaterally. The participant was instructed to remain as still and relaxed as possible during the measurement period (see figure 4.4). The participants were fully aware and verbally instructed that there was no “good” or “bad” measures.[30] The calipers of the CHEK Inclinometer were from the sagittal position, on the marked ASIS and PSIS, and the angle of inclination as read on the device was recorded in degrees. The width in which the depth caliper is open to, to reach the ASIS and PSIS effectively, was not recorded and did not serve a purpose for this measurement. Measurements were recorded for each participant both the right and left sides, one time, and averaged together for the total tilt of the pelvis as a whole, also in degrees.[30]

We used a Digital Absolute + Axis Goniometer, measured in degrees available from 0-180, to quantify flexibility during the performance of an ASLR.[31] (see figure 4.5) The principal investigator (AW) used similar procedures for establishing intra-rater reliability for the goniometric measurements and established appropriate reliability estimates ($ICC_{3,1}$=.996). The ASLR was performed immediately after a 10-minute, timed, self-administered warm-up by use of a stationary bike. Participants laid supine with straps securing the pelvis, and the thigh of the non-tested limb to stabilize and minimize excess movement not related to ASLR performance. The digital goniometer was used to measure each repetition. The axis of the goniometer was aligned with the greater trochanter of the testing leg. The moveable arm ran parallel with the greater trochanter to the femur and was repositioned as the ASLR was carried out. The non-moveable arm was aligned parallel to the participant's torso and the plinth. The participant actively raised their leg as high as it could comfortably go without rotation of the hip or pelvis. The participant was instructed to lower the leg until the hip was returned to neutral, and then measured in the event of the rotation of the hip or testing foot inversion/eversion. Rotation of the pelvis was determined by the participant's lifting of either the right or left hip and breaking contact with the plinth (see figure 4.6 and figure 4.7). Measurements were performed bilaterally, three repetitions per limb. The average of the three scores for each leg were recorded for statistical analysis in degrees.

The single leg hamstring bridge (SLHB) was used to assess the hamstrings function as per the protocol described by Freckleton et al.[27] The participant was positioned supine on a flat surface, with one heel on a 60 cm wooden box. The testing leg was in knee flexion to 20° and confirmed with a standard goniometer. The contralateral leg was in a stationary vertical position so that the hip was flexed to 90^{o}. Prior to testing, the 0^{o} position was assessed by using a wooden dowel rod to assess the ability of the participant to reach the neutral position by aligning it with the landmarks of the testing limb's knee, greater trochanter, and glenohumeral head (see figures 4.8 and 4.9). The participant repeated the maneuver as many times as possible without rest between repetitions until they could not attain the neutral 0^o position on two consecutive repetitions. A score less than 20 is poor, 25 is average, and 30 is good.[27] The participants were not aware of the classification of scores prior to testing. Repetition max was performed and recorded bilaterally for both groups.

Isokinetic strength testing was performed to calculate the functional hamstring:quadriceps ratio.[32] An isokinetic dynamometer (Biodex System 4 Pro™, Biodex Medical Systems, Shirley, NY) was used for testing purposes (figure 4.10). This valid and reliable, open chain test permits isolation of the quadriceps and hamstring muscles and ultimately allows for assessment of strength or deficits.[32,33,34] Maximal isokinetic concentric quadriceps and eccentric hamstrings strength was measured by torque values at 3 velocities: 60°/s, 180°/s, and 300°/s (5 repetitions), in that order. Participants were allowed to perform a 10-minute warm-up on a stationary bike before testing.[32] Following warm up, the participants were seated in the isokinetic dynamometer testing chair and strapped to the device to restrict excess movement, including the upper thigh of the testing limb. Allowable joint motion during testing was set based on participant's ability to flex and extend the knee through a full range of motion. Maximal contraction of the hamstrings and quadriceps was taken by obtaining peak torque during knee extension through the available range of motion in the participants' testing limbs.[32] Fifteen seconds of rest was given between trials to ensure recovery, as well as 1 minute between velocities.[32] This test was performed once between both case and control groups, bilaterally. The strength data provided by the test will be used to determine the functional ratio ($H:Q_{func}$) by diving the maximal eccentric hamstring peak

torque by the maximal concentric quadriceps peak torque. A minimum ($H:Q_{func}$) of 1.00, indicates a significant capacity of the hamstrings to provide successful joint stabilization.[32]

Figure 4.1

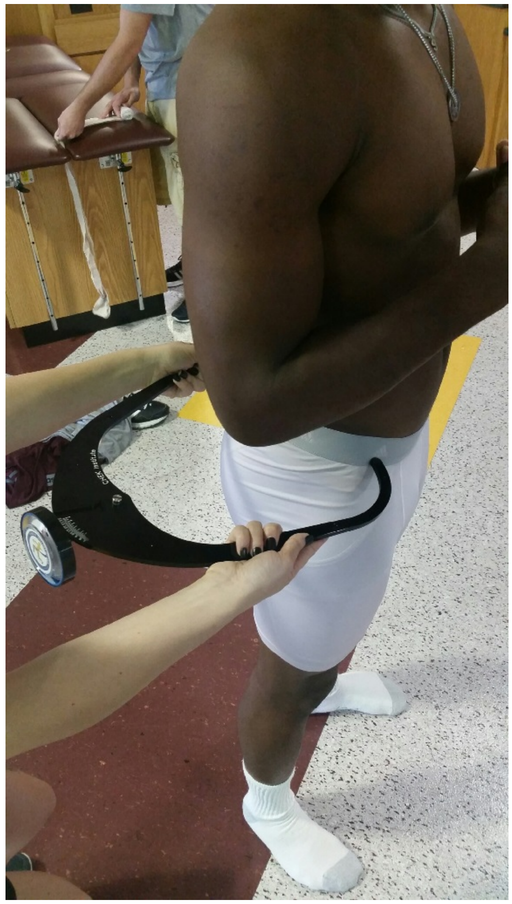

Figure 4.2

Figure 4.3

Figure 4.4


digital Absolute + Axis™ goniometer
on
off
ABSOLUTE
AXIS
BASELINE
EVALUATION INSTRUMENTS
12-1027

Figure 4.5

Figure 4.6

Figure 4.7

Figure 4.8

Figure 4.9

Figure 4.10

Statistical Analysis

IBM SPSS software version 22 (Chicago, IL) was used to perform all statistical analyses. Five mixed 2 X 2 ANOVAs were used to determine statistical differences between the two groups (HSI and healthy) and within the testing legs (injured and uninjured) for 5 variables: ASLR, $H:Q_{func}$ at 60°, $H:Q_{func}$ at 180°, $H:Q_{func}$ at 300° and SLHB. Two independent samples t-tests were used to assess differences between groups in pelvic tilt values and DPA scores. An a-priori alpha of $p=.05$ was used to determine statistical significance. Cohen's d effect sizes (ES) were calculated and the strength of the effect was assessed using Cohen's guidelines.[35]

Results

The HSI group had an average of approximately 2 previous hamstring strains and had spent an average of 6 weeks in post HSI rehabilitation (see table 4.1). The baseline disability assessment measured by DPA scores was significantly different between the HSI group and the healthy control ($t(14) = -3.66$, $p=.003$) with the HSI group displaying some low levels of disability (see table 4.2) despite the fact that the participants were hamstring injury free for at least 6 months prior to participating in the study. Additional information about the participant characteristics including leg dominance, playing position and race may be found in table 4.3.

There were no significant differences between the HSI and healthy groups in regards to pelvic tilt, ALSR, and $H:Q_{func}$ scores @60°/s, 180°/s, and 300°/s (see tables 4.4 and 4.5). No statistically significant difference were noted between the two groups in the SLHB scores, but the interaction between group and injured limb approached significance ($p=.059$). Based on Cohen's d effect size, the most noted change was between groups (HSI and healthy), which produced only a small effect (d=0.25, 95% CI =0.20 to 0.33) for $H:Q_{func}$ @60°/s. A between limb (injured and uninjured analysis) for the HSI group also produced a small effect size for $H:Q_{func}$ @60°/s (d=0.39, 95% CI = 0.31 to 0.46) and a moderate effect size for $H:Q_{func}$ @300°/s (d=0.62, 95% CI = 0.54 to 0.69). Please see table 4.6 for all reported Cohen's D effect sizes.

Table 4.1 **Participant Demographics & HSI History**	**Group (X±SD)**	
Variable	**HSI (n=15)**	**Healthy (n=15)**
Age (years)	20.93±1.28	20.60±1.18
Height (inches)	72.66±3.81	73.26±4.46
Weight (pounds)	213.33±23.83	215.60±23.59
Number of HSI	1.73±1.27	n/a
Length of Rehabilitation (weeks)	6.07±6.19	n/a

Table 4.2 **Between-Group Comparison: DPA Scores & Average Pelvic Tilt** ***Statistical Significance Difference Between groups (p≤.05)**	**Group (X±SD)**	
Variable	**HSI(n=15)**	**Healthy(n=15)**
DPA Scores*	7.67±8.11	0.00±0.00
Tilt	9.70±4.06	8.13±3.15

Table 4.3 **Injury Rate, Leg Dominance, Position & Race**	**Group**	
Variable	**HSI (n=15)**	**Healthy (n=15)**
Injured Side	No. (%)	n/a
R	11(73.3)	
L	4(26.7)	
Leg Dominance	No. (%)	No. (%)
R	13(86.7)	14(93.3)
L	2(13.3)	1(6.7)
Player Position	No. (%)	n/a
Running Backs	2(13.3)	
Wide Receivers	2(13.3)	
Defensive Backs/Safeties	5(33.3)	
Tight Ends/Linebackers	3(20.0)	
Offensive/Defensive Line	3(20.0)	
Race	No. (%)	No. (%)
Caucasian	3(20.0)	7(46.7)
African American	8(53.3)	6(40.0)
Pacific Islander	0(0.00)	1(6.7)
Hispanic	1(6.7)	0(0.00)
More Than One Race	3(20.0)	1(6.7)

Table 4.4 Between-Group Comparison: ASLR, SLHB, H:Q_{func}	**Group (X±SD)**	
Variable	**HSI (n=15)**	**Healthy (n=15)**
ASLR		
Injured Limb	85.65±15.67	86.29±11.31
Uninjured Limb	87.90±11.74	87.30±10.32
SLHB		
Injured Limb	21.93±7.85	22.73±7.97
Uninjured Limb	21.00±10.57	19.13±9.33
H:Qfunc @ 60°/s		
Injured Limb	1.00±0.15	1.03±0.92
Uninjured Limb	1.06±0.16	1.10±0.16
H:Qfunc @ 180°/s		
Injured Limb	1.04±0.93	1.10±0.17
Uninjured Limb	1.06±0.15	1.07±0.23
H:Qfunc @ 300°/s		
Injured Limb	1.06±0.13	1.07±0.99
Uninjured Limb	1.16±0.16	1.11±0.11

Table 4.5							
ANOVA Results, Within-Group Comparison							
ASLR, SLHB, H:Qfunc @60°/s, 180°/s, 300°/s							
Variable	**Group (X±SD)**				**P-Value**		
	HSI Injured Limb	**HSI Uninjured Limb**	**Healthy Matched Injured Limb**	**Healthy Matched Uninjured Limb**	**Group**	**Limb**	**Group x Limb**
ASLR	85.65±15.67	87.89±11.74	86.29±11.31	87.30±10.32	.702	.991	.723
SLHB	21.93±7.85	21.00±10.57	22.73±7.97	19.13±9.33	.487	.437	.059
H:Qfunc @60°/s	1.00±0.15	1.06±0.16	1.03±0.09	1.10±0.16	.184	.281	.885
H:Qfunc @180°/s	1.04±0.93	1.06±0.15	1.10±0.17	1.07±0.23	.932	.304	.548
H:Qfunc @300°/s	1.07±0.13	1.16±0.16	1.07±0.99	1.11±0.11	.054	.396	.432

Table 4.6
Effect Size Using Cohen's D

Variable	**Between Limb ES (95% CI)**	**Between Injury Groups ES (95% CI)**
ASLR	HSI: d=0.16 (-5.78 to 8.09) Healthy: d=0.09 (-5.13 to 5.82)	Injured: d=0.05 (-5.68 to 7.98)
SLHB	HSI: d=0.10 (-3.87 to 5.45) Healthy: d=0.42 (-3.62 to 5.14)	Injured: d=0.10 (-3.93 to 4.07)
H:Qfunc @60°/s	HSI: d=0.39 (0.31to 0.46) Healthy: d=.56 (0.48 to 0.61)	Injured: d=0.25 (0.20 to 0.33)
H:Qfunc @180°/s	HSI: d=0.04 (-0.04 to 0.51) Healthy: d=0.15 (0.06 to 0.27)	Injured: d=0.11 (0.02 to 0.58)
H:Qfunc @300°/s	HSI: d=0.62 (0.54 to 0.69) Healthy: d=0.07 (0.02 to 0.57)	Injured: d=0.00 (-0.05 to 0.07)

Discussion

By testing football athletes with a history of previous hamstring strain compared to football athletes that have never incurred a hamstring injury, we first established differences between the groups in disablement scores. The HSI group had residual disablement symptoms according to the DPA scores. Although the scores reported were low, participants in the HSI group described the majority of disablement to come from impairments and functional limitations. Upon review of the DPA surveys and demographic information, the specific concerns were stated as present overall tightness, and pain with specific movement or activity including squatting, accelerating into running, and cutting or change of direction activity. The presence of disability months after injury has been established in other injury areas, for example, the ankle. [36-39] Because of lingering symptoms and functional impairment found in other acute injuries it was important to note that athletes may continue to have disablement concerns long after an injury particularly with functional activities.[36-39] In the case of HSI, maintenance rehabilitation programs should be considered for longer periods of time after the injury. We concur with recommended specifications to incorporate principles such as strength training, flexibility training, and running drills into programs and for future prevention, into rehabilitation protocols.[40,41,42]

Based on the healing process, a history of previously injured muscle tissue leads to variability in intrinsic characteristics of the hamstring muscle.[10] Typically, predisposing modifiable risk factors from the first-time strain that typically have not been sufficiently corrected in rehabilitation are continual problems that can result in re-injury. According to this study, the average length of rehabilitation was about 6 weeks and most participants suffered on average approximately 2 hamstring strain injuries in the past 2 year inclusion period (Table 4.1). Although these athletes were limited for at least 2 weeks in specific practice or game play, most of these individuals were not removed entirely from activity through the course of acute injury.

Previous studies that addressed the rate of hamstring strain injury in football athletes based on player position found that the athletes with the highest rate of strain in the HSI category were defensive backs, safeties, wide receivers and running backs.[2] Surprisingly, in this study the highest rate of HSI were seen in defensive backs and safeties followed by tight ends and linebackers and offensive/defensive linemen (Table 4.2). This finding is not to undermine the importance of HSI injury in other playing positions. This study in particular dealt with a smaller sample size, unlike Feely et al.[2] which had hundreds of athletes recorded over a 10 year period and could have caused the variation in results.

The second risk factor addressed in this study was regarding posture, and the role of standing pelvic tilt between the designated groups. This non-modifiable risk factor, according to minimal previous research has the potential to increase the functional load on the hamstrings by defacilitating the gluteus maximus and increasing stress on the origin of the biceps femoris based on pelvic imbalances due to an excessive anterior or posterior tilt.[43] This functional measure in standing relates to sports specific function in football most identified with the terminal swing phase of the running cycle. The contralateral hip extends allowing minimal pelvis oscillation in movement. An athlete with a posterior pelvic tilt will have decreased flexibility and overall shortened length in extension. The standing position of an anteriorly tilted pelvis has a predetermined lengthening in the hamstrings by placing tension on the origin of the hamstrings at the ischial tuberosity.[43] Although the HSI group had a mean greater than that of the healthy group, the findings were not significant and therefore, cannot determine that pelvic tilt is different between those with a HSI history when compared to healthy controls. It cannot be completely ruled out as an unreliable risk factor due to the interpretation of the means in each group. Both groups have been identified as having mean measurements greater than 5° anterior pelvic tilt, therefore falling into the "excessive tilt" category. Previous research have identified the role of excessive anterior pelvic tilt position as a possible risk factor of HSI, but no study has been performed previously, especially in a collegiate football population.[43] Reasoning for these findings are possible due to limitation of sample size and further follow up is deemed necessary.

Based on the findings of this study hamstring flexibility is not significantly different between the HSI and healthy groups. Past research has been mixed regarding the role of hamstring flexibility in hamstring strain. The most influential finding that refutes evidence found in this study is Henderson et al.[7] that found that limited active range of motion led to higher HSI rates in elite soccer players. This finding is important concerning that this risk factor is still applicable, given the mean average within groups, and between groups for the injured limb is lower than the uninjured leg and uninjured counter subject. According to Mallaropoulos et al.[41] the use of stretching to increase range of motion in rehabilitation yields greater returns in flexibility and is associated with a quicker recovery in an athletic population. Based on the aforementioned information provided by previous studies, it is unknown whether the difference in activity demand or sport itself affected our findings. This study recorded a below average ASLR across the board for both groups, and both limbs according to normal ranges of motion for hip flexion in a normal, healthy population is previously recorded as (90.0°-130.0°).[45] According to Krivickas et al.[46] the lack of hip flexor mobility, specifically due to illopsoas tightness in collegiate male athletes, could play a key factor, limiting the role of actual hamstring length during an ASLR. Despite that ASLR scores were below established norms, there were no differences between the injured and uninjured limb in the HSI group (d=0.16 (-5.78 to 8.09)). Had there been between limb differences this may have been more concerning.

Strength deficits after HSI is perhaps the most relevant risk factor in football athletes for neuromuscular development and adaptation to eccentric and explosive demands in competition.[2] Hamstring strain injury is thought to lead to muscular imbalances with poor rehabilitation and recovery practices which may lead to compensation and future injury reoccurence.[23] Bennell et al.[13] failed to establish a linked relationship between hamstring muscle injury risk and isokinetic muscular strength values in Australian Rules football players. We did not find $H:Q_{func}$ strength differences at any of the three speeds for isokinetic testing. Prior studies have found significant difference at 60°/s. In this study our findings approached statistical significance, limitations in sample size may have been a reason for non-significance. Regardless of activity, a low hamstring to quadriceps ratio (H:Q) is a good indicator of the inability for the hamstring muscles to act as a braking mechanism in the terminal swing phase of running.[16] Prior research specifically notes that a healthy $H:Q_{func}$ ratio[41] is reported to be 1:1 and ratios below 0.80-0.89 suggest inequality between the action of the hamstring muscles and simultaneous knee extension, based on data collected from healthy track and field runners.[34] Mean averages were lower in the HSI than the healthy group, however, all of the averages were still above the 1:1 ratio indicating that this sample exceeded the values put forth in previous research. Findings cannot therefore, based on this test, identify that a previous HSI will lead to a significant decrease in strength changes or imbalances and all ratios were well above the designated risk range of 0.80-0.89. The largest effect sizes were noted as between limb differences in the HSI particularly at 60°/s (d=0.39 (0.31to 0.46)) and 300°/s (d=0.62 (0.54 to 0.69)). Between limb differences may be a concern in the HSI group and future research may investigate these differences particularly with a larger sample.

Hamstring strain injury rates typically occur more often in the late stages of competition regardless of sport, which is what made this SLHB assessment a relevant method to evaluate this modifiable risk factor.[5,47-49] Fatigued muscles exposed to repeated periods of over lengthening are more likely to suffer a strain injury.[50] Freckleton et al.[27] had significant findings evaluating elite soccer players in predicting HSI. The SLHB test performance demonstrated a significant deficit in preseason by correlating lower scores on the right leg of players with those who sustained a subsequent right-sided injury than those without. This study however, not statistically significant, could not verify deficit upon mean scores. According to the scores for both groups, and both limbs in each group there is the possibility for an overall deficit based on the designated scoring system (20, poor; 25, fair; 30, good) in which scores were 20 repetitions or less designating the sample as "poor".[27] There is also the potential that this same scoring system must be tested on football athletes in general in a strictly healthy population making conclusions regarding SLHB in collegiate football athletes with past HSI.

Limitations and Conclusions

This case-control study did not find significant differences in groups (HSI and healthy) in regards to strength, posture, flexibility, and endurance. The demands of other sports primarily researched such as soccer, rugby, and Australian Rules football have different work demands; therefore previous research may have limited applicability to football.[2-15] Although our data was unable to support other statistical findings in previous research, important information regarding future testing considerations, based on sample size and protocol methodology has been acknowledged. Future testing measures should be evaluated to ensure crossover applicability in studies conducted in respect to football athletes. Limitations to this study included sample size, previous lower extremity injury unrelated to HSI, and decreased enthusiasm to perform testing procedures. Although the participants received compensation to participate in the study, lack of effort may be partially due to the rigorous strength and conditioning program involved with off-season training. Further research and studies should be conducted using a larger sample size.

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APPENDIX SECTION

Appendix A

ID Number:____________

Demographic Questionnaire

1. Date:________________
2. Age:_____________
3. Height:_____________
4. Weight:_____________
5. Ethnicity:_______________
6. Position Played:____________________
7. Are you right, or left leg dominant? (Ex: Which leg would you kick a ball with?)

   Right   Left

8. Please provide a list that includes the approximate date of prior hamstring injury/injuries (month/year) and the leg that was affected with each injury (Ex. R hamstring on 10/12):

   ____

   ____

   ____

9. Do you believe you still have problems during activity due to your previous hamstring injury?

Yes No

a. If so, please explain:

____

____

____

10. During the time of prior hamstring strain injury, were you limited in regards to activity during practice or competition?

Yes No

11. Are you currently suffering from any lower extremity injury?

Yes No

If yes, please describe:

____

12. During the time of injury, did you participate in a rehabilitation?

Yes No

Is yes, about how long did you participate in rehabilitation?:____________________________________

13. Do you participate in at least 20 hours of practice during your competitive season?

Yes No

14. Do you believe you have any reason to not participate in this research due to an injury?

    Yes No

    If yes, please describe:

____

Appendix B

Disablement in the Physically Active Scale

Instructions: Please answer **each statement** with one response by shading the circle that most closely describes your problem(s) within the past **24 hours.** Each problem has possible descriptors under each. Not all descriptors may apply to you but are given as common examples.

KEY

1 - no problem
2 - I have the problem(s), but it does not affect me
3 - The problem(s) slightly affects me
4 - The problem(s) moderately affects me
5 - The problem(s) severely affects me

	1	2	3	4	5
Pain – *"Do I have **pain**?"*	O	O	O	O	O
Motion - "*Do I have impaired **motion**?"* **Ex.** decreased range/ease of motion, flexibility, and/or increased stiffness	O	O	O	O	O
Muscular Functioning - *"Do I have impaired **muscle function**?"* **Ex.** decreased strength, power, endurance, and/or increased fatigue	O	O	O	O	O
Stability - *"Do I have impaired **stability**?"* **Ex**. the injured area feels loose, gives out, or gives way	O	O	O	O	O
Changing Directions – *"Do I have difficulty with **changing directions** in activity?"* **Ex.** twisting, turning, starting/stopping, cutting, pivoting	O	O	O	O	O
Daily Actions – "*Do I have difficulty with **daily actions** that I would normally do?"* **Ex**. walking, squatting, getting up, lifting, carrying, bending over, reaching, and going up/down stairs	O	O	O	O	O
Maintaining Positions – *"Do I have difficulty **maintaining the same position** for a long* *period of time?"* **Ex.** standing, sitting, keeping the arm overhead, or sleeping	O	O	O	O	O
Skill Performance – *"Do I have difficulties with **performing skills** that are required for* *physical activity?"* 1.) **Ex**. running, jumping, kicking, throwing, & catching	O	O	O	O	O
2.) **Ex.** coordination, agility, precision & balance	O	O	O	O	O
Overall Fitness - *"Do I have difficulty maintaining my **fitness** level?"* **Ex**. conditioning, weight lifting & cardiovascular endurance	O	O	O	O	O

Participation in Activities – *"Do I have difficulty with **participating in activities**?"*					
1.) **Ex**. participating in leisure activities, hobbies, and games	O	O	O	O	O
2.) **Ex.** participating in my sport(s) of preference	O	O	O	O	O
Well-Being – *"Do I have difficulties with the following…?"*					
1.) Increased uncertainty, stress, pressure, and/or anxiety	O	O	O	O	O
2.) Altered relationships with team, friends, and/or colleagues	O	O	O	O	O
	O	O	O	O	O
3.) Decreased overall energy	O	O	O	O	O
4.) Changes in my mood and/or increased frustration					